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Sustainable Residential Landscapes

An International Perspective

Edited by

Carl Smith

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About the Special Issue Editor

Carl Smith is Associate Professor of Landscape Architecture at the Fay Jones School of Architecture and Design at the University of Arkansas, Fayetteville, USA. He has broad international experience in the practice, teaching, and research of landscape and urban design.

Smith's primary research focuses on the perceptions of landscape change, particularly as it relates to place and sustainability. His current foci include public attitudes toward relatively dense residential layouts and the use of drawings to record and document aesthetic responses to places. His research interests also encompass design studio culture. Smith is primary author of the book Sustainable Residential Landscapes: A Checklist Tool, which was published internationally by Wiley-Blackwell in September 2007, and his work has appeared in numerous journals, for example, *Journal of Urban Design*, *International Journal of Art and Design Education*, *Landscape Research Record*, and *Places*. He has delivered lectures on sustainability issues in Europe, South America, and the United States to such organizations as the British Landscape Institute, the American Society of Landscape Architects, the American Planning Association, the International Federation of Landscape Architects, and the European Council of Landscape Architecture Schools. He has held guest teaching appointments in Europe, the United States, and South America.

Smith's recent design work has been recognized through honors from the Association of Professional Landscape Designers; the Landscape Institute; and the American Institute of Architects. He is a Chartered Landscape Architect, a Fellow of the Royal Society of Arts, and a Fellow of the Royal Geographical Society.

Preface to "Sustainable Residential Landscapes"

I was approached to serve as Editor of this Special Issue in the fall of 2018. This was an intriguing proposition: it had been just over ten years since my last book-length contribution on residential landscape sustainability, and here was the opportunity to address issues that had emerged or cemented themselves during the past decade. A recently published paper by Zhou et al., "Sustainable Landscapes and Landscape Sustainability: A Tale of Two Concepts (*Landscape & Urban Planning*, 2019), explicitly addresses the multiple interpretations of landscape and sustainability while remarking upon the rapidly increasing body of literature whose keywords allude to their conjunction. Furthermore, their review reports a collaborative community of designers, planners, scientists, and managers addressing a range of ecological and sociocultural dimensions—often in concert. In this regard, the presented volume is on-task; a microcosm of interdisciplinary discourse across landscape architecture and architecture; planning and construction; ecology and horticulture; agricultural and environmental sciences; and health, exercise, and nutrition.

In the recently published Sustainability Assessments of Buildings, the editor Umberto Berardi highlights "the importance to go beyond the sustainability assessment of single buildings and to enlarge the assessment scale to communities" (MDPI, 2017, p. vii). While this current volume does—in part—respond, it is not simply a collection of empirically evaluated case studies. Where the work is more instrumental, it offers new insights into the use of vegetative landscape elements at the site-scale in addressing residential stormwater and carbon sequestration (see Chapters 1 and 2 by Morash et al. and Hyun-Kil Jo et al., respectively). However, the malleability of the terms landscape and sustainability allows for increasing scales—residential landscape as whole settlement or inhabited region—and a discussion of sociocultural dimensions of residential landscapes as places. Social sustainability from the site to community scale is addressed in Chapters 3 to 7 by Díaz Montemayor; Kumble; Washington et al.; Felstead et al; and Yongchun Yang et al. The Felstead et al. paper strays from the case study approach to review a critical concern: the translation of socially vibrant commons into a spatially coherent but adaptable landscape elements for 21st century public housing. This very week, in the UK newspaper the Guardian, John Harris discussed Britain's deeply broken housing sector and its culpability—through lack of quality, choice, and affordability—in adding to community estrangement and a "national nervous breakdown". In this light, Felstead's work on commoning is very timely, but so too is consideration of the role of open space in addressing urban crime in Northern Mexico; the provision of basic human dignity through circular economic strategies in impoverished Guatemalan neighborhoods; and improved intergenerational interaction within Australian suburban communities. All are covered here.

Yongchun Yang et al. acts as a dowel for the volume, as it straddles urban village policy and rural planning. The remaining chapters shift focus away from intensive urban residential landscapes altogether to address extensive rural landscape sustainability policy, planning, and regional change. Of late, much landscape sustainability discourse has, understandably, focused on the challenges of increasing urbanization: instant cities, urban infill, suburban compaction, and the challenges and opportunities of integrating intensifying cultural pressure with functioning and resilient natural systems. Chapters 8 through 10, however, consider the equally complex and multifaceted challenge of achieving inhabited rural landscape sustainability, specifically, effective ecological planning policy for small towns and infrastructure in East China's rural Zhejiang Province and—as a separate, complementary study—combining architectural vernacular and operational-energy performance through community-informed planning guidance for villages in China's rural southwest. The final paper in the collection deals with the threats to indigenous communities and their imbedded knowledge of the ecological capacities of their Bolivian Amazon home. The threats identified in the paper, alas, have been shown to be very real: as I write this, millions of acres of the Amazon basin lie scorched from recent catastrophic fires, a terrible legacy of neglectful land use policy and practice.

This closing paper reframes the idea of "sustainable residential landscape" altogether, towards something absolutely at the core of an aboriginal culture in balance with its home. Nevertheless, all the papers collected here touch upon the multifaceted nature of sustainable residential landscapes and, in sum, reinforce their deeply entwined environmental capacity and social performance. I am delighted that, as a piece, the volume truly delivers on its promise of an international perspective: author teams from Europe, Asia, Australia, as well as North, Central, and South America all addressing sustainable residential landscape issues across the globe. I would like to thank each of them, as well as the reviewers that worked diligently in bringing each paper to fruition.

Carl Smith
Special Issue Editor

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Article

Increasing Sustainability of Residential Areas Using Rain Gardens to Improve Pollutant Capture, Biodiversity and Ecosystem Resilience

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Abstract: Rain gardens have become a widespread stormwater practice in the United States, and their use is poised to continue expanding as they are an aesthetically pleasing way to improve the quality of stormwater runoff. The terms rain garden and bioretention, are now often used interchangeably to denote a landscape area that treats stormwater runoff. Rain gardens are an effective, attractive, and sustainable stormwater management solution for residential areas and urban green spaces. They can restore the hydrologic function of urban landscapes and capture stormwater runoff pollutants, such as phosphorus (P), a main pollutant in urban cities and residential neighborhoods. Although design considerations such as size, substrate depth, substrate type, and stormwater holding time have been rigorously tested, little research has been conducted on the living portion of rain gardens. This paper reviews two studies—one that evaluated the effects of flooding and drought tolerance on the physiological responses of native plant species recommended for use in rain gardens, and another that evaluated P removal in monoculture and polyculture rain garden plantings. In the second study, plants and substrate were evaluated for their ability to retain P, a typical water pollutant. Although plant growth across species was sometimes lower when exposed to repeated flooding, plant visual quality was generally not compromised. Although plant selection was limited to species native to the southeastern U.S., some findings may be translated regardless of region. Plant tissue P was higher than either leachate or substrate, indicating the critical role plants play in P accumulation and removal. Additionally, polyculture plantings had the lowest leachate P, suggesting a polyculture planting may be more effective in preventing excess P from entering waterways from bioretention gardens. The findings included that, although monoculture plantings are common in bioretention gardens, polyculture plantings can improve biodiversity, ecosystem resilience, and rain garden functionality.

Keywords: rain gardens; bioretention; monoculture; polyculture; substrate; phosphorus; low impact development; green infrastructure

1. Introduction

The negative impacts of urbanization on associated watersheds result in changes to hydrology, elevated concentrations of nutrients and contaminants, altered channel morphology, and reduced biodiversity [1]. Urbanization also decreases groundwater recharge, which often leads to diminished groundwater supply [2]. Contributors to altered watersheds and reduced groundwater reserves are numerous, but the primary driver is stormwater runoff. Beyond changes to natural hydrology, stormwater is also associated with pollution [3]. Stormwater carries pollutants and discharges them to surface waters. Pollutants include: Heavy metals (such as lead, zinc, copper, and cadmium), polycyclic aromatic hydrocarbons, soluble salts, pesticides, nitrogen, solids, pathogens, pharmaceuticals, and P. Phosphorus, a main pollutant in urban areas, enters waterways with surface water runoff degrading the waterways through over production of algae and aquatic plant growth [4–11]. The main source of urban P is residential lawns and streets.

1.1. Low Impact Development

Low impact development (LID) has gained popularity as a tool to increase local sustainability, resiliency and improve ecosystem health [4–7,12–14]. LID uses an approach that mimics natural hydrology practices through small, site-scale, cost-effective landscape features that soak up, hold, convey, and filter stormwater onsite [7,12,15,16]. These localized stormwater control measures (SCMs) include rain gardens, bioretention, porous paving, grass swales, green roofs and more. LID enhances the local environment, protects public health, improves community livability, and can save residential developers and local governments money by reducing construction costs [15,17–21]. The United States Environmental Protection Agency (US EPA) has reported that traditional curb and gutter, storm piping, and detention ponds of residential developments can cost two to three times as much as grass swales and other LID techniques [7]. However, the key factor in the success of LID at the residential scale is to ensure that the SCMs are attractive, low maintenance, and perceived by the property owner as adding ecological value to the property [12,15].

1.2. Rain Gardens

Rain gardens are an effective LID practice used in residential areas to capture stormwater runoff, recharge groundwater through infiltration, and remove runoff pollutants, such as phosphorus (P) from stormwater prior to entering local streams [6,22–28]. Rain gardens add ecological value to residential developments by filtering nutrients, metals and pathogens from stormwater runoff. Rain gardens are known to filter around 90 percent of copper, lead and zinc; 50 percent of nitrogen; and 65 % of P, which could otherwise flow into storm drains and eventually bodies of water [29,30]. Nitrogen (N) and P (P) are of particular concern and interest in urban stormwater runoff due to their role in eutrophication of water bodies, onset of harmful algal blooms, and fish kills [13,31,32]. Traditionally, a rain garden is constructed as a shallow depression in the landscape that receives runoff during a storm event. Trees, shrubs, and herbaceous landscape plants are planted along with a groundcover or mulch layer [5,33,34]. Rain gardens are designed to experience periodic flooding for up to two days [23,35]. A maximum of 48 h is recommended to prevent mosquitoes from breeding [36] and prolonged exposure of plant roots to anaerobic conditions [37]. Rain gardens are watered naturally and therefore may experience very dry conditions as well as the expected temporary flooded conditions [38–40].

1.3. Flooding Tolerance

Flooding imposes a substantial abiotic stress on plants that often affects growth, distribution, and productivity [41]. The major stress on flooded plants is an inadequate supply of oxygen to submerged tissues [42]. Gas diffusion is severely inhibited in flooded soils. Within 24 to 48 h of flooding, plant roots deplete soil oxygen and exhibit root stress [43]. Eventually, toxic products of anaerobic metabolism accumulate, causing harm to plant cells. Plants unable to withstand flooding stress eventually succumb to depleted carbohydrate reserves, accumulation of toxic metabolites, hormonal dysfunction, or some combination of the above. Even after flooding subsides, a plant is susceptible to post-anoxic injury as it is reintroduced to oxygen [44]. Susceptibility to secondary biotic stresses, such as pests and abiotic stresses, and wind and temperature, can also be problematic for waterlogged plants.

Flood tolerant plants overcome flooding stress through a suite of morphological and physiological adaptations [41,42]. Flooding often limits plant size. Therefore, injuries to roots, shoots, and leaves are evidence of plant fitness during and after a flooding event. Initial and final plant dry weight, total leaf area, and other growth measures are good indications of a plant's tolerance to flooding [45]. Long-term flooding adaptations often develop in the roots. Original roots may dieback and be replaced by adventitious roots [46]. The ratio of dead to living root tissue may be compared to other root systems. Leaf yellowing, or chlorosis, and death is a common injury caused by flooding [47]. Leaf yellowing due to flooding resembles nitrogen deficiency, however, it often appears 4–6 days after flooding occurs. Finally, a decrease in stomatal conductance during flooding is also common since flooding can cause a decrease in the capacity of plants to absorb and conduct water [47]. Stomatal conductance can be measured to determine how much water vapor is being emitted via the stomata [48–50]. Understanding the degree to which a plant can withstand wet or dry conditions is important in determining rain garden plant effectiveness. Furthermore, such knowledge helps determine proper rain garden placement.

1.4. Phosphorus

Plant species tolerant of flooding will generally acquire more nutrients in their plant tissue than flood-intolerant species [51,52]. In some cases, waterlogged soils can increase the ability of plants to uptake Ps and increase the soil P availability [53]. However as previously discussed, plants may face reductions in growth, biomass, and photosynthetic activity when waterlogged [52]. In turn, the release of soil P during flooding events can act as a nutrient source or sink [54]. As such, repeated flooding can result in a P release from soils, which introduces additional P to soils and waterways [54,55]. Plant selection is key to rain garden functionality—not only in terms of plant survival but in regards to nutrient removal.

1.5. Plant Selection

While studies have been conducted regarding the design and substrate composition of rain gardens to maximize capture potential and pollutant retention [56,57], research on rain garden plant selection is sparse. In light of limited rain garden plant research, initial studies focused on plant selection. Most of the research was conducted in southeastern U.S.A. [58–62]. Findings are summarized in Appendix A. The results of some studies found that not all plants commonly recommended for rain garden inclusion responded well to evaluation, which indicates that continued area specific rain garden plant research is needed. The results also suggest that research should not be limited to plant selection. For example, *Clethra alnifolia* L. Ruby Spice (Ruby Spice summersweet) did poorly in one study [60], but thrived in another study [58]. The difference in performance was attributed to plant size. Larger plants (3.8 L) seemed more tolerant of flooding than smaller plants (1 L) possibly due to more robust root systems. If true, initial plant size should be considered when installing a rain garden. Dylewski (2012) [60] noted that plant maturity also affected flooding tolerance. In that study *Itea virginica* L. Henry's Garnet (Henry's Garnet sweetspire) demonstrated decreased sensitivity to flooding with greater plant maturity. However, the opposite was true for *Vibrurnum nudum* (L.) A. Gray (Shamrock inkberry holly). A greater understanding of individual plant performance at various stages of life, exposure, and nutrient inundation would benefit those designing and implementing rain garden systems.

Polyculture planting is another important consideration. Research suggests that using a variety of plant species benefits functionality. Diversifying planting composition between functional groups—monocots and dicots, evergreen and deciduous, and shallow and deep-rooted species—can increase competition for nutrients, biomass productivity, and stress tolerance [63–65]. Polyculture planting could also increase competition in water uptake and thereby increase flooding tolerance and nutrient uptake and removal [59,64,66]. Those researchers concluded that nutrients were released during cool season perennial die back, even when evergreens were present. Nevertheless, evergreens likely helped increase nutrient uptake during the cool season. The same study noted high tissue concentrations of metals in ferns. Ferns may, in turn, have potential for greater metal uptake and removal from rain garden systems. Additionally, polyculture plantings demonstrated greater potential to remove niche nutrients and thereby increase overall nutrient removal [67–70]. Combined, the current research suggests that polyculture planting could increase overall rain garden performance through greater nutrient uptake, avoid seasonal vegetative gaps, and increase water uptake.

1.6. Objective

Characterization of plant health in response to short-term cyclic flooding is critical when evaluating plants for inclusion in rain gardens. Although many plants have been recommended for use in bioretention gardens, data are needed to document plant establishment, flood tolerance, and P uptake under repeated short-term flooding conditions. Plant selection for the two studies discussed in this paper was based on published recommendations [38,71,72] and included grasses, shrubs, an herbaceous perennial, and ferns.

Therefore, the first objective of this research was to evaluate five diverse native landscape plant species for tolerance to repeated short-term flooding. The second objective was to evaluate three diverse native landscape plant species for P uptake and tolerance of bioretention garden conditions and to compare monoculture and polyculture planting combinations of these same species.

2. Materials and Methods

2.1. Rain Garden Microcosms

Rain garden microcosms were constructed using 97 L plastic nursery containers [Classic 10,000, Nursery Supplies, Inc. (Chambersburg, PA, USA)]. One 97 L container represented one microcosm. Two types of containers were utilized: (1) Containers lacked drainage holes and could be flooded and (2) containers drained freely though drainage holes stamped by the manufacturer on the bottom of each container. Containers without drainage holes were modified with a drainage valve to allow for repeated flooding and draining. Microcosms were placed under an outdoor shade structure at the Paterson Horticulture Greenhouse Complex, Auburn University, AL. The top of the structure was covered with a double layer of 6 mil clear polyethylene plastic to exclude rainfall and 60% woven shade cloth to allow for evaluation of shade plants. The structure was constructed with an overhead sloped frame to allow the water to drain off.

2.2. Growth and Physiological Response Study

Five shade-tolerant southeastern U.S.A. native plant species, including two evergreen shrubs, two ferns, and one herbaceous perennial, were selected for this study, and the physiological responses to repeated short-term flooding were examined. All species are commonly recommended for use in rain gardens [35,71,72]. Shrubs included 11.3 L *Illicium floridanum* Ellis (Florida anise) and *Morella cerifera* L. (wax myrtle) (Figure 1). Ferns included 3.8 L *Osmunda cinnamomea* L. (cinnamon fern) and *Polystichum acrostichoides* Michx. (Christmas fern). The perennial used in the study was 3.8 L *Chasmanthium latifolium* Michx. (river oats). These sizes correspond to the sizes typically available commercially for these species for planting into a landscape. Each species was included in two experimental runs with the exception of *C. latifolium* which was included in three experimental runs.

Figure 1. Shrubs *Illicium floridanum* (Florida anise) planted in microcosms under shade and rain exclusion. Microcosms equipped with valves (circled) could be flooded for 48 h, while other microcosms had traditional drainage holes.

Rain garden microcosms were filled with an 8:1 pine bark:sand substrate amended with 1.2 kg/m^3 of dolomitic limestone and 8.0 kg/m^3 of 15N-3.9P-10K Osmocote Plus (with micronutrients, Marysville, OH, USA). A slow-release fertilizer was used to avoid mass leaching during flooding inundation [73]. Shrubs were planted one plant per microcosm. One perennial species was planted per microcosm. One of each fern species was planted per microcosm (total of two plants per microcosm for ferns).

Plants received one of two treatments—flooded or non-flooded. Flooded plants were flooded by hand watering the container until inundated and adding water as needed to maintain flooded conditions for 48 h followed by 5 days of draining (no additional water added). During flooding, water level was maintained approximately 2 cm above the substrate to ensure complete inundation. Plants were flooded once weekly for 8 weeks. Non-flooded plants were hand watered every other day with approximately 11 L of water. All plants were harvested after 8 weeks.

Three additional plants of each species were destructively harvested at a study initiation to determine initial size index (SI) [(height + widest width + width perpendicular the widest width)/3], leaf area [LA, LI-3100 leaf area machine (LI-COR, Inc. Lincoln, NE, USA)], and shoot dry weight (SDW) [leaf + stem dry weight]. For SDW, plant tissue was placed in a 77 °C drying oven for 3 days and weighed immediately upon removal.

Initial SI and final SI, LA, and SDW were collected for plants in the microcosms. Final LA was measured for all ferns and perennials. For the shrubs, final LA was measured for three plants per species per treatment. Leaf chlorophyll content [LCC, Konica Minolta Chlorophyll Meter SPAD-502Plus (Ramsey, NJ, USA)] and stomatal conductance [SC, Decagon Devices, Inc. Leaf Porometer (Pullman, WA, USA)] were measured from newly matured leaves at the end of draining (five days no water) and flooding (48 h) periods. For shrubs in both runs of the experiment and the first experimental run of perennials, LCC and SC was measured beginning midway through an experimental run and continuing for the last 3 weeks. For the ferns and second experimental run of perennials, LCC and SC was measured at 2, 4, 6, and 8 weeks. Stomatal conductance was measured between 8:00 a.m. and 11:00 a.m. for morning measurements and between 1:00 p.m. and 3:00 p.m. for afternoon measurements.

2.3. Phosphorus Retention Study

Three southeastern U.S.A. native plants species including a grass, an herbaceous perennial, and an evergreen shrub were used for this study, which examined the P uptake by plants and P retention by the substrate. Plants of *Andropogen ternarius* Michx. (splitbeard bluestem), *Coreopsis verticillata* Zagreb L. Glab. (whorled coreopsis), and *Ilex vomitoria* Schilling's Dwarf Ait. (yaupon holly) were removed from 38 L containers and replanted into microcosms, with three plants per microcosm. Four planting combinations were used. These included a monoculture of *A. ternarius*, *C. verticillata* Zagreb, or *I. vomitoria* Schilling's Dwarf (three plants of same species per microcosm) or a polyculture of *A. ternarius*, *C. verticillata* Zagreb, and *I. vomitoria* Schilling's Dwarf (one plant of each species per microcosm), with 12 microcosms per planting combination (three monocultures and one polyculture). Microcosms were filled with a substrate of a 50% sand, 25% pine bark, 25% peat moss, amended with 0.45 kg·m^{-3} P free 19N-0P_2O_5-17K_2O (with micronutrients) (Tru-prill, Plant Science, Inc, Gormley, ON, Canada). This substrate was chosen to simulate bioretention substrates suggested for use in LID projects [26,74–76].

After one week of acclimation outdoors, flood and non-flood treatments were initiated. Plants were irrigated (non-flood) or flooded with a solution containing 1.6 mg·L^{-1} P (85% H_3PO_4, Fisher Scientific, Pittsburgh, PA, USA) which is four times the median P concentration of 0.4 mg·L^{-1} in urban stormwater runoff [25,27]. Six microcosms from each planting combination were flooded with 26.5 L of solution, and no additional solution was added during each flood event of 48 h. Following each flood event, the microcosm was drained for seven days. No additional water was added to the containers during the draining period of seven days that followed each flood event (flood–drain cycle). There were 12 flood-drain cycles. The non-flood microcosms, six from each planting combination, were irrigated three times weekly with 20 L of solution.

Size index [(shoot height + shoot widest width + shoot width (perpendicular to widest)/3)] was measured for each plant at initiation, midway, and termination. At termination, plant shoots were severed at the substrate surface, and roots were rinsed to remove substrate. Shoots and roots were dried separately in an oven for 48 h at 66 °C to determine shoot dry weight and root dry weight. Four 50 g substrate samples were collected prior to planting. Upon termination, four 50 g substrate samples were collected for each planting combination x flood treatment. Also upon termination, the entire dried shoot or root tissue of three plants per planting combination x flood treatment were ground to 5 mm particle size and a 0.5 g tissue sample collected from each. Leachate samples (200 mL) were collected from three containers in each planting combination x flooding treatment using the Virginia Tech Pour Through Method [77]. Substrate samples were processed using Mehlich 1 double acid extraction method, and tissue samples were processed using dry ash and double acid extraction method by the Auburn University Plant and Soil Analysis Lab [78]. Leachate, substrate and tissue samples were analyzed for P concentrations for at Auburn University Plant and Soil Analysis Lab using Inductively Coupled Plasma (ICP) spectrophotometer.

Two experimental runs were conducted. The first run was initiated 27 September 2012 and terminated 7 December 2012 (herein referred to as fall). The second run was initiated 4 April 2013 and terminated 7 June 2013 (herein referred to as spring). There were no differences in methodology between runs, except that chemical analysis of root and shoot tissue, substrate, and leachate was conducted in fall only. Microcosms (flood or non-flood) and planting combinations were completely randomized.

2.4. Statistical Analysis

For both studies, analysis of variance was performed using PROC GLIMMIX in SAS version 9.3 (SAS Institute, Cary, NC, USA), and microcosms were arranged in a completely randomized design with six microcosms per treatment per species (or planting combination). For the physiology study, each species was treated as a separate experiment. For the P study, treatments were in a factorial treatment design of species (planting composition) and flood. All significances were at P = 0.05. The results for main effects and interactions are presented when significant, and not presented if not significant. If interactions were significant, then the simple effects of each factor are presented. The means separation was performed using Tukey for the growth and physiology study and LSMEANS for the P retention study.

3. Results

3.1. Growth and Physiological Response Study

3.1.1. Plant Response to Short-Term Cyclic Flooding

With the exception of *P. acrostichoides*, all species evaluated tolerated intermittent flooding (Table 1). Two of the six flooded *P. acrostichoides* plants died, and SI, LCC, and SC were lower in flooded plants than in non-flooded plants of this species in the summer 2015 run. In some ways, data for *I. floridanum* did not support personal observations. Growth measurements (SI, LA, DW) showed a tolerance of short-term cyclic flooding. However, physiological measurements and personal visual observations did not. Leaf yellowing, wilting, and senescence increased as the experiment progressed. Regarding the five plant species evaluated, *C. latifolium* tolerated flooding best, based on data collected and personal visual observations. The results were higher for flooded plants of this species in at least one measurement for each run, especially during summer runs.

Table 1. Summary of responses to 7–8 weeks of cyclic flooding for five species: *Illicium floridanum* (IF), *Morella cerifera* (MC), *Osmunda cinnamomea* (OC), *Polystichum acrostichoides* (PA), and *Chasmanthium latifolium* (CL). The experiment was conducted in Auburn, AL. Runs included summer 2014 (SU 14), fall 2014 (FA 14), spring 2015 (SP 15), and summer 2015 (SU 15). Measurements included: size index (SI), leaf area (LA), leaf chlorophyll content (LCC), shoot dry weight (SDW), leaf:stem DW ratio, and stomatal conductance (SC). Plants were flooded for 48 h followed by 5 days of no watering (flooded, F) or watered every other day (non-flooded, NF). If a difference occurred between species, the treatment with a higher value is highlighted.

Growth and Physiological Study Results Summary							
Type	**Species**	**Run**	**SI** [z]	**LA**	**LCC**	**SDW**	**SC**
Shrub	IF	SU 14	ND [y]	ND	ND	ND	NF
		FA 14	ND	ND	NF	ND	NF
	MC	SU 14	NF	ND	ND	ND	NF-
		FA 14	ND	ND	NF	ND	NF
Fern	OC	SP 15	ND	ND	ND	ND	ND
		SU 15	ND	ND	ND	ND	ND
	PA	SP 15	ND	ND	ND	ND	F
		SU 15	NF	ND	NF over time	ND	NF-
Grass	CL	SU 14	ND	F	ND	ND	F
		SP 15	ND	ND	NF	ND	ND
		SU 15	F	F	ND	F	ND

[z] SI = (height + widest width + perpendicular width)/3; [y] No significant difference is denoted by ND.

3.1.2. Whole-Plant Stomatal Conductance Estimates

In addition to the growth and physiological response measurements, whole-plant stomatal conductance estimates were calculated. Stomatal conductance was multiplied by leaf area to estimate the potential total amount of water that could be transpired by each species per second. There were no differences between flooding treatments for *M. cerifera* and *O. cinnamomea*. *Illicium floridanum* and *P. acrostichoides* showed differences only during the summer when total transpiration was higher in non-flooded (Table 2). Conversely, *C. latifolium* showed differences during both summer runs when total transpiration was higher with flooding.

Table 2. Whole plant transpiration rates calculated using stomatal conductance ($mmol \cdot m^{-2} \cdot s^{-1}$) and total plant leaf area (m^2) of *Illicium floridanum* (IF), *Morella cerifera* (MC), *Osmunda cinnamomea* (OC), *Polystichum acrostichoides* (PA), and *Chasmanthium latifolium* (CL) after 7–8 weeks of flooding. Plants were flooded for 48 h followed by 5 days of no watering (flooded, F) or watered every other day (non-flooded, NF). The experiment was conducted in Auburn, AL, U.S.A. in summer 2014 (SU 14), fall 2014 (FA 14), spring 2015 (SP 15) and summer 2015 (SU 15).

Whole Plant Transpiration ($mol \cdot s^{-1}$)									
		SU 14		FA 14		SP 15		SU15	
Type	Species	F	NF	F	NF	F	NF	F	NF
Shrub	IF	18.4a [z]	0.513b	0.097	0.201	-	-	-	-
	MC	0.242	0.527	0.131	0.186	-	-	-	-
Fern	OC	-	-	-	-	0.095	0.075	0.054	0.053
	PA	-	-	-	-	0.021	0.018	0.002a	0.018b
Grass	CL	0.141a	0.047b	-	-	0.022	0.025	0.237a	0.142b

[z] Letters indicate significant differences between treatments for each species within a run at $p < 0.05$.

3.2. Phosphorus Retention Study

3.2.1. Dry Weight and Size Index

All species tolerated repeated short-term flooding regardless of whether planted as a monoculture or as a polyculture [61]. There was some seasonality associated with growth for all three species. For. *C. vertcillata*, SDW was higher in flooded than non-flooded treatments (Table 3). For *I. vomitoria*, SDW was greater in fall than spring. In contrast, SDW of *C. verticillata* was higher in spring than fall. Although flooding did not affect SI of *A. ternarius* and *I. vomitoria*, SI of *C. verticillata* was higher in non-flooded than flooded (Table 3).

Table 3. Summary of responses to 15 weeks of cyclic flooding for three species: *Ilex vomitoria* (IV), *Andropogon ternarius* (AT), and *Coreopsis verticillata* (CV). The experiment was conducted in Auburn, AL. The runs included fall 2012 and spring 2013. The measurements included: size index (SI), shoot dry weight (SDW), and rood dry weight (RDW). The plants were flooded for 48 h followed by 7 days of no watering (flooded, F) or watered every other day (non-flooded, NF). If a difference occurred between species, the treatment with a higher value is highlighted.

Type	Species	SI [z]	SDW	RDW
Shrub	IV	ND[y]	ND	ND
Grass	AT	ND	ND	ND
Perennial	CV	ND	NF	NF

[z] SI = (height + widest width + perpendicular width)/3; [y] No significant difference is denoted by ND.

3.2.2. Phosphorus Concentration

Initial substrate P was 2.33 mg/kg. The final substrate P was higher in flooded (5.8 g/kg) than non-flooded (7.5 mg/kg). Similarly, leachate P was higher in flooded than non-flooded microcosms ranging from 13–15 mg/L in flooded to 6–7 mg/L in non-flooded. Root and shoot tissue P was highest among species in *C. verticillata* (Table 4). The concentration of P in root and shoot tissue along with the dry weight of root and shoot tissue, respectively, were used to calculate total phsophorus per plant. On a per plant basis, *C. verticillata* had 10.47 mg P, *A. ternarius* had 101.71 mg P, and *I. vomitoria* had 22.78 mg P in tissue.

Table 4. Root and shoot tissue P concentrations (RTP and STP, respectively) of *Ilex vomitoria* (IV), *Andropogon ternarius* (AT), and *Coreopsis verticillata* (CV) after 15 weeks. Flooding did not affect RTP or STP. The experiment was conducted in Auburn, AL, U.S.A. in fall 2012 and spring 2013.

Type	Species	RTP (mg/kg)	STP (mg/kg)
Shrub	IV	1607b [z]	2636b
Grass	AT	1945b	2443b
Perennial	CV	4089a	3088a

[z] Lowercase letters denote least squares mean separation among species within a column using ANOVA F-test in the Glimmix procedure ($p < 0.05$).

4. Discussion

4.1. Plant Recommendations

In order to provide a diverse list of research-based rain garden plant recommendations to meet varying needs and tastes, the Morash (2016) [62] and Meder (2013) [61] studies utilized plants from the following functional groups: Herbaceous perennial (*C. verticillata*), shrubs (*I. vomitoria, M. cerifera* and *I. floridanum*), ferns (*P. acrostichoides* and *O. cinnamomea*), and grasses (*A. ternarius* and *C. latifolium)*. Plants were not evaluated long-term. Therefore, it is unknown if there would be an accumulation effect of prolonged stress, particularly for shrub species. Further, research did not include a winter experimental run. Rain garden soil may stay waterlogged for a longer period of time, and nutrient uptake and stomatal conductance rates are expected to be lower in cooler months. As such, the effects of winter intermittent flooding for the plants tested in these studies are not known.

O. cinnamomea was not affected by flooding during any run. Based on its response to simulated flooding and its visual appearance, *O. cinnamomea* is recommended for use in rain gardens. The following species were negatively affected by flooding during at least one run: *C. verticillate* (SI and SDW), *I. vomitoria* (SDW in combination planting), *A. ternarius* (SDW in combination planting), *M. Cerifera* (SI, LCC, and SC), *I. floridanum* (LCC and SC), and *P. acrostichoides* (SI, LCC, SC). Despite evidence of flooding stress, *C. verticillate, I. vomitoria, M. cerifera, and A. ternarius* appeared to tolerate the type of flooding expected in rain gardens and are therefore recommended for use in rain gardens. The results for *I. floridanum* were less clear. Although growth measurements (SI, LA, and SDW) suggested tolerance to short-term cyclic flooding, physiological measurements (LCC, SC) and personal visual observations (not quantified) did not. A likely explanation for the disparity relates to sample size. Destructive harvests were used for LA and DW. Due to time restrictions, only three plants of each shrub species per treatment were recorded. With such a small sample number, confidence intervals for detecting significant differences were large. A larger sample size could have decreased confidence intervals and increased precision [79]. In any case, results from these studies show the importance of coupling growth and physiological data with visual observations, seasonality, and survival to gain a full picture of a species suitability for use in a rain garden. Although leaf senescence and chlorosis are common symptoms in flooded plants, no previous research on flooding tolerance or drought tolerance was found for this species. Based on the results, it is unresolved whether to classify *I. floridanum* as suitable or unsuitable for use in southeastern U.S.A. rain gardens. The following species were benefited by flooding during at least one run: *C. latifolium* (every measurement) and *P. acrostichoides* (SC during the spring run). Based on experimental results, *C. latifolium* is an excellent southeastern U.S.A. rain garden plant. However, *P. acrostichoides* is not recommended for use in southeastern U.S.A. rain gardens without supplemental irrigation. Although the plant withstood rain garden conditions in the spring, results from the summer run suggest possible drought intolerance, which is a common rain garden condition.

4.2. Flooding and Seasonal Effects on Growth

The Morash [62] and Meder [61] studies provide the opportunity to compare responses of different species within the same functional group to repeated short-term flooding. The conclusions based on growth measurements could help individuals implementing rain gardens make better plant selections after considering site-specific conditions. Both studies used the maximum flooding time recommended for rain gardens, 48 h, and demonstrated that flooding affects plants differently within functional groups. For example, the Morash [62] study identified that *C. latifolium*, performed better under cyclic flooding, while Meder's results did not reveal a significant difference in growth measurements of *A. ternarius* when planted as a monoculture. Looking beyond these two studies, a third study that used a similar flooding technique and surveyed a native landscape grass, *Muhlenberia capillaris* (Lam.) Trin., found that SDW and root dry weight (RDW) was higher in non-flooded than flooded treatments (Christian et al., 2012). Comparing the results of the three studies establishes that plant tolerance to short term flooding cannot be assumed based on plant functional group. The results also provide rain garden implementers options for grass selection depending on the expected frequency of flooding.

Morash [62] made an interesting observation regarding flooded grass roots. Although RDW was not measured, Morash [62] described personal observations of the roots upon inspection of the plants at harvest. *C. latifolium* developed two characteristics not seen in any of the other species examined—robust root systems that penetrated the entirety of the 97 L containers in flooded plants and aerenchyma tissue in the stems. Aerenchyma are a well-known plant acclimation in waterlogged environments that transport oxygen to depleted roots [42]. Flood tolerant grass species, such as *C. latifolium*, can increase the number of adventitious roots per stem and nearly double root porosity [80]. Meder [61] provided similar observations for *A. ternarius* as well as data that support Morash's [62] observations. Mixtures of shallow and deep-rooted species can improve the uptake of limiting nutrients, such as P, leading to higher productivity over time, and potentially, more nutrient removal from stormwater [64]. Therefore, the inclusion of deep-rooted plants, such as grasses as well as shallow rooted plants as herbaceous perennials, is recommended for rain gardens.

Like the grasses, the ferns demonstrated that plant recommendations should be based on site-specific conditions. *Osmunda cinnamomea* was very tolerant of rain garden conditions, and *P. acrostichoides* was not. *Osmunda cinnamomea* was not affected by flooding. Furthermore, the researcher stated that this species was visually appealing regardless of the treatment. Under the same flooding conditions, *P. acrostichoides* performed poorly. Flooding did not affect *P. acrostichoides* in the spring, but summer SI, LCC, and SC were negatively affected by flooding. Two of the six summer 2015 plants died. A time by flooding treatment interaction was found for LCC and SC, which suggest that a longer experimental period could have resulted in more loss. The researcher reported that plants seemed to suffer from the 5 days drying period and somewhat recover from drying when flooded. Intolerance for dry conditions may explain why this species was not negatively affected by flooding in the fall as opposed to the hot summer months. In a vegetative community study, *P. acrostichoides* was identified as a strong indicator species for the presence of near surface water (defined as saturated soil or water table within 30 cm), which supports that this species was intolerant of the 5 days no watering period [81]. The results from *P. acrostichoides* emphasize the importance of rain garden research under various wet/dry periods as well as seasonal studies. Even though *P. acrostichoides* performed poorly in the rain garden simulation, it may succeed in areas with milder or wetter summers. Therefore, regional studies of rain garden plants are recommended for future research as well.

Growth measurements were helpful in identifying rain garden impacts on plants other than flooding, for example, the change in seasonality effects inevitable within a rain garden. When comparing runs of *C. verticillata*, the plant exhibited its highest growth measurements in the spring. The result is consistent with the typical growth pattern for *C. verticillata*, which predominately occurs during spring and summer [82]. Likewise, the growth of *C. latifolium* is also known to peak in the summer [83]. The average summer 2015, SDW of *C. latifolium* was more than 2.5 times higher than the spring 2015 average for both flooded and non-flooded plants (flooded spring:summer—31.3:82.1

and non-flooded spring:summer—18.7:49.5). Shrubs exhibited a different growth pattern in both studies. All four shrub species grew throughout experimental runs including those conducted in fall, when growth typically peeks. Based on the evidence, monoculture planting or a planting of the same functional group (all grasses or all shrubs, for example), may result in vegetation gaps within seasons. If so, restrictions in nutrient uptake and transpiration rates would likely ensue. Furthermore, the general health of the rain garden could suffer. With a planting gap, another species, such as an invasive plant or weed, could move in more readily. Polyculture plantings are known to better resist invasion and are more resilient to mortality of another single species [84,85]. Having a variety of plants in a rain garden can reduce vegetation gaps caused by seasonal growth variations because successful species can take turns filling the gaps caused by unsuccessful species.

4.3. The Effects of Polyculture on Growth and Phosphorus Uptake

The Meder [61] study delved deeper into polyculture effects on growth. Polyculture planting in that study included three different functional plant groups—herbaceous perennial, shrub, and grass. Meder [61] revealed that polyculture treatment values, which were collected in the spring, were neither the highest in weight nor the lowest. Seasonal growth rates explain the intermediate dry weight of the polycultures. *Andropogon ternarius* and *I. vomitoria* were high growth species in fall, and *C. verticillata* was a high growth species in spring. Applying Meder's [61] results to a proper rain garden would mean that a rain garden populated by *A. ternarius*, *I. vomitoria* and *C. verticillata* would produce more biomass in the summer than a garden planted with only *C. verticillata*. Furthermore, had the polyculture experiment extended beyond one season, research suggests that it is likely that the average polyculture dry weights would have exceeded monoculture dry weights. A study of diversity and canopy structure on grassland ecosystems found that species and functional group diversity increased mean vegetation cover from 64% in monocultures to 100% in a 32-species mixture [86]. The most species rich community produced 143% more biomass than monoculture plantings over several seasons. Plant functional group richness exerts positive effects on plant biomass and productivity. When competition exists between different functional groups, compared to within the same functional group, there is a higher biomass yield than when a functional group is grown alone, as the plants are occupying different resource niche spaces [64]. Therefore, by maximizing biomass through polyculture, greater nutrient uptake can likely be achieved.

The handling of P is of particular interest in rain gardens since it is known to be in high concentrations in urban runoff. Meder's study [61] provided insight into how different functional groups handled Pin monoculture and polyculture plantings. Slower growing plants from low-resource ecosystems, such as shade understory, have low capacity for nutrient uptake. This may explain why *I. vomitoria*, an understory shrub, had low shoot and root P concentrations [87–89]. Among species, root and shoot tissue P was highest in the perennial, *C. verticillata*, and similar in *I. vomitoria* (shrub) and *A. ternarius* (grass). Among planting combinations, root tissue P was also highest in *C. verticillata* monoculture pots, and the next highest root tissue P was in polyculture pots. Perennial plants from higher nutrient ecosystems, such as *C. verticillata*, may have higher nutrient uptake than faster growing plants, such as grasses [90,91]. Nutrient storage can occur in perennial plants as an insurance against future loss and as a support for growth when conditions are favorable, thus *C. verticillata* may have had the highest root and shoot tissue P, due to its natural ability to take up more nutrients [87]. However, when total P for each plant was measured, *C. verticuillata* has the lowest total P uptake, which was 10 times lower than *A. ternarius* and 2 times lower than *I. vomitoria*. Furthermore, RDW was lowest for *C. verticillata*. In contrast, root tissue P was lowest for *A. ternarius* and *I. vomitoria*, and RDW was highest for *A. ternarius*. Thus, it is possible that while some species, such as *C. verticillata*, are storing excess P in plant tissue, species from low nutrient ecosystems or those with long life history traits, such as *A. ternarius* and *I. vomitoria*, may be allocating additional P to biomass production [87].

Lastly, Meder [61] examined how polyculture and flooding affected P in leachate. Leachate P was higher in flood treatments than in non-flood treatments. A similar study also found that P concentration in leachate was higher in flooded plants than non-flooded [59]. In non-flood treatments, leachate P was similar regardless of planting combination. When flooded, leachate P was lowest in polyculture plantings, which suggests there is more nutrient competition for P in polyculture plantings than monoculture plantings [86,90,92].

4.4. Stomatal Conductance in Rain Gardens

Stomatal conductance was consistently higher in non-flooded plants than flooded plants in *I. floridanum*, *M. cerifera*, and *P. acrostichoides* (summer 2015 only). Stomata are known to close in response to flooding to prevent loss of oxygen [93,94]. However, in plants that are adapted to waterlogged soils, such as *C. latifolium* and *P. acrostichoides*, stomatal conductance can be enhanced (as it was in this research) by continuous flooding or periodic flooding [95]. Understanding evapotranspiration potential is an important consideration because transpiration modifies rain garden hydrology. Evapotranspiration can be nearly 50% of the hydrologic budget when shrubs were planted in rain gardens, which is consistent with the findings of this research [96]. Whole plant transpiration estimates for both shrub species were nearly double that of *C. latifolium* in the fall 2014 run. Therefore, transpiration rates may be considered when designing rain gardens. Utilizing plants with lower transpiration rates may result in longer drying times in a rain garden, but may also allow more infiltration for groundwater recharge. Conversely, plants with high transpiration rates may speed dry in areas where standing water may not be acceptable. Additionally, the inclusion of evergreen plants, such as the shrubs used in this research, promotes year round rain garden functionality [97].

4.5. The Rain Garden Plant Selection Conundrum

Regarding the eight species examined by the Meder [61] and Morash [62] studies, one plant was highlighted for its ability to adapt to flooding—*Chasmanthium latifolium.* This species not only tolerated repeated short-term flooding, but it responded positively to flooding based all of the data collected. Likewise, *C. latifolium* thrived in a complimentary three-year low-input performance study, which bolsters this plant's recommendation as an excellent rain garden selection [83]. Herein lies the case that a multitude of factors must be considered when choosing rain garden plants. While *C. latifolium* was proven to be hardy in low-input environments, tolerant of raingarden flooding, capable of higher transpiration rates when flooded, and prone to developing deep-rooted plants, especially when flooded, its ability to store P is likely lower than perennials from high nutrient environments. Once maximum height is achieved, the grass's ability to remove phosphorus could plummet. However, the transpiration rate would likely remain steady when flooded, even when fully mature. Therefore, no one plant is a catchall rain garden selection.

5. Conclusions

Implementers must choose the parameter most important to their system's success (for example transpiration in systems with expected high volumes of water or P uptake in systems with high nutrient inputs) from well researched rain garden recommendations. The Morash [62] and Meder [61] studies lay the groundwork for future rain garden plant studies and provide a method for simulating rain garden conditions with their use of microcosms in any region and with a range of plants species. Their research built a strong case for the use of polyculture in rain garden systems as well as six diverse species proven to tolerate fluctuating wet/dry periods in the southeastern U.S.A.

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Appendix A

The following table summarizes rain garden plant recommendations for the southeastern U.S.A. based on research conducted at Auburn University, Auburn, AL.

Table A1. Southeastern U.S.A. native landscape plant species evaluated at Auburn University, Auburn, AL for tolerance to repeated short-term flooding. Species are classified as suitable or not for use in rain gardens based on the results of research similar to that described in this paper.

Group	Plant	Suitable	Reference	Additional Comments
Grass	*Andropogon ternarius* broomsedge	Y	[61]	
	Muhlenbergia capillaris muhly grass	Y	[59]	
	Chasmanthium latifolium river oats	Y	[62]	
Evergreen Shrub	*Ilex vomitoria* 'Schillings dwarf' yaupon holly		[59,60]	
	Illicium floridanum Florida anise	Unknown	[62]	Poor visual quality
	Morella cerifera wax myrtle	Y	[62]	
	Ilex glabra 'Shamrock' inkberry	Y	[60]	
Deciduous shrubs	*Itea virginica* 'Henry's Garnet' sweetspire		[60]	
	Viburnum nudum 'Winterthur' possumhaw	Y	[60]	
	Fothergilla x *intermedia* 'Mt. Airy' dwarf witch alder	N	[58]	Flood intolerant
	Ilex verticillata 'Winter Red' winterberry	Y	[58]	
	Clethra alnifolia 'Ruby Spice' summersweet	Y/N	[58]	Young plants not suitable
Perennial	*Echinacea purpurea* 'Magnus Superior' purple cone flower	N	[61]	Flood intolerant
	Coreopsis verticillata 'Zagreb' whorled coreopsis	Y	[61]	
Fern	*Osmunda cinnamomea* cinnamon fern	Y	[62]	
	Polystichum acrostichoides Christmas fern	N	[62]	Drought intolerant

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Article

Carbon Offset Service and Design Guideline of Tree Planting for Multifamily Residential Sites in Korea

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Abstract: Multifamily residential sites (MRS) are practical alternatives for securing a carbon uptake source in urban areas where hardscape is dominant, as trees must be planted in the lot area, according to the current landscape-related ordinances in Korea. Tree planting contributes to sustainability of residential sites through carbon reduction. This study quantified direct and indirect carbon reduction from tree planting in MRS in Korea and explored sustainable design guidelines to maximize the carbon offset service of MRS. The total annual direct and indirect carbon reduction through tree planting in all the MRS was estimated to be about 101.1 kt/year. This carbon reduction equaled 3.3% of the total annual carbon emissions from the heating and cooling energy consumption of multifamily buildings. This study considered both direct and indirect carbon reduction from trees in MRS which was insufficient in previous studies. The results of this study can be useful internationally by sharing the information of sustainable residential design in enhancing carbon offset service.

Keywords: carbon reduction; building energy saving; urban tree; design model; ecological service; tree planting structure

1. Introduction

Climate change may lead to adverse effects on natural ecosystems and socio-economic systems, such as a reduction in biodiversity, rising sea levels, decreasing agricultural productivity, and extreme weather events [1]. International society has promoted various international treaties to fight critical climate change, and the Paris Climate Agreement has been signed to assign the obligation of greenhouse gas (GHG) emission reductions to every country in order to limit the rise in the Earth's average temperature to 1.5 °C [2]. CO_2 is the most significant GHG contributing to climate change. The global CO_2 concentration in 2017 averaged approximately 405 ppm, an increase of 45% compared with the CO_2 concentration prior to the Industrial Revolution [3,4], and this is expected to increase to 650 ppm by 2050 [5]. The global CO_2 emissions in 2016 were 32,316 Mt/year, representing an increase of 57% compared with the emissions in 1990 [6].

The global urban areas where carbon emission activities occur totaled 602,864 km^2 in 2000, representing an increase of approximately four times compared with the global urban areas prior to the Industrial Revolution [7]. Residential land is one of the major land use types (40–50% of urban areas) in urban land [8,9]. The energy consumption of residential sites accounts for 45–55% of total building energy consumption [10,11]. To reduce the carbon emissions of residential sites, energy conservation, the development of renewable energy, and tree planting are required. In particular, tree planting is effective for reducing the atmospheric carbon level in a short period of time. Trees planted in residential sites contribute to carbon reduction in two ways: By directly sequestering carbon through photosynthesis (direct carbon reduction) and by avoiding carbon emissions through building energy savings (indirect carbon reduction). In addition, according to the 2005 Kyoto Protocol to the United Nations Framework Convention on Climate Change and the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines, revegetation in settlements with an area of 500 m^2 or more is recognized as an activity that improves carbon uptake sources [12,13], and tree planting in residential sites can be acceptable for this category of activity.

As the importance of carbon reduction through tree planting in residential sites has been recognized, related studies have been conducted [14–21]. Akbari et al. [14] analyzed cooling energy savings by shade trees in two detached residential sites (DRS) in Sacramento. A 25% increase in tree cover was estimated to reduce cooling energy consumption by 17% in Phoenix, 25% in Lake Charles, and 57% in Sacramento [15]. Jo and McPherson [16] quantified the avoidance of carbon emissions due to energy saving by trees in DRS in Chicago and suggested planting strategies to maximize indirect carbon reduction. Donovan and Butry [17] reported that planted trees in the west of a house can reduce carbon emissions from summertime electricity consumption by 31%. In hot arid climates, shade trees in residential sites can reduce the use of cooling energy by up to 0.37 MWh/year compared with the absence of shade trees [18]. Most of these studies have focused on estimating the energy savings of DRS at the house or city scale.

Few studies have estimated the energy savings and carbon reduction of residential sites, including multifamily residential sites (MRS) and DRS [19,20]. Jo et al. [19] reported that tree planting in all residential sites in Chuncheon, Korea, saved annual heating energy by 2.2% and cooling energy by 8.8% through shading, evapotranspiration, and windspeed reduction. These heating and cooling energy savings reduced carbon emissions by 3% annually. The urban and community trees in the US lowered residential energy consumption by 7.2% annually and reduced CO_2 emissions from energy savings by approximately 43,820 kt [20]. However, the above-mentioned studies only estimated indirect carbon reduction from energy saving of residential trees. The annual direct carbon reduction by existing trees in MRS in Sydney was approximately 2.2 t/year [21]. The carbon offset service of tree planting in residential sites needs to be estimated considering both direct and indirect carbon reduction. However, there is little research that estimates both the direct and indirect carbon reduction of residential trees worldwide. In addition, the appropriate design guidelines regarding residential sites are required to maximize carbon offset service, since carbon reduction in residential sites differs depending on orientation, density, species, dimensions, and the vertical structure of planted trees [16,17,19,22].

In Korea, where CO_2 emissions are the sixth-highest worldwide, the predominant type of land use in urban areas (all land use types except natural land) is residential land (64%) [23]. Of the percentage of dwelling types in Korea, MRS account for 50% of all residences, which is the most common, followed by DRS (33%) [24]. Since the 1960s, the number of MRS has increased rapidly in Korea due to overpopulation in urban areas caused by industrialization. Whereas the average number of floors of MRS was five stories in the 1960s, MRS are becoming higher and denser. The MRS where the floor area ratio is high and in which most of the urban population lives consume a large amount of energy every year, significantly increasing carbon emissions in urban areas. On the other hand, MRS are becoming a practical alternative for securing carbon uptake sources in urban areas where greenspace is limited because a tree must be planted in some part of the lot area due to landscape-related ordinances in Korea.

However, as mentioned previously, there is little information about the carbon reduction of tree planting in MRS and low carbon design of MRS not only in Korea but also globally. The carbon offset service from residential trees could vary significantly among nations based on differences of climates, tree planting structures, and energy uses. Diverse studies by region, nation, and dwelling type will contribute to our understanding of carbon offset service with residential trees. Thus, the purpose of this study was to quantify the carbon offset service, including both direct and indirect carbon reductions from tree planting, and to suggest sustainable design guidelines for MRS in Korea. The results of this study could be useful internationally by sharing the information of sustainable residential design in enhancing carbon offset service as there is a lack of research regarding carbon reduction by trees in MRS.

2. Materials and Methods

2.1. Study Framework

The study consisted of six phases: Selection of study cities; sampling of study MRS in the selected cities; field survey of planting trees in study MRS; collection of data on building characteristics and energy consumption of all MRS in Korea; estimation of carbon offset service; and exploring design guideline to enhance the carbon offset service of MRS. Figure 1 explains the framework and procedure of this study. The Korea was selected because there is little information on carbon offset service associated with residential trees, while MRS are dominant in urban areas.

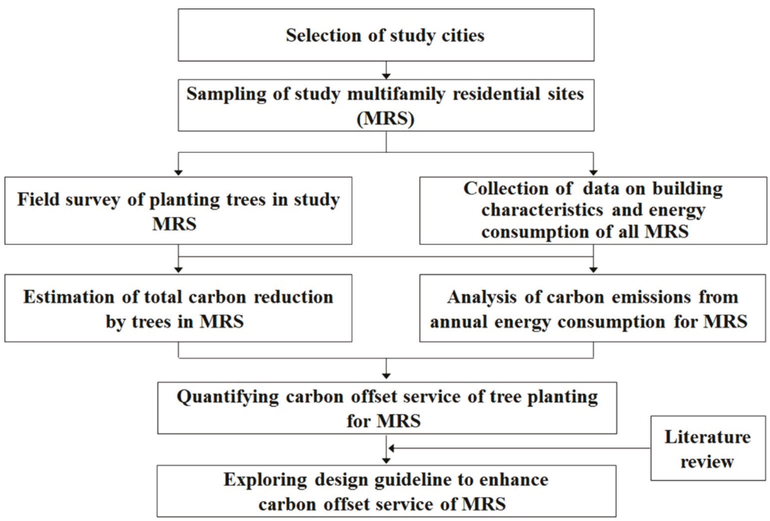


Figure 1. Systematic study flowchart.

2.2. Selection of Study Cities

The cities examined in this study were selected by considering the regional distribution to quantify the carbon offset service and tree planting structure of the MRS in Korea. The cities selected for the study included Seoul (the capital of south Korea, located in the north), Daejeon (located in the middle), and Daegu (located in the south) (Figure 2). In Korea, these are capital or metropolitan cities and represent the typical urban landscape dominated by MRS. MRS were surveyed in this study because they are the largest distributed residential dwelling type in Korea (50%) [24], they have a large annual energy consumption, and because a planting space can be more easily secured for MRS than for DRS. Based on the current landscape-related ordinances in Korea, no planting is required within a residential lot smaller than 200 m^2 [25]. According to Jo [26], residences smaller than 200 m^2 in the lot area account for approximately 50% of the total detached residences in the middle of Korea. Thus, most DRS have no trees.

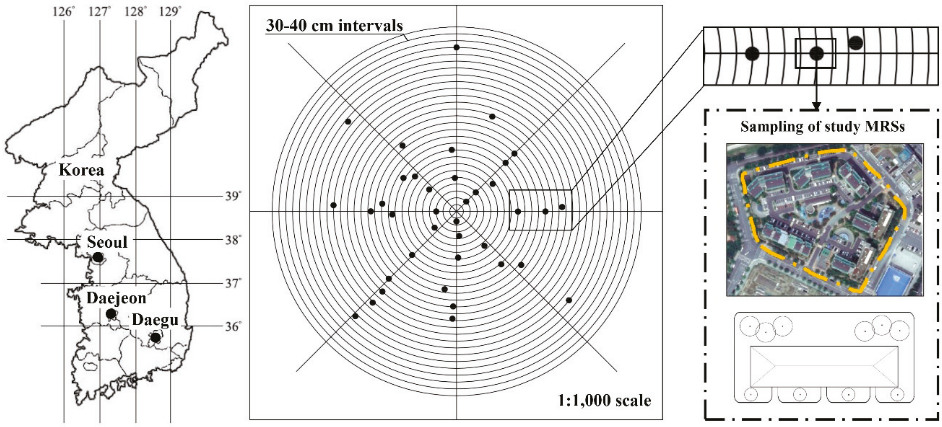


Figure 2. Location of three study cities and systematic random sampling method used in this study.

A total of 110 sample MRS (36 for Seoul, 38 for Daejeon, and 36 for Daegu) were selected for the study by applying the systematic random sampling method to a 1:1000-scale aerial photograph (Figure 3). Specifically, eight evenly spaced straight lines radiating from the centers of the study cities were drawn and based on the city size and MRS distribution, looping circles were plotted at 40 cm intervals for Seoul and Daejeon and at 30 cm intervals for Daegu. Then, the MRS located at the intersections of the lines and the circles or at the shortest distance from these intersections were selected for this study. This sampling design is a useful method for sampling MRS randomly on a city-wide scale, avoiding selection bias [27]. The number of samples was determined based upon a compromise between the competing concerns for data reliability and cost availability.

(**a**). planting space (**b**). parking lot (**c**). square

Figure 3. Typical landscape of study multifamily residential sites.

2.3. Field Survey and Analysis

In this study, a field survey was carried out for all of the existing trees in each of the selected MRS with the residents' approval, and the total lot area and areal distribution of the land cover types (buildings, pavements and facilities, trees and shrubs, grass and bare soil) of the study MRS were measured. The field survey tree data included the species, height, crown width, stem diameter at a breast height of 1.2 m (dbh) for trees and at a height of 15 cm above ground for shrubs (2 cm or less in dbh), vertical structures, and size of the planting space. Moreover, potential planting spaces that could accommodate newly planted trees with a crown width of 2 m or wider and height of 3 m or higher in a permeable area unoccupied by various facilities (utility lines, manholes, and septic tanks) were measured. These survey data were used to analyze the density and cover per unit area, dbh distribution, and importance values of tree and shrub species. The collected data were also used to compute the annual direct and indirect carbon reduction by the trees in each of the study MRS.

2.4. Estimation of Carbon Offset Service

Trees planted in MRS can reduce atmospheric carbon in two ways: By directly sequestering carbon through photosynthesis (direct carbon reduction) and by avoiding carbon emissions through building energy savings (indirect carbon reduction). Annual direct carbon reduction by urban trees can differ from that by forest-grown trees due to management input and less competition. Therefore, this study estimated the annual direct carbon uptake by residential trees using quantitative models developed for the urban open-grown trees of each species [26,28–34] (Table 1). These quantitative models in which the stem diameter was the most important independent variable were derived from either seasonal CO_2 exchange rate measurements or the direct harvesting method of urban trees. In cases of tree species for which a quantitative model was unavailable, regression models of the same genus or group were used to compute the average carbon estimates. The mean direct carbon reduction per unit of MRS area and per crown cover was calculated for the surveyed area and tree cover. The carbon uptake per unit of MRS area was then applied to compute the total annual direct carbon reduction of the entire MRS area [35] in Korea. In this study, carbon uptake refers to the annual rate of carbon absorption by trees.

Table 1. Quantitative model sources used to calculate carbon uptake of tree and shrub species in the study multifamily residential sites.

	Species	Diameter Range [a] (cm)	Reference
Tree	*Abies holophylla*	5–19	Jo et al., 2014
	Acer palmatum	7–27	Jo and Cho, 1998
	"	5–20	Jo and Ahn, 2012
	Chionanthus retusus	3–11	Jo et al., 2014
	Cornus officinalis	3–15	Jo et al., 2014
	Ginkgo biloba	6–31	Jo and Cho, 1998
	"	5–25	Jo and Ahn, 2012
	Pinus densiflora	5–29	Jo and Ahn, 2001; Jo et al., 2013
	Pinus koraiensis	5–33	Jo and Ahn, 2001; Jo et al., 2013
	Platanus occidentalis	10–58	Jo and Cho, 1998
	Prunus yedoensis	5–23	Jo and Ahn, 2012
	Taxus cuspidata	2–15	Jo et al., 2014
	Zelkova serrata	6–34	Jo and Cho, 1998
	"	5–28	Jo and Ahn, 2012
	General hardwoods	3–28	Jo, 2017
	General softwoods	5–31	Jo, 2017
Shrub	*Pinus* spp.	0.6–3.5	Jo, 2002
	Quercus spp.	0.5–4.0	Jo, 2002
	Rhododendron spp.	0.4–3.4	Jo, 2002
	General hardwoods	0.4–4.0	Jo, 2001; 2002
	General softwoods	0.4–4.0	Jo, 2001; 2002

[(a)] Stem diameter at breast height of 1.2 m for trees and diameter at 15 cm above ground for shrubs.

Annual indirect carbon reduction was quantified based on a carbon estimate per unit of conditioned floor area (CFA) by trees planted in multifamily buildings; that is, the annual energy saving per CFA was calculated by applying the annual total heating and cooling energy consumption [36–38], the total CFA [39], and the ratio of energy saving per CFA by trees [19] to the MRS in Korea. These energy savings were converted into the carbon emission reduction using the carbon emission coefficient per energy source [40,41], such as oil, gas, and electricity. In addition, the total indirect carbon reduction in all MRS in Korea was calculated by multiplying the carbon emission reduction per CFA by the total CFA for up to two floors because, considering the mean height (6.6 m) of the planted trees in the study MRS, it is clear that only the first two floors benefit from energy savings due to trees.

The total carbon reduction of the entire MRS was calculated by summing the direct and indirect carbon reduction. In addition, the carbon offset service by the trees planted in MRS was quantified compared with the carbon emissions according to the annual heating and cooling energy consumption of the MRS. Based on the above results and review of the literature, this study explored sustainable design guidelines for enhancing the carbon offset service of tree planting in MRS.

3. Results and Discussion

3.1. Land Cover Types

The total area and resident population of the MRS in the study cities were 14,215 ha (Seoul: 9975 ha, Daejeon: 1813 ha, and Daegu: 2427 ha) and 6,940,000 people (Seoul: 4,581,123, Daejeon: 910,459, and Daegu: 1,451,045), accounting for 28% and 51% of the total area and resident population of the MRS in Korea, respectively [24]. The area of the study MRS ranged from 0.2 to 15.7 ha. The study MRS with an area of less than 3 ha accounted for 60% of all of the study MRS, comprising the largest proportion, followed by 3–6 ha (28.1%) and 6 ha or larger (11.9%). The total surveyed area of the study MRS was 422.3 ha (Table 2), which accounted for approximately 3% of the total MRS area of the study cities. The average number of floors and the floor area ratio in the study MRS were 15 stories and 250%, respectively. The resident density of the study MRS ranged from 161 to 1209 persons/ha.

Table 2. Total area and building density of multifamily residential sites (MRS) sampled in study cities [a].

City	N	Total Area (Ha)	Building Area (Ha)	Floor Area Ratio	Residents	Resident Density (Persons/Ha) [b]
Seoul	36	140.1	28.9	261	87,590	613.0
Daejeon	38	156.0	35.9	240	87,133	572.9
Daegu	36	126.2	35.3	256	81,001	632.7

[(a)] Source: Korean Statistical Information Service [24]. [(b)] Resident density was calculated by dividing residents by area of MRS.

The percentage of land cover types in the study MRS averaged 57.7 ± 1.3% for pavements and facilities, 23.7 ± 1.0% for buildings, 17.9 ± 1.2% for trees and shrubs, and 0.7 ± 0.0% for grass and bare soils (Table 3). Thus, the study MRS were composed mostly of impervious areas such as pavements, facilities, and buildings. Most of the pavements and facilities were parking lots, roads, and large squares with no specific purpose of use. Kim [42] reported that the ratio of impervious areas of the residential sites in Roanoke, USA was approximately 25.9%. Compared to this value, the impervious areas of the study MRS were about three times higher. To improve the carbon offset service of the MRS, it would be desirable to expand the planting areas by reducing the amount of unnecessary impervious areas.

Table 3. Percentage of land cover types in study multifamily residential sites.

City	Land Cover Type (%)			
	Paving/Facility	Building	Tree/Shrub	Grass/Bare Soil
Seoul	59.3 ± 3.1	25.2 ± 1.5	15.1 ± 3.0	0.4 ± 0.0
Daejeon	59.0 ± 2.2	23.0 ± 1.6	17.0 ± 2.0	1.0 ± 0.3
Daegu	55.2 ± 1.8	23.2 ± 1.4	21.1 ± 1.5	0.5 ± 0.0
Total	57.7 ± 1.3	23.7 ± 1.0	17.9 ± 1.2	0.7 ± 0.0

3.2. Tree Planting Characteristics

The planting density of trees was in the 0.2–5.5 trees/100 m^2 range and varied between the different MRS surveyed in this study. The density of <2 trees/100 m^2 comprised 45.0% of all study MRS, followed by 2–3 trees/100 m^2 (43.4%) and ≥4 trees/100 m^2 (11.6%). The mean tree density for the study MRS was 2.5 ± 0.1 trees/100 m^2 (Table 4), which was slightly lower than the 2.8 trees/100 m^2 of the residential sites in Roanoke, USA [42].

Table 4. Density, basal area, and cover of existing trees in study multifamily residential sites.

City	Density (Tree/100 m^2)	Basal Area (cm^2/100 m^2)	Cover [a] (%)
Seoul	1.9 ± 0.1	457.3 ± 54.1	21.9 ± 1.5
Daejeon	2.7 ± 0.2	483.1 ± 42.8	23.1 ± 2.0
Daegu	2.8 ± 0.2	453.8 ± 31.0	23.9 ± 1.6
Total	2.5 ± 0.1	465.4 ± 24.4	23.0 ± 1.0

(a) Cover includes shrubs.

The basal area of the planted trees ranged from 28.5 to 1322.6 cm^2/100 m^2 with an average of 465.4 ± 24.4 cm^2/100 m^2. A total of 54.2% of all study MRS had < 400 cm^2/100 m^2. The mean basal area was quite similar among the study cities. The dbh of the trees averaged 13.6 ± 0.1 cm across all study MRS. The trees with a dbh of <20 cm accounted for 81.6% of all planted trees, which was the most (Figure 4). A previous study showed that in some residential sites in the UK, trees with a dbh of <20 cm comprised approximately 50% of planted trees [43]. Thus, the distribution of small trees in the study MRS was about 1.6 times higher than that in the UK.

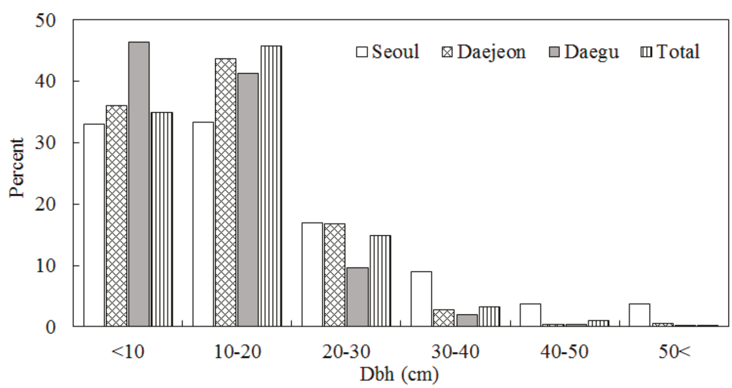


Figure 4. Diameter at breast height (dbh) distribution of trees planted in the study multifamily residential sites.

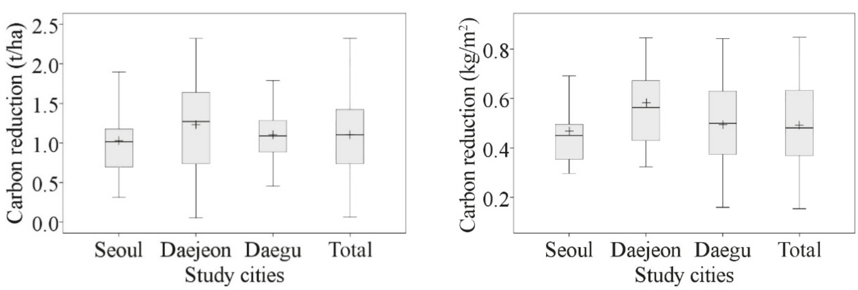
The average cover of the planted trees and shrubs was 23.0 ± 1.0%, ranging from a minimum of 4.3% to a maximum of 48.4%. The tree and shrub cover of 20–40, <20, and >40% comprised 54.4, 39.8, and 5.8%, respectively. There were no significant differences (95% confidence level) in the tree and shrub cover among the study cities. The tree cover of some residential sites in the USA and Australia ranged from 30.4 to 31.4% [42,44]. Compared to these values, the tree cover of the study MRS (19.2% excluding shrubs) was lower by 11.2–12.2%.

A total of 197 tree and shrub species were found in the study MRS, indicating a diverse composition of species. The dominant tree and shrubs species in the study MRS (based on the importance values) were *Zelkova serrata*, *Acer palmatum*, *Pinus densiflora*, *Prunus yedoensis*, *Rhododendron yedoense* var. *poukhanense*, and *Buxus microphylla* var. *koreana*. They are major landscape tree species that are typically highly dominant in most cities of the Korea [26,27,45,46].

The vertical structures of tree planting in MRS exhibited multi-layered structures in which an overlap of upper (tree) and lower (shrub) layers accounted for 75.1% of the total planted area, whereas single-layered structures of only the upper or lower layer comprised 24.9%. The single-layered areas were mostly areas with trees (21.4%), and a much smaller area was found to be covered by shrubs (2.6%) and grass (0.9%). Multi-layered structures from natural forests, in which there is an overlap of upper (large trees), middle (large shrubs and small trees), and lower layers (herbs and small shrub) would increase carbon storage per unit area [26]. This planting structure is effective in maximizing carbon uptake in urban areas with limited planting space. However, the vertical structure of the study MRS consisted only of upper and lower layers, and there were no middle layers. To improve the carbon reduction of MRS in the future, it would be desirable to apply multi-layered structures of upper, middle, and lower layers. The potential planting area in the study MRS was approximately 1.5 ha, in which about 4700 trees with a crown width of 2 m could be additionally planted.

3.3. Carbon Offset Service

The annual direct carbon reduction per unit area by the planted trees in the study MRS ranged from 0.3 to 2.9 t/ha/year with an average of 1.1 ± 0.1 t/ha/year (Figure 5). The annual carbon uptake per unit area of some residential sites in the US and Australia were 2.2 t/ha/year and 2.3 t/ha/year, respectively [21,42]. The direct carbon reduction in the study MRS was only 50% of the estimated values, which was due to the differences in the density, size, and growth rate of the trees planted. The annual direct carbon reduction per unit of crown cover of the planted trees in the study MRS ranged from 0.2 to 0.9 kg/m^2/year with an average of 0.5 ± 0.0 kg/m^2/year. Currently, no information is available regarding the direct carbon reduction indicator per unit of tree cover in the MRS. The urban land average carbon uptake per unit of tree cover in Korea was 0.5 kg/m^2/year [26]. The average direct carbon reduction per unit of tree cover in the study MRS was similar to the estimates for entire cities. There were no differences (95% confidence level) in the direct carbon reduction per unit area and tree cover among the study cities.



(**a**) (**b**)

Figure 5. (**a**). Annual direct carbon reduction per area; (**b**). Annual direct carbon reduction per tree cover. Annual direct carbon reduction by trees and shrubs planted in study multifamily residential sites.

The annual heating and cooling energy savings by the planted trees per CFA of the MRS were 17.3 MJ/m^2/year and 0.7 kWh/m^2/year, respectively, due to shading, evapotranspiration, and windspeed reduction. The annual indirect carbon reduction per unit of CFA, building, and tree cover due to heating and cooling energy saving by residential trees was 330.3 g/m^2/year, 384.4 kg/year, and 0.4 kg/m^2/year, respectively. Jo et al. [19] reported that the carbon emission reduction per CFA of the MRS in Chuncheon was 462.1–974.8 g/m^2/year depending on the differences in tree cover. Due to the changes in the heating facilities and carbon emission coefficients of Korean MRS, the indirect carbon reduction obtained in this study was smaller than that of previous studies. The primary heating fuels of the MRS in the 1990s were oil and liquefied petroleum gas (LPG), while liquefied natural gas (LNG) has been used more recently. Based on the energy saving estimates per CFA of the MRS, tree planting at MRS in Korea annually saved 2,305,234 GJ/year of heating energy and 89,683 MWh/year of cooling energy. These energy savings are equivalent to $39 million/year of heating and cooling energy cost savings based on the residential LNG ($0.02/MJ) [47] and electricity prices ($0.01/kWh) [48] in Korea.

The total annual direct and indirect carbon reduction by the planted trees in all the MRS in Korea was estimated to be approximately 101.1 kt/year (direct: 56.9 kt/year, indirect: 44.1 kt/year). This carbon reduction equaled 3.3% of the total annual carbon emissions from the heating and cooling energy consumption of multifamily buildings in Korea. The cost of carbon capture and storage was reported to be approximately $116/t/year [49]. Based on this cost, the economic value of the carbon reduction by MRS trees was equivalent to approximately $12 million/year. When the heating and cooling energy saving cost ($39 million/year) is also taken into account, tree planting in the MRS provides an economic benefit of approximately $51 million/year. The per capita carbon emissions from residential electricity consumption amounted to 163.3 kg/year [50]. The planted trees in all of the MRS annually offset the amount of carbon emitted by approximately 620,000 persons. Thus, trees in the MRS play an important role in reducing the atmospheric carbon concentration in urban environments with limited greenspace.

3.4. Sustainable Design Guideline

MRS are key resources that can practically secure carbon uptake sources in urban areas that have limited greenspace, because tree planting is required within an MRS by the current landscape-related ordinances in Korea. However, the carbon offset service by the trees in the MRS has been limited due to the presence of large impervious areas (including parking lots, roads, and squares), narrow planting space around the building, lack of consideration of planting technique for building energy saving, and the predominance of small trees. Thus, it is necessary to establish sustainable design guidelines to enhance the carbon offset service by tree planting in MRS by overcoming the above-mentioned problems.

To maximize the building energy savings and carbon reduction in MRS, the following design guidelines including planting and building layout are suggested (Figures 6 and 7). Here, the length, width, and number of floors for the building were assumed to be approximately 56 m, 11 m, and 15 stories, respectively, based on the average dimensions of the buildings in the study MRS. The building coverage ratio and floor area ratio were approximately 17% and 265%, respectively, which did not violate the current ordinances.

The reduction in energy consumption by an advantageous building layout is closely related to the utilization of solar light. Buildings in the MRS should be arranged toward the south to maximize solar gain in winter. South-facing buildings can save 20% more heating energy than east-or west-facing buildings [51]. However, even if all buildings are arranged toward the south, the shadows of adjacent front buildings will interrupt the solar gain at the rear side of the buildings in winter. The most widely applied building layout of the MRS in Korea is a parallel building layout toward the south. If this layout is applied, a lower-floor area corresponding to 35% of the rear building cannot gain solar light between 8 am and 4 pm in winter. Therefore, it would be desirable to arrange buildings toward the south and place them in a zigzag pattern with a solar azimuth axis of 30° at 10 am and 2 pm to gain solar light for more than four hours a day for all households during the heating season [51].

According to the landscape-related ordinances in Korea, the minimum planting space to be reserved in MRS is one-third of the lot area, which is then reduced to 15% of the lot area. As a result, although the importance of carbon offset service by trees has increased globally, the opportunity to secure a carbon uptake source in urban areas has diminished. It would be desirable to expand the planting space by amending the minimum mandatory planting area to the previous third of the lot area in MRS to enhance the carbon offset service by tree planting in urban areas. The large impervious areas in MRS should be decreased to improve tree planting by minimizing the square with no specified purpose of use and by creating underground parking, while trees should be actively planted in potential planting spaces. In the cases where it is difficult to create planting spaces within MRS, the establishment of playgrounds and resting spaces inside buildings should be encouraged, and trees should be planted outdoors. In addition, it is necessary to implement the greening of the hardscape such as roofs, walls, and fences.

A narrow planting space around the building may inhibit the normal crown and root growth of the planted trees and limit the selection of the tree species that can be planted. Based on the regression model for estimating the crown width from the tree age [52], the crown width of the planted trees (mean dbh: 13.6 cm) in the study MRS was estimated to be 6.5 m for deciduous trees after 30 years, which is the approved re-construction term in Korea. However, the average width of the planting space around the building in the study MRS was approximately 2 m, and this parameter was limited to ensure the continuous normal growth of the planted trees. It is necessary to maintain the productive growth of the planted trees to improve the performance of the carbon offset service. To supply the space for normal crown and root growth, the width of the planting space around the building should be set to more than 3 m.

Figure 6 shows a planting design model for building energy savings in MRS. The best location for planting trees to maximize energy savings through the shading effects of trees was opposite the west and east facing walls [16,17,22]. Thus, the mixed planting of deciduous and evergreen trees close to the west wall of the buildings is recommended to obstruct solar gain in the afternoon during the summer. It is necessary to plant large deciduous trees in the east to block solar gain in summer mornings and secure solar gain in winter mornings. Shade tree planting in the south should be avoided because this can increase the heating energy during winter through solar gain obstruction. If the residents desire to plant trees in the south, solar-friendly trees that can transmit solar light well during the heating season should be planted. Solar-friendly trees are deciduous trees that possess relatively open crowns when out of leaf, leaf out late in spring, and drop their leaves early in the fall [16]. For the Korea, these species include: *Celtis sinensis*, *Cornus controversa*, and *Ginkgo biloba* [22]. The multi-layered planting of evergreen and deciduous trees in the north is recommended to maximize the annual energy savings through cold wind reduction and evapotranspiration. Along the north walls, shade-tolerant evergreen trees should be planted to minimize heat loss in the winter. In addition, to enable the use of ladder trucks, tree planting in front of balconies should be avoided.

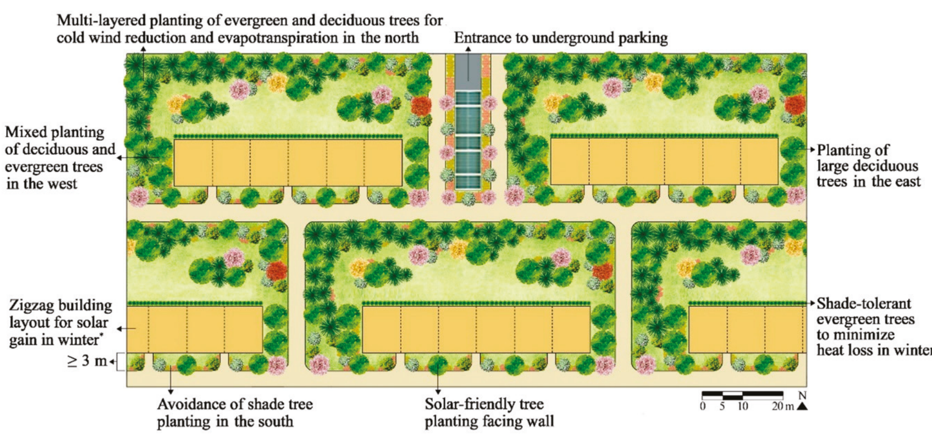


Figure 6. Planting design model for building energy savings in multifamily residential sites.

It would be desirable to apply a multi-layered and clustered planting model (Figure 7) in the large planting space of the backyard instead of single-layered planting, because multi-layered planting is more effective for obtaining the maximum tree biomass and carbon uptake per unit area [26]. The carbon uptake per unit area in multi-layered and clustered planting was approximately two times higher than that for single-layered planting [53]. The planting space of the streets should also be applied for multi-layered planting to enhance carbon offset service. It is recommended that existing mature trees be preserved instead of removed when the buildings of a MRS are constructed. In addition, this study suggests that large trees with better growth rates (e.g., *Zelkova serrata*, *Prunus yedoensis*, *Pinus koraiensis*) [27,54] rather than small trees and tree species should be planted.

Figure 7. Section view model of multi-layered and clustered plating to enhance carbon offset service.

4. Conclusions

Urban trees provide an environmental and ecological service, including carbon sequestration, building energy saving, microclimate amelioration, biodiversity enhancement, and rainfall interception. In particular, urban trees play a significant role in mitigating climate change, which is a serious environmental problem globally. Since MRS, which account for the largest proportion of urban land use, are required to establish greenspaces according to current ordinances in Korea, they are the main resources for practically obtaining carbon uptake sources in cities where hardscape is dominant. However, few studies have been conducted globally on the carbon reduction quantification of trees in MRS and a desirable design to improve this service. Thus, this study quantified the building energy saving and carbon reduction of tree planting and explored sustainable design guidelines to maximize carbon offset service for MRS in Korea.

The annual direct and indirect carbon reduction by tree planting in all MRS in Korea was estimated to be approximately 101.1 kt/year. The trees planted in all MRS played an important role in offsetting the annual carbon emissions from heating and cooling energy consumption in multifamily buildings by 3.3%. The primary factors related to the carbon offset service level in MRS are the orientation, dimensions, density, species, and vertical structures of trees [16,17,19,22]. Based on such results, the design guidelines of this study include a zigzag building layout, the mixed planting of deciduous and evergreen trees in the west, the planting of large deciduous trees in the east, multi-layered planting in the north, and the avoidance of tree planting in the south.

The application of a low-carbon design and the enlargement of greenspace would not only reduce atmospheric carbon in MRS, but also improve the property value and well-being of residents. Despite the multiple services of residential trees, construction firms focus on the expansion of buildings instead of tree planting to increase profits. They establish only the minimum planting space according to the ordinances and do not plant more trees. To enhance the carbon offset service of MRS in substance, it is necessary to consider providing incentives for the construction firms to apply low-carbon designs and secure more greenspace than the ordinances require. In addition, it is important to inform the public about the multiple services of residential trees. Unlike past research, this study considered both direct and indirect carbon reduction by residential trees. This study serves as a stepping stone to acquiring indicators of carbon reduction per unit of MRS area and tree cover and is significant in that design guidelines to enhance the carbon offset service were suggested based on a detailed field survey and data collection to attain reliable results. The results of this study can be useful internationally by sharing the role and technique of sustainable residential design to maximize carbon offset service. More studies, at a regional or national scale, including DRS, are required to compare and verify the study results. Related studies about life-cycle assessments of carbon for residential trees are also needed to explore desirable maintenance decisions to improve net carbon uptake.

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Recovering Subsidized Housing Developments in Northern México: The Critical Role of Public Space in Community Building in the Context of a Crime and Violence Crisis

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Abstract: México has subsidized and built millions of low-income homes and thousands of subdivisions in the period of 2000–2012. These occupied and expanded urban peripheries far away from work, learn, service, commerce, and recreational amenity centers. These communities had no chance to offer a high quality of life. They were rapidly abandoned and deteriorated physically and socially. Amid the still ongoing crime and violence, inhabitants experienced a loss of trust in their neighbors, a deep sense of insecurity, and consequently reduced public life and activity to a minimum. This article describes and reflects on a project implemented in two neighborhoods of two northern México cities, with the objective of mitigating crime and violence, while recovering public spaces in these communities. The project implemented a hybridized methodology, including Crime Prevention Through Environmental Design (CPTED), attention to Youth at Risk, and the prevention of Gender Based Violence. All these were integrated transversally with a community participation approach incorporated throughout the project actions. This article reflects on the successes and failures of this pilot project, as demonstrated by differentiated results between a neighborhood located in Chihuahua City and another in the municipality of Guadalupe, within Monterrey's Metro Area. The lessons learned, include the relevance of local political timing and interests, the importance of accurate and manageable geographic definitions for the areas of implementation, the role of NGOs, the importance of local educational institutions—in particular schools of architecture and the need for community oriented strategic consultants, to appropriately advise local governments in the implementation of projects of this nature. The article demonstrates the effort to make it accessible, and to anticipate the issues and opportunities as many Mexican, and other Latin American countries and cities engage in the spatial and social recovery of public spaces, neighborhoods, communities, and cities after years of high crime and violence.

Keywords: CPTED; youth at risk; public space recovery; prevention of gender-based violence; tactical urbanism

1. Introduction

This article describes and critically reflects on a pilot project intended to socially and physically recover public spaces. The project's objective was to mitigate crime and violence through a series of spatial/urban and social interventions implemented in two urban areas of northern México cities during the years of 2017 to 2018. The project leverages a growing momentum and awareness of social and spatial intervention tools, such as Tactical Urbanism, a practice that is growing in Latin America [1]. This project explored the potential to hybridize and create a methodology that incorporates three main concepts and their associated established methods. The three main concepts or methods were: Crime Prevention Through Environmental Design (CPTED); attention to Youth at Risk (AYAR); and the Prevention of Gender Based Violence (PGBV).

Being a pilot-test-project, the basic practical question was, "whether there could be a way to effectively integrate CPTED, AYAR, and PGBV, in a model that could be replicated in other urban neighborhoods or districts of México and Latin America". The premise was a challenge, as these three areas have their own processes, methods, and tools, and are not necessarily easily arranged in an operational critical route for implementation, especially when multiple actors are involved.

The two selected neighborhoods are in the City of Chihuahua, in the Municipality and State of Chihuahua, and in the Municipality of Guadalupe, part of the Metropolitan Area of Monterrey, in the State of Nuevo León, México. Chihuahua's selected neighborhood was Riberas del Sacramento—Spanish for Sacramento Riverside, henceforth the 'Chihuahua neighborhood'. Guadalupe's selected neighborhood was Paseo Guadalupe—Spanish for Guadalupe Promenade, henceforth 'Guadalupe neighborhood' (see Figure 1). Both neighborhoods are composed of recently developed subsidized low-income housing subdivisions.

During the first 12 years of the current century, the country of México implemented an aggressive program [2] of subsidized housing construction as the federal government, shifted from acting as a developer and builder to a financier of a housing production. Unfortunately, a vast number of these subdivisions were inadequately located in their towns and cities [3]. Many were positioned in large, wide, empty, and expansive urban peripheries, including the Chihuahua neighborhood, and many others situated mostly in the vacant urban fringes of expansive metropolitan areas. The case of the Guadalupe neighborhood is similar, however, this community is surrounded by other low-income subdivisions and vacant properties, while the Chihuahua neighborhood is like an island, surrounded by vacant and agricultural lands, detached from the city's urban fabric and infrastructure [4], except for a highway connecting it to the city.

In 2006, the Mexican Federal Government declared the "War on Drugs" by a massive militarization and intensification of policing activities in the country [5]. The unintended consequences of this action, included the expansion of criminal activities beyond the conventional drug trade, including kidnappings and extortion, which made the peri-urban areas an easy prey for territorializing by organized crime, as cartels were beheaded and transformed. Gangsters increased their recruitment of youth in many of the new subdivisions and made these areas a significant location for their criminal activities. Along with long commuting distances to work, service, commerce and education centers, inadequate architectural quality of housing, inability to pay credits, this made the subdivisions undesirable and/or unaffordable places to live for many. A high national perception of insecurity has also contributed to the abandonment of housing and public spaces, taking public life out of street life, parks, and plazas, which are included in the master planned subsidized communities. Both Chihuahua and Monterrey Metro are also among the Mexican cities with highest murder rates—above 65.3 homicides per 100,000 [6].

Another critical problem in México is gender-based violence. Verbal and physical aggression inflicted by male romantic partners to their female partners is a mute, as it is often not denounced [7]. This type of violence is very common and normalized in México. The 2016 National Survey on Home Relationships Dynamics (ENDIREH) delivered dismal indicators on this for women over 15 years of age in México: Where 29% have suffered economic violence or work discrimination, 34% have suffered physical violence, 49% have endured emotional violence, and 41.3% have suffered sexual violence [8].

Both the Chihuahua and the Guadalupe neighborhoods were selected by their municipal governments as neighborhoods suitable for assessing the implementation of the CPTED-AYAR-PGBV project. The selection occurred through the analysis of municipal authorities of crime and violence statistics, controlled by municipal police departments.

The implementation of this pilot project was supported by technical support, provided by the United States Agency for International Development (USAID), through its contractor Chemonics International, to local municipal governments who have agreed to provide their institutional resources. This was executed within an umbrella program called "Juntos por la prevención de la violencia", Spanish for "Together for the Prevention of Violence." The author of this article was the general consultant, leading the technical team supporting local governments. In each city, there was a local expert hired to implement the CPTED strategies, as well as community participation methods and techniques. The international development agency supervised the technical team, facilitated and coordinated with the municipal government entities, including an active participation of the mayors.

2. Materials and Methods

The hybridization of the three methodologies was, since the beginning, understood as a pilot project to be evaluated through its implementation. Evidence based results were expected. Therefore, one of the intended first steps was the planning and collection of baseline data against which to compare results as the project strategies and tactics were implemented. The project was envisioned by the technical team and the partnering local governments as a social and environmental intervention. As such, it was meant to demonstrate a social impact by diminishing indicators of crime and violence. Also, integral to the project was the materialization of an environmental, physical, and spatial impact, as demonstrated by reclaimed public spaces, active streets, parks, and plazas.

2.1. CPTED

The unifying methodology, among the three, was CPTED. USAID already had ample experience in the implementation and development of projects, based on this methodology, in México. In 2015, through USAID's 'Program for Citizen Living' (a precursor to the one hosting this project), had already produced a guide titled 'Safe Public Spaces Design Guide', which became an initial start-up methodologic reference for the project [9].

CPTED is a well-established and proven method for crime and violence prevention [10]. It is focused on spatial aspects in its first generation [11] and adds social ecology in its second generation [12].

"CPTED is a compendium of crime prevention strategies seeking to reduce the possibilities of crime of opportunity, as well as reducing fear in the community, augmenting its cohesion." [13] Its main hypothesis is that human behavior is influenced by physical and spatial conditions [14], where a sense of community is key for safe public spaces [15], and that the defense of public space depends on the capacity of the community to unite for a common good [16].

CPTED is originally based on a set of spatial criteria shaping the physical urban/architectural environment. However, as it emerged and was developed initially in Canada and the United States, it was crafted according to the physical characteristics of urban centers and neighborhoods of these countries. These are different to the spatial characteristics of Latin American urbanism and architecture. Northern México is no exception.

In Latin America, Macarena Rau, a Chilean author and CPTED expert, has spearheaded efforts in many countries of the region. Rau and the International CPTED Association (ICA) have tailored the methodology to better fit and respond to the social and spatial characteristics of Latin America. However, impact evaluation methods of CPTED in Latin America are still under development [17].

CPTED is generally organized around five basic principles and criteria:

1. Natural surveillance: The ability to see and be seen.
2. Territorial Strengthening: Public space identity and ownership.
3. Natural access control: A set of spatial design techniques to avoid exclusionary and aggressive urban/architectural elements.
4. Maintenance: Techniques to keep public spaces well maintained and cared.
5. Community Participation: The citizen as the expert participating in the construction and maintenance of his or her neighborhood. This aspect is not as present in the original, spatially oriented, first generation version of CPTED.

These five principles were selected and planned to be sufficiently adaptable to specific constraints identified by implementation teams, local governments, NGOs, and local community members. For the purposes of this hybrid project, the fifth principle, largely based on Latin American experiences, was the fundamental articulation between spatial and social operations.

2.2. Attention to Youth at Risk (AYAR)

Young men between 15 and 25 years of age are the most vulnerable and likely to become victims or perpetrators of violence through recruitment into criminal organizations [18]. Many young men in these communities left school early, often with only partial or complete elementary education, and lack qualifications for employment. In México, this group is dismissively known as "Ni-ni", loosely translating as a person that neither studies nor works.

As a project with ample holistic social objectives, the inclusion of AYAR was crucial to mitigating current and future rates of crime and violence. AYAR expertise was sought and provided by a combination of technical support with experts hired by the international agency, local governments and their specialized entities, and non-governmental organizations, specialized in the subject matter.

AYAR was introduced conceptually to the technical team by YouthBuild, an NGO specialized in these activities with significant presence in Latin America. The process to implement an AYAR project is deployed in six phases [19]:

1. Community engagement: To identify young community members at risk and understand the community itself.
2. Recruitment: Identified youths at risk.
3. Training: Employment and education.
4. Insertion: Into their communities as functional members.
5. Follow-up: To monitor their progress in society, work and school.
6. Graduate mobilization: To have former recruits help in helping others.

YouthBuild introduced the Community Asset Building (CAB) method as part of the proposed initial plan. Other planned AYAR tools were both, group-oriented activities designed to unify young communities and mitigate conflict, and individualized tools, including the Youth Targeting Tool (YTT), which is designed to identify persons in high risk of becoming part of crime and violence. Group activities included music competitions, such as hip-hop tournaments and sport competitions. The individualized tool was implemented by experts who identified subjects who would become part of a program designed to convert individuals into functional members of society and prepare them for employment.

2.3. Prevention of Gender Based Violence (PGBV)

This component of the hybrid methodology was delivered in its technical capacity by experts who were part of the team by the international development agency, along with the premise that in the Mexican context 'we know that we do not know much about GBV' [20]. There is a lack of information around this type of violence as most of it goes unreported to the police, there is a lack of updated information, and there is little disaggregated data at local or municipal levels.

For the specific purposes of this study, the objective population were women subject to violence. A series of social activities, designed to raise the awareness of this problem, were brought in the process of implementation. Specifically, actions intended to de-normalize violence between romantic partners. With regards to spatial interventions, a conceptual foundation was the understanding that space is gendered [21]. This approach was employed to understand and signify the importance of sound urban and landscape design techniques to make safer public spaces for vulnerable populations.

3. The Selected Neighborhoods

Chihuahua City is within the municipality of Chihuahua. The urban area of Chihuahua, of around 20,120 hectares, lies within the municipal boundary. The urban population of Chihuahua is 918,339 inhabitants [22]. Chihuahua, and in general, northern México, enjoys a relatively low grade of marginality and a high level of prosperity due to the industrialization of the border region with the United States.

Guadalupe is an urban municipality, which is almost completely urbanized, within the metropolitan area of Monterrey in the state of Nuevo León. The urban area of Guadalupe is 8,740 hectares with a population of 682,880 inhabitants. This urban area represents only the 11.1% of the total urban area of the metropolitan complex [23].

In México, municipalities are governed by a mayor who is elected every three years. It was just until the 2018 election cycle that mayors, nationwide, had the chance to seek reelection for a second term only. Mayors work within a top-down armature, where they can select all municipal officers, including the police chief. There are several decentralized entities that still depend on municipal taxes, including the Municipal Planning Institutes who assess and develop urban planning and policy for their human settlements.

The mayors in both Chihuahua and Guadalupe were eligible for their only additional and second three-year cycle, if they won reelection in the summer of 2018. The mayor of Chihuahua decided to run for re-election and won; the mayor of Guadalupe decided not to run for re-election. These circumstances may have been decisive in the development and implementation of the projects, as it is a socially oriented initiative with a potential result in political-electoral capital.

Both the Chihuahua and Guadalupe neighborhoods are composed of various phased and independent subdivisions, as opposed to one developed at the same time. These are also rather large, and because of their scale and physical urban design, difficulties arise in fostering cohesion in one social group or community. The people occupying these subdivisions arrived in phases, inhabiting successive phases of urbanization, further complicating social fragmentation.

Figure 1. The Chihuahua Neighborhood (**left**) and the Guadalupe Neighborhood (**right**). Source: Author, with Google Earth Aerials and municipal cartography.

3.1. Riberas de Sacramento, Chihuahua City, Chihuahua

The neighborhood is a 187.24 hectares polygon isolated from the continuous urban fabric at the north end of the western valley of the city of Chihuahua. According to INEGI's last census (2015), it has 5844 housing units, from which 1513 are abandoned, representing 25.9% of the total. The total population of the polygon was 13,114 people, for an average occupation of 3 persons per household. 4970 people were of ages 0 to 15, representing 37.9%, while 3,990 were of ages 15 to 29, representing 30.4%. Counting both together, this is a very young community, where 68.3% of its members were aged 29 or younger.

This neighborhood is a planned community with a dozen neighborhood scale parks and plazas. It also has a central square and park of 0.9 hectares. Around it are public middle, elementary, and kindergarten schools. Its urban design is defined by repetitive, long, rectangular blocks, a common and efficient geometry for achieving density and efficiency in infrastructure systems.

3.2. Paseo Guadalupe, Municipality of Guadalupe, Monterrey Metropolitan Area, Nuevo León

This is a neighborhood composed of various phased low- to middle-low income subdivisions. The 45.22 hectares polygon has 2160 housing units, with a total of 7560 inhabitants. A total of 26% of the population was between 0 and 15 years of age, 27% was between 15 and 29, while 29% 30 to 49, and 18% 50 or more years of age.

The neighborhood includes 5.4 hectares of green areas—as parks and plazas are typically referred to in Mexican urban planning—which equal 12.6% of the total polygon area. In this sense, this community enjoys a significant share of dedicated public spaces, when compared to similar subsidized housing areas.

Of note is a central park, that runs along a transversal storm-water management canal. This park has an area representing about half of the open public space area of the neighborhood. It divides a northern half of the polygon with low-income housing from a southern half with middle-low income housing.

4. Implementation Process

4.1. General Aspects of the Implementation Process

Once agreements for collaboration were signed between USAID and the local municipal government, this hybrid project was implemented following these six phases:

4.1.1. Diagnostics

The general objective of this phase was to identify what, where, and when real and perceived threats to personal and communitarian safety. It was critical to understand the location and concentrations of perceived insecurity and therefore be able to intersect this with statistical data from the local police departments, municipal governments, and INEGI.

The social diagnostic tools employed included:

- Community walks: Executed at various times and days of the week to identify unsafe and safe areas within the neighborhood.
- Drawing workshops with elementary school children: Where children expressed their desires for their community, while also sharing where they felt safe and unsafe in their community.
- Community mapping workshops in open public spaces in the community: Where community members of all ages participated sharing their perceptions and opinions.

In addition to these community participation tools, a base-line study was collected by a specialized consulting firm for each neighborhood. This was in the form of a representative survey, which would collect opinions on the perception of public safety and the environmental state of the community.

The results of these exercises were compiled and synthesized by the local consulting teams in each city, and then the results presented to municipal authorities and the community.

Assessments of the existing physical conditions of public spaces in both neighborhoods were executed during site visits by the technical team during the summer of 2017. In both neighborhoods, public spaces—in the form of small to medium neighborhood parks and plazas of an average area of 2500 to 5000 sq. mt.—were in generalized condition of deterioration and public lighting was damaged. Urban elements, such as benches and playgrounds, were in fair condition in most cases. One of the obvious problems in both neighborhoods was the lack of shade provided either, by trees or structures. Negative graffiti was ubiquitous. However, most importantly, the spaces were not being sufficiently used by community members. Most remained empty during the day, and only improved slightly once the higher temperatures receded.

This general assessment, done through a visual inspection by the technical team and municipal authorities, was confirmed by the social diagnostic results of both communities, where most neighbors pointed at desired parks and plazas with cared-for trees, vegetation, and shade.

4.1.2. Planning and Design

The plan for each project was guided by the technical team in collaboration with local municipal authorities, synthesizing the results of the diagnostic phase into a social and environmental set of operations.

However, the specific plan also responded to the level of operational capacity installed for each municipality. While, the Chihuahua plan was supported by a multi-sectorial working group, composed of diverse municipal entities and NGOs, the Guadalupe plan was tailored to fit a more executive format, that would cater to the local, socially-oriented, large employer companies as partners of the municipal government.

4.1.3. Implementation

The first step, which also preceded the formal implementation phase, was a capacitation effort for the training of public officials. In order to be able to implement novel methodologies and techniques in both cities, the project included a component for the development of local technical capacity in the various municipal government entities participating. A prime objective of the workshops was to train public officials on a new mode of communication with the people. As opposed to doing all the identification and programming of public works and operations themselves, the newly trained officials were tasked with establishing an effective communication channel with the communities they serve, in order to identify and respond to social and infrastructural needs. A series of training workshops for public servants was executed in both cities during the early months of diagnostics, design, and planning, and even through implementation.

The workshops included presentations from experts on the three areas of hybridization for the project. After these, quick workshop exercises on community participation and communication efforts were practiced amongst the workshop attendees. The government entities most critical for this were the departments of parks and recreation, public works, public safety (police), attention to youth and to women (which are today common in municipal governments of medium to large cities in México.) These workshops laid the foundation for the implementation of the various phases and components of both plans.

Recruitment and formation of neighborhood groups:

A fundamental part of the groundwork to enable implementation was the recruitment and formation of leadership individuals and groups in each of the neighborhoods. This was implemented by collaborative groundwork between the local technical team and the municipal government.

Recruitment of local schools of architecture as project partners:

One of the strategies included in the project was the recruitment of the local schools of architecture, existing on each of the cities, to participate in the planning, design, and construction of public space recovery projects. This collaboration would also lead to the training of local schools of architecture in community participation techniques, where faculty and students would learn and practice how to design with, and for the community, while also increasing the social awareness and impact of the institutions and future professionals.

4.1.4. Monitoring and Evaluation

The project's initial framework required the development of tools to monitor the implementation and results of one of the project's components. These tools were developed by the technical team and were specifically crafted for each of the activities, wither in social or environmental interventions. These were also meant to be employed by each one of the implementation entities to self-monitor and report results to coordinating multi-sector groups.

4.1.5. Systematization

A phase where all initial phases were recorded and critically analyzed by the technical support team in order to effectively adjust to increase the feasibility of replication through the institutionalization of the project.

4.1.6. Institutionalization

A critical intention of this pilot project was to leave an installed local technical capacity for the replication of the project in other neighborhoods, that need to mitigate their crime rates and recover public space. This included the training of public servants and of academic institutions particularly schools of architecture, their faculty and students in the project methodology.

4.2. Project Conceptualization and Branding

A pre-requisite for the implementation of the project was its branding. The project was discussed and agreed with municipal authorities as a program with the objective to reduce crime and violence in troubled neighborhoods and districts of the cities. However, it was decided, as is common practice, to brand the initiative without explicit language in this respect. The projects were described and communicated as community building and physical reconstruction efforts. A project where the municipal government, with specialized technical support, would help communities organize and reclaim their public spaces.

The Chihuahua project was branded as "Mi colonia es mi casa en Riberas" or 'My neighborhood is my house in Riberas'. The Guadalupe project was branded as "Un paseo para todos" or 'a promenade for all'. Both included graphic imagery developed by the municipal government. Both proposals were presented to community members of each neighborhood early in the process to confirm acceptance and legibility of the community building message.

4.3. Specific Aspects of the Implementation Process in the Chihuahua Neighborhood

4.3.1. Diagnostic Phase

This phase was implemented from late 2016 to early 2017. The initial physical condition assessment identified in all public spaces dry and irrigation-less areas, which were supposed to be vegetated.

4.3.2. Planning and Design Phase

This phase was executed in March 2017. After synthesizing the results of the various activities, belonging to the participative diagnosis implemented in the neighborhood, the plan was encompassed in three general phases:

1. Social mobilization: Where participatory processes for diagnostic and identification of social leadership in the community was executed.
2. Formation: Where neighborhood groups were organized and operationalized with the help of local citizen leadership and stakeholders.
3. Environmental improvement: Once a social organization was set in place, several plan components geared to the mitigation of crime and violence and the recovery of public space was implemented.

These phases organized the appearance of plan components, including: Repair and improvement of urban signage, maintenance and improvement of green areas in public spaces of the community, a campaign to improve and produce a safe culture of mobility (against reckless driving in particular), neighborhood clean-up campaign, citizen surveillance, addiction prevention activities, an integral program of activities (most of which happened in public spaces) for the local youth, a campaign against public scandal to promote a culture of respect between neighbors (bring down the noise of nightly parties), abandoned housing recovery, the establishment of a cultural corridor in the neighborhood, formation against violence, safe routes (with working public lighting and appropriate signage) to, and from, public transportation, and a flagship project in the transformation of the central public park into a much more functional and enjoyable public space.

This diversity of actions required an equal diversity of actors, stakeholders, and agencies. Including various municipal government entities, NGOs, schools and universities, and neighborhood groups. These were organized in realms belonging to each of the three areas (CPTED, AYAR, and PGBV), and the general coordination. This complex armature created a project ecosystem. (See Figure 2).

The plan was presented to a municipal board or multi-sectorial group, purposefully organized to evaluate, monitor, and implement the project, with representatives from various local government agencies, including the police, public works, planning institute, and others. This board was organized to meet periodically, on a monthly basis, to review the progress of the project's implementation. Eventually, not all initial components of the plan were implemented, and the plan itself was significantly transformed as project components and their interventions were made available for implementation, as determined by human, economic, and political resources.

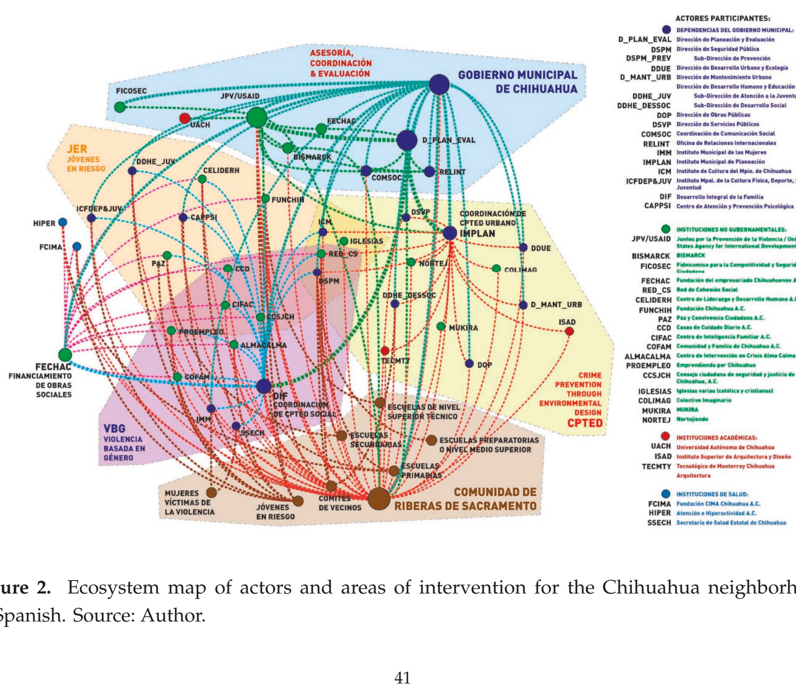

Figure 2. Ecosystem map of actors and areas of intervention for the Chihuahua neighborhood, in Spanish. Source: Author.

4.3.3. Implementation Phase

The formation of neighborhood groups was implemented by the local consultant who identified, organized, and trained neighbors in a new model of communication with the local government, and in empowering them to participate in the maintenance and reshaping of their public spaces. The tools employed to organize these groups ranged from smart-phone applications such as WhatsApp, the local consultant put together a group consisting of hundreds of contacts to traditional posters and banners. This wide spectrum of communication tools was used to communicate training workshops and community meetings. Word-of-mouth was also instrumental.

The social and interpersonal skills of the local consultants and staff were determinant to successfully organize and establish groups of neighbors. While, full spatial coverage, in all the polygon, was not achieved, localized concentrations of working neighborhood groups were to prove critical for the later implementation of project components in the community. The local consultant had, in this case, the 'mystic' [24] to make this communication happen.

This neighborhood began positively in working with neighborhood groups and a collaborative municipal government actively engaging with the project.

On 9 June 2017, a one full-day kick-off implementation event was organized. It incorporated the participation of various municipal agencies and the presence of the mayor. The activities for this day included the clean-up, by municipal authorities, of the central park; the removal of rubble and trash from a vacant site identified by community members as a visual nuisance; collection and removal of large trash and discarded objects; fumigation of the public school yards (with direct participation of the mayor) and; the reopening of the local police station, which had been abandoned for years.

The local community was also actively involved on the first day. A mural painted by local youth, organized by the municipal art department, was completed. Middle-schoolers participated in the design and painting of a crosswalk connecting their school to the central park.

Significantly, at the reopening of the police station, local officials, including the chief of police and the mayor, gave speeches framing the efforts as part of the plan, and committing to working with the community to recover their public spaces.

Various activities were implemented over the remaining months of 2017 and early 2018. These were eventually executed without a strict following of the original plan, which was by itself conceptualized as a dynamic scheme. From these, one would stand out in the relationship to the public space recovery efforts.

4.3.4. Hands on to My Park

The "Manos a mi parque" or 'Hands on to My Park' project was executed during the second half of June and first half of July 2017 (Figure 3). This project component was led by the local Superior Institute of Architecture and Design, known as ISAD for its acronym in Spanish, who was recruited to participate in a public space recovery project. ISAD proposed to proceed within the framework of a quick and intensive summer studio for which they hired a Spanish professor, with a significant experience on this kind of projects, a local professor with expertise on public space design and landscape, and a local professor in carpentry and building.

Under the leadership of a member from Zuloark, the summer studio tackled the recovery of a neighborhood park, which was identified by community leadership as an important opportunity to strengthen their reclamation of public life. The park was in a typical condition of semi-abandonment. An arid, mostly devoid of shade park with a multi-purpose, basketball sized sports court, a playground, and gardened areas.

The studio departed from the diagnostic information collected and analyzed by the consulting team. The main complaints from the local community were identified and a studio was planned so that students would work with community members in the design and construction of the project.

With the help of local leadership and the technical team, the studio group started the summer course with meetings, onsite, with community members, in order to extract a precise assessment of the issues and opportunities specific to the park. Within a timeframe of only five weeks, the studio was also tasked with searching for funding for materials required in the construction of the intervention.

The community process defined a project program largely consisting of three main needs in order to revitalize the park: Seating, shade, and gardening. In this program, the studio developed a series of design alternatives that were presented to the local community in a public meeting. A selection was done, and construction proceeded.

The building process took two weeks. Local children and teenagers participated onsite in painting and simple assembly, while students and professors coordinated the efforts and led the more technically challenging processes. The main design device was a steel-framed module, assembled at ISAD's workshop, which was then transported by truck to the park. Seating was designed into the module, and gardened planters were integrated into a C shaped plan, fitted into one of the bare grounds but in central areas of the park.

A community event marked the completion of construction and opening to the public. This celebration included the participation of the municipal government and technical team.

Figure 3. The 'Hands on to my park' project under construction, July 2017. Photograph: DELFOZ, Enrique Portillo.

Other efforts, led by the municipal government, were effectively implemented. This included a repair program of street signage, maintenance of public lighting, and reforestation of public parks in collaboration with community members. While, the signage and public lighting efforts posed obvious difficulties in allowing neighbors to join in the execution, these relied on community reporting for the identification of the most significant needs with respect to the orientation within the subdivisions and the perception of safety; citizens assisted in installing signage.

In comparison, the reforestation program was community-based. First, personnel from the parks and recreation department were provided with training for tree planting and care, through a series of community workshops held in streets and front yards of participating neighbors. The municipal government provided free trees, produced in the local municipal nursery, tools for excavation, and organic soil for fertilization. Several neighborhood parks were reforested in this collaboration.

Additionally, up to eight different murals were painted between local youths and the technical and material support of the municipal government. The premise for the selection of themes was the need for positive messaging. These tactical urbanism activities were devised to integrate social and physical interventions, as well as allow for the construction of a critical mass to participate in social awareness actions.

With regards to social interventions, several activities were organized with the objective of activating public spaces in the polygon. These included hip-hop competitions, sports competitions, and music concerts. The AYAR component was implemented through the implementation of 36 surveys with the Youth Targeting Tool (YTT), designed to identify individuals at risk of becoming victims or perpetrators of violence. The PGBV component, included a series of workshops and theater shows, intended to de-normalize violence between romantic partners.

4.4. Specific Aspects of the Implementation Process in the Guadalupe Neighborhood

4.4.1. Diagnostic Phase

This phase was implemented from February to June 2017. In this neighborhood, the gardened areas were overgrown and unmaintained. The central park was identified as a hotspot for petty crime and violence. The park contains a central stormwater drainage canal, which is bridged by three structures that create chokepoints, that were often employed by criminals to ambush their victims. Because of this, few crossings occurred in these pedestrian bridges at night.

4.4.2. Planning and Design Phase

This phase started in June of 2017. An initial plan was crafted first, to cater to the main local employers within the municipality of Guadalupe. It was presented to the mayor, industrial, commerce, and service stakeholders in the early weeks of this phase. The plan was initially designed to deliver a series of projects, which could be distributed or adopted by various stakeholders in the community.

The plan was organized in three executive phases:

1. The first phase was composed of 'trust construction' projects. These included clean-up, maintenance and improvement of access points to the subdivisions and the central park. Access point interventions were focused on tactical urbanism techniques and defined by the urban design of the community, which included small commercial areas with convenience stores. The interventions included signage and urban art, intended to be financed and implemented by the companies owning the stores, in collaboration with young local community members. The central park clean-up and maintenance would be executed by organized neighbors in collaboration with the local government.
2. The second phase was characterized by the formation and improvement of spatial/environmental qualities. This included the retrofit of selected small parks and playground areas, access points, and traffic calming measures in a section of the community that identified unsafe pedestrian conditions as a priority. All these interventions were implemented in collaboration between the community and the municipal government.
3. The third and final phase was concentrated on the redesign and retrofit of the central park. The diagnostic phase identified the central park as a concentration of perceptions of insecurity. However, the socio-economic data also confirmed that the central park divided two communities of different incomes, thereby, transforming a social barrier into a physical barrier. All resources available to the community, including local government, neighbors, and participating NGOs contributed to this project. As the most expensive intervention in the plan, it was located at the end of the implementation process. More time would be allowed for financial resources to be garnered, while the accumulation of social and physical interventions of phases 1 and 2 would help solidify and build strong neighborhood groups to collaborate in a final project, bringing together the entire community.

4.4.3. Implementation Phase

The preliminary work of the formation of neighborhood groups was not successfully executed in the Guadalupe neighborhood. The community had gone previous efforts in the formation of neighborhood groups and leaderships that failed. Lingering tensions between community leaders prevented the formation of groups.

Initially, the project received the support of the municipal government. On 1 June 2017, a 'macro-brigade' was implemented in the neighborhood. This was an event intended to bring the municipal government closer to the community. It involved the presence of executive entities related to the project areas, including public safety, public works, youth, and women. Even the mayor attended the event. Recreational and sports activities were deployed to attract people to the tables, which executed social diagnostic tools, such as additional community mapping exercises (see Figure 4). On 2 June 2017, a meeting with the main local employers and companies was held. The municipal government invited large, local employer companies to join and participate in the project.

Figure 4. Community mapping exercise at the macro-brigade event in Paseo Guadalupe, Guadalupe, Nuevo León, México. Source: Author.

The physical/spatial interventions included the organization of one event at a local school for creative engagement of the young in painting crosswalk signage, a common tactical urbanism technique. A total of four neighborhood parks received maintenance, including clean-up, gardening, the repair of urban elements and public lighting, among others, with the support of OXXO, México's biggest convenience store chain and the participation of neighbors; and the implementation of three public service brigades, which consisted of coordinated visits from various municipal agencies to the neighborhood for general clean-up, weeding and gardening, repair of public lighting, and collection of citizen demands.

The social interventions were limited and only a fraction of those were included in the original pilot project framework. These included workshops with children from local schools to raise awareness on violence and crime, workshops on community centers for the same purpose, and a mobile classroom where job-skills training for women—intended to empower them—was delivered. The AYAR component remained largely unimplemented, as the application of the YTT was not executed. In the summer of 2018, SUPERA, an NGO, was planned to engage on a one-year intervention to address the issues in AYAR.

5. Results

5.1. Specific Results to the Neighborhood Interventions

5.1.1. Chihuahua Neighborhood

The most significant evidence on the performance of the project, in the mitigation of crime and violence, was delivered by statistical records of the municipal police. The crime incidence report for Riberas de Sacramento for the period of January to June 2018, which coincided with the program's implementation in its various phases and components, demonstrated a clear decrease on reported crimes. Crimes decreased from 32 in June 2017, around the same time of the implementation of the 'trust construction projects', to 12 in the following year. However, the administrative faults -misdemeanors- reportedly rose from 48 in May 2017 to 107 in May 2018 [25]. The technical support team points to the possibility of increased calls to report these conducts, due to an increase in trust in the municipal government's police response and enhanced channels of communication between the community and the local government. This is, by itself, a potential success of the project.

It is unclear, unfortunately, how directly these results on crime rate mitigation relate to the community-oriented and public space recovery efforts, or to a more obvious presence of municipal government agencies and the local police. The latter increased its visibility in the polygon with the operational station and more frequent policing.

Mixed results would be revealed in other project components, specifically all those related to physical improvements of public spaces. The physical improvement of the public realm proved to be challenging. The 'Hands on to My Park' project was quickly vandalized and destroyed. While, there is no clear reason as to why this happened, it may be that this act of vandalism was a response from the local gangs against the organization of the community and the resulting physical manifestations. In other words, criminal groups and minds are not in favor of a stronger sense of union. Community guardianships [26], designed to protect collaborative neighborhood work, may have not been achieved, or the fear of local gangs was simply not erased.

However, the project methodology was successfully extended, fulfilling the institutionalization phase objective, to four other problematic neighborhoods, which were also developed in the first 12 years of the 21st century in the city of Chihuahua (see Figure 5). This was decided after one year of work in Riberas de Sacramento, and, in view of the success of the multi-sectorial municipal working group who had actively committed to the project. In this case, the technical support provided by the international development agency was substituted on the ground by the selection and training of 'neighborhood managers'. These were public municipal officials from different areas, but who shared an expertise in community organization and participation initiatives. The extension of the project's methodology to other neighborhoods is probably the most important product of this pilot project.

The preliminary results presented in the intermediate evaluation to the program 'My neighborhood is my house', demonstrated a clear improvement in various areas by measuring a six-month period from baseline to survey in the five neighborhoods where it was implemented. The victimization rate of persons who have themselves or a family member been a victim of crime fell from an average of 26% to 8%. The general perception of insecurity in the neighborhoods fell from 64% to 39%. However, only 29% of the community members of these neighborhoods were aware of physical improvements, that were implemented as part of the program in their public spaces [27].

5.1.2. Paseo Guadalupe

In the March 2017 to August 2018 period, when the technical support team consultants were present, the partial implementation of the project in this neighborhood did not result in measured results, including in the improvement of public space, other than the activities briefly described in the implementation section. It did, however, provide valuable lessons to be discussed in the next section.

Figure 5. Reforestation in a joint collaborative effort between the municipal government and teenagers from a neighborhood under the extension project in Chihuahua City. Source: Marta Raquel Facio.

5.1.3. General Results to the Hybrid Methodology

As intended, since the beginning of this consultancy project, a systematization document was produced and delivered to both the international development agency and the participating municipal governments of Chihuahua and Guadalupe.

At the planning and strategic level, the local planning institute of Chihuahua (IMPLAN), who actively participated in several interventions and studies supporting the project, tasked itself with including the hybrid methodology and its concepts into the future update of the urban plan of the city. IMPLAN worked with aspects related to community engagement and participation, social and spatial crime prevention, and a policy to integrate and propitiate neighborliness, in what are often fragmented housing subdivisions and even traditional 'barrios'. This would be in fulfillment of the institutionalization objective of the project.

6. Discussion

The project's process of implementation produced and confirmed a series of critical questions in relation to the pertinence and feasibility of this kind of project and its concepts in the urban and social Mexican context.

On 10 August 2019, an important local newspaper, the Diario de Chihuahua (Chihuahua Daily, in Spanish), published an editorial note on the Riberas de Sacramento neighborhood as being marked by violence. Murder and violence have continued to be prevalent in the community [28]. Organized criminal activities and high-impact executions have continued to occur regularly. This may be a reminder of the limitations of crime and violence prevention strategies that focus on situational or opportunistic crime and violence. This hybrid methodology does not impact targeted crime and violence and may be therefore of limited use.

With respect to the hybridization of the methods, reconciling and coordinating processes with the various demands on time was confirmed to be highly complex and difficult to achieve. Spatial/physical interventions to retrofit and rehabilitate the public space, ranged from the immediate and quickly accessible, such as tactical urbanism interventions, to the long-term and expensive, like the full retrofit of central parks. Effectively identifying, training, and graduating the local at-risk youth is time-consuming and requires sustained efforts. Raising awareness against gender-based violence to the extent where evidence can be collected to demonstrate results, requires even more time and its own processes. Analyzing the three trajectories of implementation, one beside the other, requires a highly responsive and adaptable system, and, even if willing, the local protocols and processes of various municipal entities and NGOs are often sluggish and rigid.

For the purposes of public space recovery, the larger questions lie with the central method in achieving the prevention of crime and improving the perception of safety.

First, the spatial aspects of CPTED conflict with critical ecological needs of natural systems belonging to open public and private spaces of cities. What is the method for achieving open visual fields, while allowing riparian habitats to be restored? Especially, when it is precisely in creeks and rivers where some shade can be achieved with the right techniques, and species are present to produce cooling effects and micro-climate conditions that may propitiate more active public spaces. How can you implement the introduction of native plants, beyond the conventional groundcovers, such as the English-origin lawn, while maintaining visual control of public spaces? These questions are particularly relevant in the context of arid—Chihuahua, with 403 mm of annual precipitation and the semi-arid, Monterrey Metro, with 604 mm [29]. Moreover, the location of Riberas de Sacramento, in Chihuahua, is over an over-exploited aquifer [30] in dire need of measures to capture and infiltrate stormwater for the replenishment of underground water sources.

Second, many of the spatial/physical techniques and design criteria from CPTED originate in the urban and suburban form of a neighborhood morphologies of Canada and the United States. México's urban form is more compact and denser. The spatial thresholds that enable some of the design concepts, employed by CPTED, either are simply non-existent, or have to be reframed to more compact dimensions. While CPTED has updated its criteria to a 'second generation' applicable to Latin American urban form and society, more precise application is required, and guidelines, in the intensive occupation of space existing in México and Latin America.

The evolution and understanding of the relationship between space/environment and crime/violence is ongoing. While, CPTED was concentrated on the qualities of the environmental conditions, which would propitiate or discourage crimes of opportunity, in its first iteration, its second generation incorporated an emphasis on social and neighborhood ecology. A proposed third iteration of the methodology may be more effective in addressing questions of sustainability and public health [31], which are like those presented in this discussion.

The contemporary conditions of deterioration and abandonment of public space, in the ubiquitous, low-income subsidized communities of México, clearly require considerations to effectively improve the quality of life in these communities. INFONAVIT, the National Institute for Workers Housing of México, has in 2013, through 18 federal administrations attempted to tackle this issue by developing design concepts and criteria. Some of these were implemented in public parks and plazas of selected neighborhoods in México, mostly in México City, through the program "Mejorando la Unidad" Spanish for 'Improving the Unit', in reference to how mid-rise subsidized housing is commonly known. INFONAVIT's gamble is mostly based on high-quality architectural and landscape architectural design and community participation. One of the most well-known examples of the program is the San Pablo Xalpa Unit public space rehabilitation by Rozana Montiel Architecture Studio [32]. It may be a good exercise to compare this approach to the crime prevention approach, described in this article, and consider which model may lead to higher success.

This project poses more questions than answers as it intersects a socially oriented spatial design with an emphasis on preventing violence against vulnerable populations.

With regards to the violence inflicted on women, it is important to acknowledge the limitations, as 43.9%, the most significant share of this kind of violence, occurs between romantic partners, Nonetheless, 'community' violence occurs in 38.7% of cases, of which 65.3% takes place in streets and other public spaces [2–8]. There may be an opportunity to improve this through gender sensitive public space design [33]. Architectural design might also be improved to mitigate conditions of overcrowding and comfort efficiency in small subsidized homes, potentially lessening domestic violence. It has been demonstrated, among others, through the analysis of the subject in Hermosillo, Sonora, in northern México, that there is a relationship between environmental conditions of housing and violence [34].

There may be a clearer effective path in the relationship between higher spatial quality of public spaces, and the ability of these to instigate higher activation and use from young populations.

As an example, in the Chihuahua neighborhood, the most successful public space infrastructure was a box gymnasium, built just a few years before the implementation of this project, but with a manifest interest on delivering high quality architecture in places where it does not normally happen [35]. Following a similar model to the recent approach to high quality public infrastructure in low-income neighborhoods made famous worldwide as 'Social Urbanism' with a capacity to mitigate violence as is the case of Medellin [36] and Bogota, in Colombia. This gymnasium was both the most visible and active recreational and sports infrastructure in the neighborhood, and it may deserve additional analytical attention to replicate and improve the model locally.

Finally, one other complex barrier for the implementation of the project, was the definition of the neighborhood boundaries. Where is the neighborhood and its community of neighbors? Where are the geographic limits of a particular social group? Is there one community in a polygon with thousands of housing units and population? If not, how many? Establishing the limits to a social group includes isolating it from the dynamic mantle of the city and this can be an ineffective and arbitrary act [37].

The implementation of the project, in the case of Paseo Guadalupe, demonstrated that the area of action or study cannot be defined only by a criterion, established by subdivisions and their progressive accumulation. In this case, this decision proved to be inadequate, since the neighborhood's polygon was determined spatially by construction phases of different income strata. In a neighborhood divided by a central, supposedly unifying public space, with one half of low-income housing and the other with middle-low income housing, the result, at least for the purposes of public space, was the opposite: the enactment of spatial separation and segregation.

Therefore, in addition to employing statistical data on crime, violence, and social issues, there is a need for spatial analysis and urban systems criteria to determine the areas of implementation. This could be done if Municipal Planning Institutes actively collaborate with public safety and other municipal entities in the establishment of community, or neighborhood, boundaries. And these will still have to be confirmed with work on the ground, with community members.

7. Conclusions

Developing a Mexican and/or Latin American crime prevention model, through community participation with an emphasis on vulnerable populations, working in tandem with a sound urban landscape and architectural design, is still a pending task. The value of this pilot project and its attempt to hybridize three well-known approaches in social ecology, as well as urban and landscape architectural design, resides in the testing of the feasibility of implementation of a multi-sector and multi-entity, complex initiative, based on process over time.

Some final reflections, shared by project team members, during project wrap-up meetings for Paseo Guadalupe, have shed light on some of the aspects described and discussed in this article. First, it may be that this project was too complex to be successfully implemented. The large number of topics, methods, tools, stakeholders, and actors with insufficient political capital proved a challenge for implementation. An unstable political leadership due to electoral timing and limited available economic capital resulting in few resources to be possibly directed for the improvement of public infrastructure, may point to an opportunity for future testing with less ambitious objectives and scale. More targeted and punctual interventions, which may be related to smaller and more precise neighborhood units, may be more achievable. The time span of implementation can also be shorter, this would allow for more precise and immediate commitments from both the community and the government [38].

The most significant reward is likely to be the will from both municipal governments and local communities to collaborate in projects of this nature. Especially important is the emerging empowerment of communities capable of enabling positive change. Municipal officers were willing to learn a new mode of communication and action with their constituents. Citizens and neighbors felt enabled to participate in the construction of their communities and reconstruction of their physical realm. It is just a matter of fine tuning to deliver, in a future iteration, a model that can be efficiently replicated by other communities in need of improving their quality of life and space.

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sustainability

Article

Reflections on Service Learning for a Circular Economy Project in a Guatemalan Neighborhood, Central America

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Abstract: The research presented in this paper explored multiple objectives. First, what are the requirements for establishing a new composting business that embraces the principles of circular economy? Second, how can employment opportunities for at-risk youths from the most impoverished neighborhood in Guatemala City be created, while adhering to the tenets of social sustainability, of which human rights is the corner stone? Third, what were the requirements involved in making compost in the challenging climatic conditions of Guatemala City? And finally, from an educational perspective, how can this be taught to university students incorporating community service learning in its pedagogy, coupled with the model of action research? What are the obstacles to overcome when initiating a startup business, balancing what appeared to be a mix of complex economic, environmental, and social elements? These three elements are the recognized pillars of sustainability, and as such, there existed a great opportunity to meld the principles of circular economy, community service learning, and action research within the context of putting theories into practice. This applied research attempted to explore how effectively this could be accomplished in Guatemala while overcoming complex cultural, environmental, and economic barriers.

Keywords: circular economy; Guatemala; action research; social sustainability; community service learning

1. Introduction

Located in Central America, Guatemala is bordered by the Pacific Ocean to the west and the Caribbean Sea to the east and shares international borders with Belize to the northeast. Geographically, the country is unique, as it touches both the Pacific Ocean and the Caribbean Sea. Neighboring countries include Honduras and El Salvador to the southeast and Mexico to the north and northwest (Figure A1).

The capital, Guatemala City, is situated centrally in the southern portion of the country at an altitude of 1500 m (nearly 5000 feet), resulting in cool evening temperatures during the summer months. According to the United Nations Department of Economic and Social Affairs (DESA) Population Division, Guatemala City has approximately 1,202,536 residents; this number triples during the week when low-income people from rural areas travel by bus into the city for work [1]. However, many low-income people also live within the city and are concentrated into 22 specific neighborhood and employment zones. The social and economic classes of those who live and work within each of the zones typically distinguish the demographic and economic character of each zone.

Zone 3 is the most impoverished of all the 22 zones where dwellings have been built upon early vestiges of the nearby *basurero*—landfill (Figure A2). People who work in the *basurero*—not for a living wage but rather to pick through the unsorted trash to support their fledgling substance have erected a neighborhood using concrete blocks and plywood, placed upon a layer of soil and trash to construct shanty houses [2]. It is here that families are caught in a cycle of poverty as they manually sort through the trash as it is dumped from trucks. Many are in search of either plastic and/or glass that may be redeemed at recycling facilities in the city, discarded food to eat, or discarded household items to claim as their own; the dangers of this existence are significant [3].

The *basurero* is located within a 16.2 hectare (40 acre) ravine that receives an estimated one-third of Guatemala's waste each day. Although municipal authorities claim that the site has reached its capacity and must be shut down [1], the waste stream continues to flow in, primarily because an alternative site has not been identified. During the five-to-six month rainy season (May through October), the unstable land frequently collapses [4], engulfing some of those who are sorting through the trash (Figure A3). Often, the bodies are never recovered because of the natural composting process of the organic waste contained in the decomposing trash. The organic waste produces high levels of methane gas, which caught fire in 2005 resulting in contaminated air and heavy smoke and claiming numerous lives over a period of many weeks. The *basurero* caught fire again in January 2014; fire fighters had great difficulty in extinguishing the blaze due to the aforementioned flammable methane gas and hazardous terrain. In addition, the greenhouse gas emitted from the waste typically causes cancer and tumors among those working in the *basurero*; these laborers have little or no access to basic health care.

The research conducted in this paper attempted to determine if one could make compost for the use in the parks and planting beds managed by Guatemala City from the green waste generated by a large central market (CENMA), thus diverting it from disposal in the landfill. In addition to selling the finished product locally, the research attempted to determine if the finished compost might have a regional market by using the trucks that brought fruits and vegetables to the market and sending it back to those very farms to augment their soil. In theory, this goal of developing a closed-loop system supported the principles of circular economy (CE), a term that first appeared in the literature as part of a study by Pearce and Turner (1990) [5]. Their research, as later reported by Anderson (2007), attempted to make a connection between a variety of complex production activities at both an economic and environmental scale [6]. This is an approach broadly acknowledged as an appropriate strategy for reducing waste and improving manufacturing efficiency in urban contexts [7–9], often referred to as a "closed-loop system", first discussed by Boulding (1966) and later by Leontief (1991), whereby one repeatedly uses the same resource within a closed-loop [10,11]. This principal assumes that a finished product or the byproduct of some sort of manufacturing can then return to the source from where the raw materials originated, with the intention to then improve growth of that material for greater future use. Achieving this goal is perhaps most recognized in different forms of agricultural production where green and animal waste is directly recycled into the soil as fertilizer. This type of closed loop system can be more challenging within the manufacturing industries; however, this is very much a case-specific comparative analysis. The United Nations Environment Program (2012) stated that within a circular economic system, nutrients and associated resources circulate and remain within different "biospheres and product systems" [12]. However, when measuring ecological efficiency within the context of CE, the diverse and complex nature of what we make and how we distribute and consume it can cloud what one might think is a clear connection between the two—ecological efficiency and CE. More affluent populations demand more resources to meet their social and economic needs [13–15], which tend to threaten depletion of finite resources. Others found that circular economy is a concept that has achieved recognition by academics, governments, and the private sector [16]. Merli et al. (2018) explored how scholars might better understand the complexities of CE through their extensive literature review of 565 articles. The literature found that while CE works to overcome what they refer to as the "take–make–disposal linear pattern of production and consumption", the real goal is to maintain materials, resources, and their associated products in the economy as long as possible [17]. Their review confirmed that a very close relationship exists between CE and the concepts of sustainability; however, they also found that scholars seldom consider social and institutional implications of the implementation of CE at the environmental and economic level. Lyle (1985) worked to overcome this disconnection through his applied research in the 1980s, presenting the concept of regenerative design in his book, *Design for Human Ecosystems* [18], which effectively illustrated closed-loop systems for achieving waste recycling, energy production, and a more efficient use of resources. This continues to be demonstrated in application at the Center for Regenerative Studies at Cal Poly Pomona, California.

Yet, CE remains a disputed or contested concept [19,20], perhaps due to many different definitions of what it means, likely due to its interdisciplinary theory and application. Kirchherr et al. (2017) analyzed 114 definitions of the term and developed a meta-definition: "a CE describes an economic system that is based on business models which replace the end of life concept with reducing, and alternatively reusing and recycling materials in production, distribution, and consumption processes . . . " [21]. Perhaps the challenge not only lies within its definition but in how to apply business and policy models to a myriad of legal, technical, and environmental situations. Geissdoerfer et al. (2017) found that CE is now seen as a possible solution for achieving the principles of sustainable development [7]. They found that the sustainable "performance" of circular business models and circular supply chains are necessary to implement sustainable development based on case studies and a review of the literature. De Jesus and Mendonca (2018) reported that CE should be viewed as a "motivational and inspirational compass" and proposed the concept of eco-innovation (EI) as a way to better achieve positive impacts on the environment and society. They found that EI has an appropriate role in the move toward CE on a broader scale, in that EI proposes new or improved socio-technical solutions to preserve resources, reduce environmental degradation, and improve the recovery of waste [22]. Others have proposed the need to have measurable indicators of the longevity of a resource as a measure of CE efficiency. Yet, what should those indicators be and how do they vary, given the enormous range of product(s), resources, and other measures of CE? Figge et al. (2018) argue that longevity and circularity are necessary for sustainable resource use, but thus far, there are no applied measures that combine both approaches [23]. They argue that the number of times that a resource is used and reused must also consider the time and duration of that use (longevity) and proposed a complex combination matrix to measure both. This is unique, as it applies both quantitative and qualitative parameters to the concept of CE. Recent trends in the agro-food industry have argued for fair trade and responsible consumption as a necessary measure of sustainable development within CE [24]. With most fair-trade models, consumer demand for products produced in developing countries are marketed and then consumed at a much broader worldwide scale. This forces one to question if achieving true CE is possible within a global scale of consumerism, at a high level of production. However, in practice, achieving a process of sustainable CE can in fact be realized on multiple scales, be that the production of coffee, clothing, or compost. In recent years, financial markets and their associated intermediaries have advocated investing in "green projects" that contribute toward the development of a more environmentally sustainable economy. Falcone el al. (2018) reported on the trend toward ethical investing and socially responsible projects [25], whereby financial institutions are now making access to capital easier while venture capitalists find that green projects add value to companies. They found that there has also been a trend toward funding radical green innovation. Some may call this little more than green-washing business as usual, while others see it as a shift in how business is now being done because it costs less, requires less energy, and achieves socially measurable outcomes. Thus, linking green finance (GF) to CE where waste management is achieved through superior design of materials, products, and associated systems [26] has been achieved particularly within the biomass production sector. The United Nations Environmental Program (2011) found that the movement toward a low carbon and climate resilient economy required investment in green sectors of business [27]. To place this within the context of green economies, such as biomass production, investment in renewable energy, or other CE related industries, e.g., making compost from green waste in Guatemala, the necessary investment worldwide will equal 2% of the GDP between 2010 and 2050 [28]. This is a significant sum of financial investment, but it is necessary to slow the impacts of climate change on a worldwide scale. Considering this, how does CE fit in within the context of this paper—making compost—and how does it begin to form a guiding principle for local municipal governments to follow? While some countries have adopted a top-down centralized approach, such as China [28], others emphasize a more localized bottom-up policy direction [29], more typically used in municipal and regional planning. Perhaps the difference is again associated with the scale of CE.

As such, this research had multiple objectives: What are the requirements for establishing a new composting business that embraces the principles of CE? Could this initiate a break from the cycle of poverty, create opportunities for a future livelihood, while adhering to the tenets of social sustainability [30], of which human rights is the corner stone [31]? From a more technical and perhaps scientific perspective, what are the challenges involved in making compost in the climatic conditions of Guatemala City, high in altitude, dry during portions of the year, and inundated by rainstorms during other times? Finally, from an educational perspective, how should one teach this to university students through a new class that incorporated community service learning (CSL) in its pedagogy coupled with the model of action-based research?

Thus, the research described in this paper explored techniques that could provide living-wage jobs for unemployed and disadvantaged young people who subsist in one of the most impoverished neighborhoods of Guatemala City. This was achieved by initiating a startup business, balancing what appeared to be a mix of complex economic, environmental, and social priorities. These three elements are recognized key pillars of sustainability [32], and as such, there existed a great opportunity to meld the issues at hand, while providing an appropriate context for putting theories into practice. The important movement toward sustainable development within society has been part of the broader dialog dating to 1992 and the Earth Summit in Rio de Janeiro and again repeated at the World Summit for Sustainable Development in Johannesburg in 2002 [33]. However, bridging the gap from theory to actualized process and practice brought forth the challenges in truly understanding the operational relationships between each in application. Boyer et al. (2016) identified the challenges in understanding and managing social sustainability due to its many meanings and gaps in interdisciplinary research [30]. In retrospect, social sustainability, along with environmental factors and key components of economy are in fact very much place-based; however, the challenges in understanding and managing the social aspects proved to be one of the greater challenges. Boyer's research team used the analogy of a three-legged stool as well as the triple bottom line, the 3Es, and the 3Ps—prosperity, planet and people—as better approaches for solving complex world problems rather than completely inventing new approaches. Thus, the rationale for this new research effort seemed to be a win–win scenario; compost created from organic waste diverted from the landfill would be used to amend marginal soil, train workers, create jobs, mitigate an ecological and environmental crisis, and serve as an image of hope and renewal for those whose livelihood is dependent on the *basurero*. This idea would adhere to the concepts of CE and, if successful, would reduce many negative environmental impacts and stimulate other business opportunities, thus adhering to the bottom-up model proposed by Ghisellini el al., 2016 [30]. It is not a new idea as the concept of a closed loop material cycle has been practiced since the dawn of the industrialization in manufacturing [34,35]. Our research question attempted to explore how effectively this could be accomplished in Guatemala while overcoming complex cultural, environmental, and economic barriers.

Context and Local Situation

As a research scholar, one approaches a new opportunity with the intention of testing a preconceived idea, anticipating a successful outcome; you identify a problem and hope for a compelling result or solution. Perhaps the flaw in this approach is that you may overlook a hidden gem of a different research idea, initially not obvious. Thus, how should one move forward when what is discovered was completely unexpected? A chance encounter with a remarkable local activist, a bright and highly motivated graduate student, and an ominous neighborhood trapped within a cycle of poverty—these factors all contributed to an opportunity to produce real and meaningful change to the lives of marginalized children living in a squat neighborhood. The importance of remaining open to all possibilities and paying attention to amazing new connections for collaboration wherever they present themselves led to significant learning opportunities. The results of this effort were used to develop a startup business, using the principles of circular economy and social sustainability to improve the living conditions through job-creation at one of the most impoverished neighborhoods in Guatemala City.

This endeavor began with the Director for Public Works, Department of Construction, in Guatemala City. The original intention involved conducting research that would explore the landscape of urban parks and recreation zones. Because the author was a professor of landscape architecture, the director provided tours of the City's municipal nursery where much of the ornamental plant stock is grown for beautification of the parks and public spaces in Guatemala City. The nursery was also responsible for making compost; however, nearly $300,000 USD was spent each year to produce compost for soil amendment to the rocky and volcanic planting beds prevalent in Guatemala City. A visit was also paid to the city-owned CENMA market; this extensive outdoor market is where much of the fruit and vegetables produced in the country are prepared for sale and distribution both locally and internationally. The CENMA site is enormous (Figure A4), and it essentially functions as a city within a city, employing a broad spectrum of workers and containing numerous small shops where the public can purchase prepared food and other daily necessities.

The author also visited the *basuerto*, the largest municipal landfill in Central America also located within the City (Figure A5). Follow-up meetings with the Director for Public Works confirmed that much of the green waste from CENMA added to the overflowing landfill. With this realization, a proposal was offered as a solution to the disposal of green waste and a reduction in the money that the city spent each year to produce soil augmentation for their parks and green spaces.

2. Materials and Methods

Why focus on helping the youth? Minica and France (2008) merged the social components of sustainable development into four key objectives: promotion of education and training; protecting and promoting human health; the fight against poverty; and equity, i.e., not marginalizing one demographic sector [36]. It has been shown that self-empowerment can be achieved through education. According to Knoth (2009), only 69.1 % of Guatemala's population can read, making it the most illiterate nation in Central America. Similarly, more than 80% of the Guatemalan population will never graduate from high school, not as a result of laziness but rather out of the need for contributing to the family income. At present, the high school dropout rate of the impoverished youths from Zone 3 is incomprehensibly high because of the dire need for these children to earn money to support their families. Sustainable part-time jobs are inaccessible for this demographic group from Zone 3 due to their poor educational background. This trend results in elementary and high school students who tend to leave their short-lived scholastic careers to inherit a place in the cycle of poverty [37]. This sobering realization lead us to believe that the social or human component of sustainable development plays perhaps the dominant role, if not the most important, because of the dire need for equity in the evolution of society today.

CENMA, Guatemala City's largest fruit and vegetable market, sends 114.7 cubic meters (150 cubic yards) of organic waste to the *basurero* daily.

Although other entrepreneurs have tried to capitalize on reducing the waste from CENMA, Guatemala City chose to work with graduate students from the University of Massachusetts, Department of Landscape Architecture and Regional Planning, under the direction of the author, because of the project team's commitment to social justice and social sustainability. The City granted 0.48 hectares (1.2 acres) of land and a plethora of organic material from CENMA for developing a sustainable start-up composting operation. Our goal was to do this embracing the principles of CE and sustainability in action.

The compost produced would have a guaranteed client. As described earlier, Guatemala City was spending annually nearly $300,000 USD on low-grade soil amendment. As such, a contract was developed concerning the municipal purchase of the compost to amend public-sector landscaping projects. This compost would be purchased from a new University of Massachusetts student-initiated start-up company. This compost could also be sold to local farmers, private landscaping contractors, and homeowners, adhering to the principles of CE.

2.1. Design Response

This paper does not intend to discuss the finer details of production of compost—the correct mixing of brown and green waste. A plethora of detailed research exists, and how-to manuals are available that document the art of making compost. However, to fully appreciate the work attempted in Guatemala, it is important to provide a brief overview of how one makes compost. The first step in managing the compost process is to determine what is introduced or added to a compost pile. Note that the use of animal manure or carcasses makes composting much more complicated, as human contact with animal waste can spread diseases. Thus, the work reported in this paper only concerns itself only with the composting of organic plant material. Achieving the correct combination of plant material is important for speeding up the composting process and producing a quality product. The two categories of plant materials are referred to as brown and green material [38]. Brown material, such as wood chips or dry grass stalks, do not break down as rapidly, thus giving compost its light fluffy texture. Green material is fresh, wet, and usually green in color. Green material, such as vegetables or plant biomass, will decompose quickly and is balanced, so to speak, by the brown material which is more stable [39].

The word 'organic' refers to alive, or once living, organisms. It is the flesh, bones, tissues, stems, and bark of plants and animals; organic material is natural and not created by man. For example, manure is a natural fertilizer and can be called organic. Cardboard, although processed by man, comes from trees and is organic unless it contains dyes or is coated with plastic on its surface. Pesticides are usually man-made, cannot be found in nature, and are therefore not organic. Yet, sometimes pesticides are organic because some plants make chemicals naturally in their leaves to protect against insects.

Decomposition is the natural process of organic material breaking down to a more chemically stable state. This process constantly occurs on forest floors in the leaf litter or dead wood from trees and shrubs. Decomposition creates nutrient-enriched humus (a fine organic substance seen in high-grade soil), returns nutrients to the soil, and allows new plants to grow [40]. Decomposed material appears in the top layers of soil as dark in color. Non-organic materials do not decompose or may require many hundreds of years to do so [41].

Commercial composting is a process by which the decomposition of organic material is controlled such that it occurs faster and produces a consistent, quality product. A 'compost pile' refers to a pile of organic material that is decomposing [42]. The stable finished product is called 'compost', which is typically mixed with existing soil, making that soil healthier and more capable of growing plants. As farmers plow soil and cut vegetables from fields, that soil becomes degraded, making it less fertile or less capable of growing plants. Mixing compost into soil replenishes the nutrients, which in turn contributes to increased soil fertility [43].

2.2. How It Works

Decomposition of organic matter in a healthy forest occurs through the digestive processes of microorganisms [41]. These microorganisms feed on dead or dying plant material and animals, recycling them back into the humus layer on the forest floor. As these organisms eat, grow, reproduce, and die themselves, organic material is broken down (decomposed) into compost. These tiny creatures are contained in decomposing organic material and do not need to be added to a commercial composting pile.

Microorganisms require food, water, and air to live in the same way humans do. Their food is the organic material in the compost pile. Although some animals, such as worms and snails are beneficial to a compost pile, they do less work to promote decomposition than the microorganisms do.

By providing air, water, and the appropriate mix of organic material, a compost pile can reach its finished state in a predictable amount of time. For example, the naturally occurring composting process for organic material in a compost bin, windrow, or pile, can take approximately 90 to 120 days to occur [44], assuming that the composting material receives the necessary blend of oxygen and moisture and that it is turned periodically [45]. The duration for achieving a finished product can in fact be accelerated significantly by increasing the amount of oxygen that enters the composting material.

2.3. Site Design

Initially, a large flat space located immediately adjacent to the CENMA market was promised to the UMass team for designing the compost operation (Figure A6). This was an ideal location, given the proximity to the CENMA market, easy access to green waste, space for loading completed compost onto trucks for delivery to the City and export to regional farms, and most importantly, ample space for the production of compost. Guatemala City provided an aerial photograph and site topography details, and UMass students began to prepare a site plan for the development of the compost plant. However, when the team arrived in Guatemala City and met with the Director of CENMA, we learned that he would not allow this flat space adjacent to the market to be used out of fear that the compost would smell and hinder business within the market area. The Director was only willing to make a much smaller and more challenging site available, located next to the larger property but situated outside of the market-proper (Figure A7). This alternative site is a 0.48 hectare (1.2 acre) parcel of land that borders the eastern edge of the CENMA market property and is separated by a 3.7 m (12 foot) cement wall. The parcel is divided into three sections by smaller 2.4 m (8 foot) pieces of wall. The parcel runs next to a very steep and hazardous embankment that leads to a small stream meandering through the adjacent property. The main access to the site is via a 6.7 m (22 foot) entrance gate. Needless to say, the smaller site was less than ideal and contained many physical obstacles to make it fully useable, such as the very narrow profile and hazardous embankment. It also forced a redesign of the methodology for how compost would be produced.

2.4. Compost Cells or Windrows?

There are two different ways of organizing compost piles. Windrows [46] are long piles of compost (Figure A8). They are at least 1.5 m (5 feet) high, with equal width, and are difficult to manage with only manual labor.

Most commercial operations rely on windrows because they are effective when dealing with large quantities of material; however, they require many hectares of land and expensive machinery, such as a windrow turner and tractor to turn the mix the piles, allowing necessary oxygen to enter and accelerate the decomposing process.

An alternative to windrows, the in-cell technique, uses modular structures that hold the compost in place. These systems can be managed with manual labor and do not require machinery. There are several reasons why in-cell composting on the CENMA site was more appropriate. These include the following:

- Manual labor would employ more youths who would shovel the compost from one cell to another to accelerate the decomposition process;
- Cells eliminate the cost of expensive equipment typical of the wind-row system; and
- Cells will keep heavy equipment such as tractors or front-end loaders safely away from hillside edges.

To some degree, the in-cell technique more closely resembles the compost "bin" typically used by homeowners for decomposing kitchen and yard organic waste, (Figure A9). While most people who do home composting have one compost bin/cell, three cells should be employed to be more effective

(Figure A10). A compost mix is started in cell #1: once contents begin to increase in temperature and shrink in size as the green waste decomposes, all of the contents should then be shoveled into cell #2 and a new batch started in the now available cell #1. The act of moving the mix from cell #1 to cell #2 adds oxygen and mixes the contents, similar to what a windrow turning machine might accomplish. Later, the contents from #2 are moved into #3 for completion, and a new batch is begun in cell #1, which has seen its material moved into cell #2, similar to hopping checkers over each other.

There are many ways to construct cells for producing compost. Wooden shipping pallets were selected for use at the CENMA site because they are inexpensive to purchase, are readily available locally, and site conditions with hard rocky volcanic ground prohibit the use of metal stakes or poles with welded wire fence to form a cell. Thus, cell construction can be modified according to any site, the type of materials to be composted, and the effects weather may have upon producing compost.

For a newly established compost pile, (in cell #1), the temperature will increase during the initial weeks while the size of the pile decreases. This indicates that the compost process is successfully occurring. Table A1 illustrates cell-monitoring data for one of the two test cells constructed initially to chart the time and temperature, in addition to odor (smelliness). Approximately one month after the pile is made, the temperature will drop, and the pile size will stop decreasing. This is when the pile needs to be turned or shoveled into cell #2. Turning the pile involves taking the material out of the cell and mixing it up; it is important to get material from the middle of the pile to the outside layer.

As the microorganisms feed on the organic material. They consume all that is around them. Because they cannot move very far, it is important to mix the pile and put them in contact with new organic material for consumption. Turning a pile also introduces new oxygen, but this oxygen is quickly used and is not the primary function of turning. Oxygen gets inside a compost pile through proper ventilation and pore space (voids in the mix).

In total, the site physically accommodated 409 cells and produced 1483 cubic meters of compost a year. The cells were 1.8 m (6 feet) deep, 1.5 m (5 feet) wide, and 1.2 m (4 feet) tall. An estimated 140 cubic meters of compost production was stored on-site each month. The benefit of storing the finished compost is two-fold: first is the close proximity to the entrance of the site; second its location along the portion of the wall that has the natural loading dock, enabling trucks to back in, load material, and transport the product to its final destination.

2.5. Waste Separation

The general public typically does not fully understand the importance of separating organic waste from non-organic waste. The UMass experience at the CENMA market has shown this to be true as the organic waste from CENMA also contained a tremendous amount of un-compostable trash. The public must be educated on this issue if composting organic waste is to be successful. Since most of the waste collected for this site originates from the CENMA market area, education should begin there. Clearly marked barrels were later placed wherever trash is disposed of. The organic waste barrel should not be easily mistaken for a non-organic waste dump container. Because this was a new concept in Guatemala, simply placing different colored barrels side by side clearly conveyed which are intended for organic material and which should be used for all other waste material—trash. The compost facility received 20 cubic meters of raw materials daily: (1/3 organic waste, 1/3 wood chips, 1/3 cardboard).

3. Results

While this project and its intended outcome might appear to be achievable, the capital requirements and structural organization needed to begin such a venture were significant, particularly in a challenging Guatemalan economy. The project began as a collaborative effort between Masters of Landscape Architecture student Travis Shultz and the author, resulting in a new graduate class at the University of Massachusetts Amherst Department of Landscape Architecture and Regional Planning. The class would train students on how to make compost and then start a new non-profit company–in Guatemala–built upon the pillars of sustainability.

This new class incorporated key elements of CSL with action-based research in its pedagogy. Entitled "Applied Field Studies in Guatemala", the class attempted to ask and answer the following question: How can we, as aspiring landscape architects and regional planners, connect the passions of our hearts, the skills we have acquired thus far in our educational careers, and the needs of the world? The focus of the class was on the research, design, and application of a specific project: the start-up of a municipal composting facility in Guatemala City. The class included lectures, presentation of research, field trips to visit commercial compost operations, and educational site design. The goals were multi-fold: experiment with pedagogical education through the lens of CSL, focusing on the Zone 3 neighborhood in Guatemala City; teach students how to write effective grant applications; learn how to make compost; construct test compost cells in Guatemala to be monitored weekly; learn to speak Spanish; and then teach students how to begin a start-up business employing principles of CE at the local municipal level [47]. What we explored are the necessary tools for implementation in Central America; and what does it really mean to start a company based on the recognized three pillars of sustainability [24]? The team discovered that starting a new business at this admittedly small scale did not create obstacles for basing all business models on the principles of sustainability. The endeavor would achieve critical areas of social sustainability through employing at-risk youth who had marginal future prospects in their lives. Diverting green waste from the landfill and making compost with that material for use in municipal planting beds and for sale to local merchants provided a net-positive environmental benefit. Economically, if the City made adequate production space available, we could produce enough compost to meet their needs and employ 12 or more youth.

The author along with the eight graduate students enrolled in the class and a Boston-based brownfield remediation consultant traveled to Guatemala City in the spring of 2009 for 10 days of site design and practical work. Once in Guatemala, the group met with local experts and municipal officials to gather information needed to advance the site design, prepare a business plan, and clarify critical operational information. The team also spent some days working with families in the Zone 3 neighborhood to renovate and reconstruct roofs and other parts of their shanty homes, with the intention of developing a one-to-one connection with the real "client".

As mentioned, the class and its supporting fieldwork were built upon the principles of action-based research. This is an idiom used by educators; yet, it is an approach sometimes surrounded by a lack of clarity in practice, similar to that of CE. Tomal (2003) grouped together the following techniques as a possible definition of action research: field research; a collection of primary research data; and research in which the research question later follows the initial findings [48]. All of these statements combine to form a rational definition; however, a more thorough characterization is needed to clarify why action-based research is one of the most practical, rational, and efficient methods of conducting applied research by educators. In Tomal's book, *Action Research for Educators* (2003), he clarifies that action research is not based upon quantitative methods requiring statistical analysis. It is also not qualitative, requiring enquiry with extensive narrative explanations. "Action research is a systematic process of solving ... problems and making improvements" [48]; the author's experience in Guatemala validated Tomal's theories.

Greenwood and Levin (1998) define action research as "social research carried out by a team encompassing an action researcher and members of an organization or community seeking to improve their situation" [49]. The authors make a powerful statement that "social research generating results void of action is counter-intuitive", and they claim that "action is the only sensible way to generate and test knowledge" [49]. The intent of this process of generating information and then testing it in an applied context aims to bridge theory and practice in such a way as to involve a diversity of groups, each contributing their skills to increase the sustainability of communities and organizations.

Sagor (2000) put forward that action research is "a disciplined process of inquiry conducted by and for those taking the action" [50]. For these reasons, the proposed Guatemalan Field Studies class embraced tenets of action-based research and incorporated many key elements of CSL with the aim of creating transformative learning experiences for both the university students and youth from Zone 3, with the proposed composting company embracing CE theory.

CSL is an academic model for merging education and social justice [51]. It provides a basis on which students benefit from the real-world applications of their academic training, and with this a community benefits from the pro bono time and skills offered by students. Although there are many organizational and logistic components to deal with in any CSL endeavor, the results almost always outweigh the initial efforts invested in the experience. In a study conducted by Westheimer and Kahne (2004), students who had completed a CSL class "expressed excitement at the prospect of getting involved in ways they did not know were available to them before their experience. The curriculum also developed students' desire to participate in civic affairs and gave them a sense that they could make a difference in the lives of others" [52]. Forsyth et al. (2000) asked "*Is Service Learning Worth It?"* and concluded that CSL "has the potential to provide the kinds of skills and approaches that are essential for the professions, particularly the design professions, if they are to retain their relevance" [53]. If faculty, students, and the community are informed beforehand of the challenges concerning the process, many foreseen and unforeseen issues can be more easily pacified as they arise. An important but often overlooked aspect of CSL is self-reflection throughout the process. Simple journaling, surveying, and discussing one's experiences can be the difference between a good class and a semester that challenges one's beliefs, reforms ideals, and redirects lives.

4. Discussion

The UMass students in association with locally based faith organization *Vida Joven* (Young Life) were successful in establishing a new business enterprise called AbonOrgániCo, based in Guatemala City. The mission of the company was to supply necessary part-time jobs to at-risk youth from Zone 3 and the surrounding communities. AbonOrgániCo was incorporated in Guatemala as a not-for-profit corporation; excess capital earned would be invested back into the business. As mentioned above, AbonOrgániCo began under the umbrella of Vida Joven in order to facilitate a quick start-up process for the business using recognized local support for the Zone 3 neighborhood. Under the not-for-profit designation, the business did not incur a tax liability in Guatemala. The director of Vida Joven also served as the interim director of AbonOrgániCo. Under the director were a site manager and a supervisor. The supervisor oversaw the work of the employed at-risk youth. For this type of operation, total quality management was essential to the success of the company. Marketing was not necessary for the product, as it was sold to the largest customer, Guatemala City's municipal government. However, promotional strategies were developed to reach other smaller-volume customers (Table A2), testing the theories of CE.

Technical and Organizational Challenges

In the short-term, AbonOrgániCo was located on a tract of land adjacent to CENMA; however, this site was not ideal for two reasons. It was not large enough to produce compost that would meet municipal demand, and it was much too small to utilize the entire supply of organic waste generated daily by CENMA. Workers were responsible for the daily activities necessary to operate the business. This included mixing raw materials, turning compost piles, and taking moisture and temperature measurements of the piles. Ten to twelve workers were initially employed. The workers were selected from a pool of at-risk youth within the city who were in need of part-time employment. Only candidates who were currently enrolled in a secondary school were employed. This is directly in support of the mission of AbonOrgániCo, which is to employ youth on a part-time basis so that they may receive an education and break out of the cycle of poverty. Each of the young workers/employees were taught how to open a bank account locally so as to receive their weekly pay. Sponsors from the USA matched each dollar earned by the local kids with a donation of equal pay, thus doubling the money earned.

Guatemala City's municipal government (MUNI) used 15,000 cubic meters of low-grade soil to landscape the area along their roads and scenic-ways projects. For these purposes, an ideal ratio of compost to soil would be 1:1. This means that the municipality had a demand for roughly 7500 cubic meters annually. Because the current 0.48 hectare site adjacent to the CENMA market is incapable of meeting this demand for compost, a larger work site would be necessary. To produce the 7500 cubic meters of finished compost annually that Guatemala City would purchase, AbonOrgániCo would need to produce 625 cubic meters monthly, or approximately 31 cubic meters each day. It would seem that the necessary site would need to be roughly six times larger than the size of the current CENMA site. This would equate to about 2.6 hectares (6.4 acres). However, if the more efficient windrow method were utilized on a larger site, the actual area needed to meet the municipal demand is estimated to be approximately 1.6 hectares (4.0 acres). Although the City promised that a larger site would be provided just to the southern edge of CENMA on municipal land, this did not happen.

Another key point when considering an ideal site for AbonOrgániCo is the volume of organic waste that CENMA sends to the landfill each day. This amount equals roughly 138 cubic meters. The current site, and even the 2.6 hectares site discussed above, is vastly insufficient to handle this supply of organic material if all the waste were to be converted into compost. In order to effectively divert all of this waste from the landfill, a site of approximately 5.8 hectares is necessary. Ultimately, the limitations of space had a significant negative impact on the volume of compost that was produced. AbonOrgániCo has never been able to meet the real demand for compost by the Municipal Government of Guatemala City; however, with a larger working production site, this could be achieved in the future.

What we learned from the monitoring data of the two test cells (Table A1) was that the high altitude dry climate of Guatemala City caused much of the moisture in the newly mixed compost (cell #1) to dry out prematurely, resulting in a very slow or even stalled rate of decomposition. This required altering the brown to green mix to increase the green organic volume during the initial mixing of the new compost piles in cell #1.

While poverty will never be completely overcome—and improved living conditions for those from Zone 3 achieved—through a commercial composting business, every step in support of this goal can and will make a tangible, and most importantly a sustainable, difference in the future of children who live in Zone 3 with little future prospects. Each individual who becomes involved in a venture, such as AbonOrgániCo, has a unique skill to contribute, whether it is the desire for developing programs to address social justice, expanding the knowledge-base of composting methods, developing fund-raising opportunities, or connecting people who have these skills. Each part or component of the program for recycling green waste from CENMA, putting to work at-risk youths of Zone 3 neighborhoods, and creating a useable product that was economically viable adhered to the three pillars of sustainably (Figure A11).

Sustainability in practice applies here, regardless of whether one is a proponent of social justice, an entrepreneur in search of starting a sustainable company to help the poor, or a public official determining the level of feasibility of a project, or even a potential financial donor. The intention is that this project will encourage others to follow the passions of their heart to where they intersect with the skills one may have learned professionally or in school.

5. Conclusions

During the applied field-learning excursion to Central America, students kept daily journals—a key pedagogical technique used in many CSL classes—and held daily group meetings to ensure communal learning. Each day they shared indelible memories that resulted in personal growth and new understandings of their place within the project and perhaps beyond. Although the spoken Spanish language skills of the students often meant that communication with residents from Zone 3 and other potential vendors in Guatemala was kept at a very basic level, they received respect and support in that we were not perceived as elite scholars but rather as individuals who tried to communicate and connect with locals. Other opportunities for reflection were provided though daily group discussion sessions each evening while in Guatemala. To quote the summary provided in the thesis reflection prepared by Masters of Landscape Architecture student Travis Shultz, "these meetings began with each member of the team quickly explaining his or her most indelible or memorable moment of the day and ended with a student giving an overview of their life experiences and how they have come to where they are today" [54]. Although this may appear to be merely a "feel-good" exercise, the opportunity to unify the group far outweighs the difficulties and awkwardness of organizing these interactions. Encouraging students to recall their most memorable moments of the day enabled a more lasting impact, as spoken words affirm experiences [53].

Opportunities for people to express themselves without interruption rarely presents itself, and many people even struggle with communicating their own life story, as American culture does not typically allow time for interactions such as these. However, from this experience, each student can now say that they truly know each other, not superficially or for the purpose of putting a document together, but because there is now a shared atmosphere of interest and concern for each other as people within a community. This cohesiveness could be seen in group presentations and group work products—from constructing the test compost cells to preparing an achievable business plan and securing significant grant funding to start the company.

After the trip, the class continued with meetings twice a week for the purpose of producing an operational manual (Figure A12) for how to make compost, summarize the site analysis and field assessment, prepare an operational budget and business plan, design the physical components for a compost operation, and finally, learn how to write funding grants in support of the project. Table A3 shows the table of contents for the operational manual. The manual is extensive with a variety of construction techniques prepared in detail (Figure A13) and can be used to guide the development of a composting business in locations other than just Guatemala City. The group also developed strategies for how the compost could be effectively sold to a variety of customers within Guatemala (Table A2) and prepared different promotional strategies to achieve success (Table A4). The goal of loading finished compost onto the empty trucks that had just finished unloading fruit and produce at CENMA, and then to deliver the compost to the farms that grew the fruits and vegetables, adhered to the theories of CE. This was the motivational and inspirational compass as described by de Jesus and Mendonca (2018) [22]. However, this goal was never realized as the farmers were not willing to pay money for the compost and the truckers were not willing to deliver a product that they would not be financially compensated for without some level of government support. In addition, the composting business was not able to produce the volume of compost needed by Guatemala City Municipal Government. It also could not accommodate all of the green waste generated by CENMA—all primarily due to the inadequately small space allotted by CENMA for the compost operation. Regardless, nearly all of the youth hired by the company did learn a trade and make some money to support their family. On reflection, this was a good beta-test or experiment to determine if compost could be made in the environmental conditions of Guatemala City. The team learned about the spatial requirements necessary to produce a commodity viable for sale to the municipal government, local contractors, and for shipping back to farms. From an educational point of view, the effort did adhere to the principles of CE, EI, action research, and CSL. Considering the complexity of melding so many different educational, environmental, social, and economic theories, the effort was successful. As mentioned, the limiting factor was adequate space for the production of enough compost.

During the final weeks of the semester, the group discussed and analyzed their experiences, focusing on how this work relates to their educational and professional careers in landscape architecture and regional planning. The group concluded their work with a University-wide presentation to professors and peers and graduate student Travis Shultz successfully defended his Masters of Landscape Architecture thesis reflecting on this experience.

In keeping with the mission and spirit of a CSL project, the students found that the level of success that they achieved while working within the marginalized Zone 3 neighborhood of Guatemala City was tremendously powerful. Everyone felt that if eight university students could achieve this level of success in three months, the possibilities for what could be achieved through implementing this concept professionally after graduation are limitless.

The students discovered that if they were to apply the broad range of skills taught in a landscape architectural curriculum, coupled with one's ability to support the underprivileged, the opportunities available have no limits or bounds. Helping and being helped by those in need is not a concept foreign to the professions of landscape architecture and regional planning. It is a genre within the profession that should be taught, learned, and then experienced first-hand to be fully appreciated.

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Photographic Credits: The author took all of the photographs depicted in this research paper, unless otherwise noted.

Conflicts of Interest: The author declares no conflict of interest.

Appendix A. Figures and Tables

Figure A1. Guatemala is bordered by both the Pacific Ocean and the Caribbean Sea (Guia Geografico).

Figure A2. Squat dwellings constructed upon a former landfill that typify the Zone 3 neighborhood.

Figure A3. People scramble to gather what they can for recycling, food to eat, or other discarded waste items.

Figure A4. CENMA market (Central Market) is extensive. Note the covered open-air market structures (aerial image from Google Earth).

Figure A5. The landfill is expansive, very dangerous, prone to landslides, and emits methane gas from decomposing waste material.

Figure A6. This aerial image of the large truck parking area located to the east of CENMA was promised to the University of Massachuesst team as the location of the compost operation (aerial image from Google Earth).

Figure A7. The blue shaded areas indicate a narrow strip of land that turned out to be the space made available for the compost plant design (aerial image from Google Earth).

Figure A8. Windrows at a commercial compost operation in Greenfield, Massachusetts.

Figure A9. A back-yard compost bin typically employed by homeowners.

Figure A10. An image of the three-cell hybrid compost bin system adapted for the Guatemala test project.

Table A1. Data for each cell was carefully recorded to track decomposition, temperature, and odor.

Wendell									
						1 = no smell		1 = dry	
						10 = smelly		10 = wet	
Date	Days	Height	Change	Temp	Change	Smell	Change	Humidity	Change
22-Mar		30		75		3		4	
27-Mar	5	26	−4	120	45	3	0	4	0
3-Apr	7	23	−3	130	10	2	−1	3	−1
13-Apr	10	23	0	130	0	1	−1	1	−2

Table A2. Market segment analysis for compost produced.

Segment	**Description**	**Volume**	**Frequency**	**Comments (Including Where, Income, Reliability etc.)**
Municipality	Government Projects	High	Seasonal/annual demand	Transportation implications low. Reliable demand and ability to pay.
Farmers	Rural Agriculture	High	Seasonal/annual demand	Possibility of unloading produce then loading compost. Reliable demand, low ability to pay.
Nurseries	Mostly urban flower or plant growers	Medium	Seasonal	Often a local market. Medium reliable demand and pay.
Households	Private gardeners growing vegetables or flowers	Low	Not strongly Seasonal, though peaks during spring	Local market, high ability to pay, packaging implications.

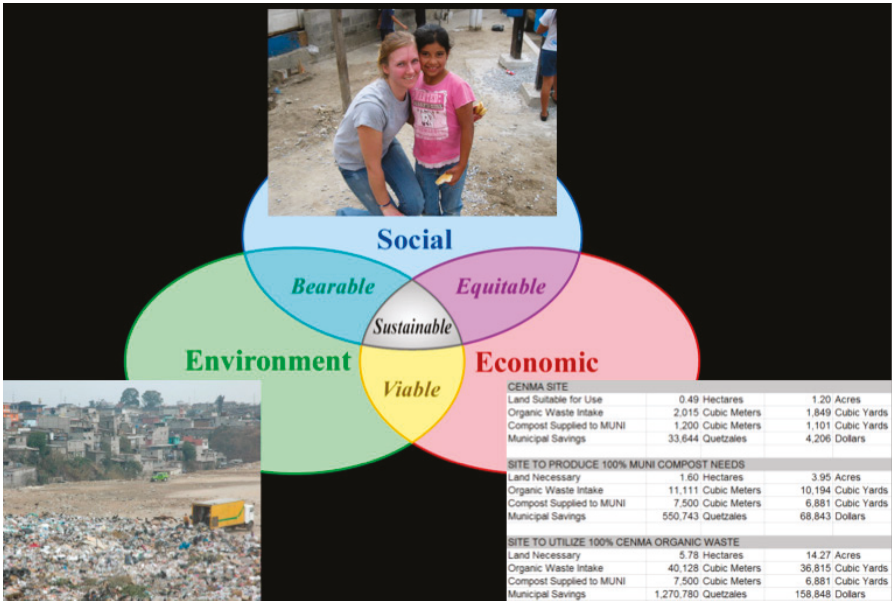

Figure A11. This applied research project in Guatemala City adhered to the three pillars of sustainability.

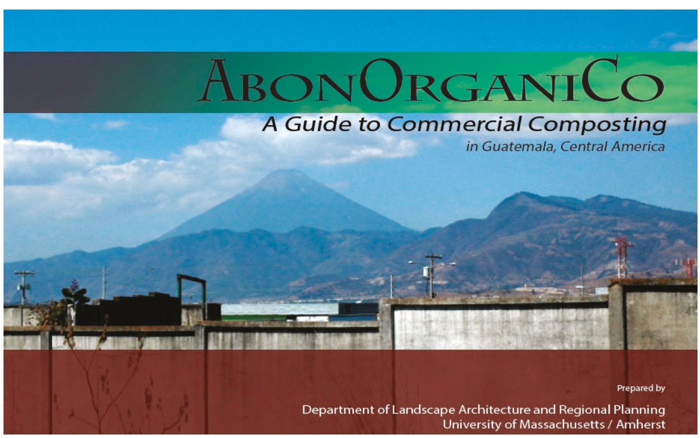

Figure A12. An operational guide prepared by the University of Massachusetts team detailed how to establish a non-profit company for employing at-risk youth from Zone 3 neighborhoods. Techniques for how to produce commercial-grade compost, along with site design guidelines, are also illustrated.

Table A3. Operational Manual for AbonOrganiCo.

Table A4. Promotional strategies.

Word of Mouth	One Customer Tells Another about Your Product
Selling Technology	Face-to-face selling to the customer
Advertising	Communication through print, television, radio, billboard, etc.
Sales Promotion	Encourage people to buy more, "more for less", or trial periods.
Direct Marketing	Door-to-door, sales mail outs, telephone calls
Publicity	Press releases, public service events
Sponsorships	Where cash from one business supports an activity (e.g., sports) return for advertising and accociation with popular activities
Exhibitions	Displays promoting and demonstrating products
Identity	Developing a logo or catch phrase establishes professionalism and differentiates form competitors
Packaging	Important in attracting first time customers, and also getting marketing information across

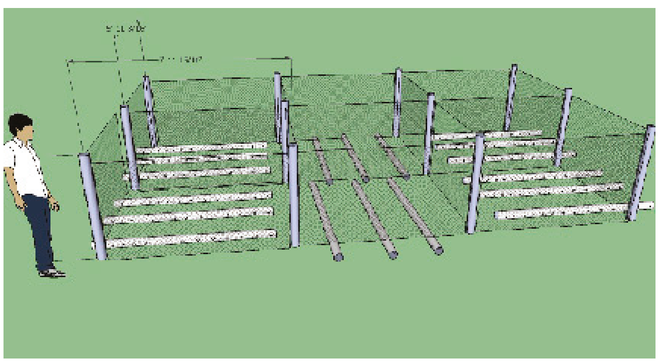

Figure A13. Schematic illustrating the cell construction using metal stakes and wire fencing from the Operational Manual produced by students. Note the perforated piping for movement of air that will accelerate decomposition (illustration by Seth Morrow).

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Fostering Social Sustainability through Intergenerational Engagement in Australian Neighborhood Parks

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Abstract: Social sustainability includes aspects of equity and is associated with two of the United Nations Sustainable Development goals focused on promoting good health and well-being for all ages. Yet, this pillar of sustainability is considered the least understood, as compared to economic and environmental components. To address this, our study focused on intergenerational engagement within residential neighborhood parks to foster social sustainability and encourage healthy and active living. This study included an intercept survey with open-ended questions of 386 adult park users within 12 parks in South-East Queensland, one of Australia's fastest-growing areas. Approximately two-thirds (68%) of adult participants visited the park with one or more children, primarily to use the playground. Further thematic analysis shows that intergenerational interactions predominantly include adults playing with or teaching children. However, intergenerational interactions were limited in numerous situations, such as when adults accompany older children. This paper concludes with a discussion on potential ways to increase intergenerational interactions in parks to promote health and well-being for all ages, thus increasing social sustainability within residential developments.

Keywords: intergenerational engagement; parks; residential neighborhood parks; social sustainability; wellbeing

1. Introduction

1.1. Social Sustainability

Social sustainability, which is the process of promoting, supporting, and maintaining positive relationships between people, is essential for building relationships, mutual learning, and improving well-being [1]. It is also associated with the United Nations Sustainable Development goals focused on promoting good health and well-being for all ages. Although it is an important component of sustainability more broadly, social sustainability is often discussed in terms of social capital, social cohesion, social inclusion, and social exclusion [2]. People also develop relationships with others through belongingness and proximity, such as through shared activities, goals, experiences, and culture [3,4]. These relationships are important building blocks for sustainable neighborhoods and places. Further, social sustainability promotes wellbeing within communities, "by understanding what people need from the places they live and work" and "combines the design of the physical realm with design of the social world—infrastructure to support social and cultural life, social amenities, systems for citizen engagement, and space for people and places to evolve" [5].

Within a social sustainability framework, we focused on intergenerational relationships. As opposed to multigenerational approaches that consider each age group separately [6], intergenerational approaches seek to foster meaningful engagement between different generations [7]. Intergenerational practice often involves three aspects: people of different generations participate; participation involves activities with goals that benefit everyone, and the participants maintain relations based on sharing those experiences [8]. This engagement is particularly important for child and adolescent development. The older person (e.g., parent, caregiver, teacher, mentor, etc.) can provide support, guidance, and mentorship to the younger generations by drawing on their experiences. Several studies demonstrate that strong intergenerational relationships are not only at the root of healthy and productive aging; they are also important for child and youth development and are a critical component for sustainable societies [9–11]. For example, a study of social interactions found that adolescents who worked with an older person on a difficult life problem exhibited more pro-social behavior than adolescents who worked with a peer on a similar problem [12].

Intergenerational shared spaces can offer multiple generations the opportunity to co-participate in and interact with each other through sedentary (e.g., picnicking, observing nature) and active activities (e.g., playing sports). Interactions may be informal due to the proximity of usable areas within one large space [13] or formalized within the context of programmed activities, which have been shown to result in higher park use and physical activity [14,15]. However, despite the apparent value of these types of shared spaces, most research on intergenerational activities has been limited to institutional settings and does not focus on parks [16].

1.2. Encouraging Socialization and Physical Activity through Public Parks

In residential areas, neighborhood public parks and leisure spaces can encourage socialization and physical activity [17–19]. Such parks are located in accessible, prominent areas which promote active transport and provide for the recreational needs of a local community for informal passive and active recreation and leisure opportunities, they also provide an important focal point for social interaction [20]. Regarding intergenerational interactions, researchers in Europe and North America found that children are often accompanied by adults (e.g., parents/caregivers) at public parks and leisure spaces [21,22]. Fathers have shown to be more physically involved with their children at parks than mothers [23]. Upkeep, availability of outdoor equipment and amenities, and friendly community were associated with increased neighborhood park use. However, these studies fail to examine how the parent/caregiver and child benefit from intergenerational park activities. One study in Canada used an intergenerational physical activity intervention program at school, the researchers found socially engaging activities, and an energetic atmosphere helped facilitate social interaction between students and adults [1]. This finding suggests having enjoyable and interesting activities in a friendly atmosphere helps facilitate the development of positive social interactions. Interactions achieved within public neighborhood parks in residential neighborhoods may provide parents/caregivers and children valuable opportunities to socially engage with each other and in turn, build social sustainability. These studies lead us to consider the interactions, shared activities, and intergenerational experiences that occur in parks between children and parents/caregivers.

The benefits of having a strong social support system may influence the use of parks, as parental and peer support can increase the level of young people's activity in parks [24]. Outley and Floyd [25] suggest making use of kinship networks and neighborhood organizations to encourage park use and allow children to participate in available leisure activities, regardless of crime and violence levels in urban neighborhoods. Yet, it is important to recognize that intergenerational park use might not happen naturally. For example, Ries et al. [26] determined park use by urban youth was associated with their friends' park use, but not with park use by their family.

There is a need to connect and not divide generations. When people of different generations are divided, they become susceptible to relying on media portrayals to understand younger and older people [27]. Consequently, those media portrayals lead to misunderstandings, prejudices, stereotyping, and overall worsening of social connections between people of different generations [27]. Families and communities will struggle if people negatively perceive those who are different from themselves. To thrive, societies need to engage and value the assets each generation has to offer. Furthermore, when people of different generations recognize their mutual concerns and interests, they are in a better position to develop comprehensive plans that engage and support all people [27]. Policymakers in many countries are giving renewed attention to intergenerational practice as a method of counteracting stereotypical negative perceptions of aging and overcoming the physical and social segregation of generations [28,29]. Public parks offer a potential setting where people of all ages can be valued and engaged.

1.3. Theory

This study used affordance theory as a framework to understand what opportunities for action were present in the parks that foster intergenerational engagement. Affordance theory, as first conceived by J. J. Gibson (1986), provides a way to understand how we perceive the actionable properties of our environment [30,31]. Heft (1989) further explained that using a phenomenological lens, environmental features or spaces are often experienced with respect to their function and how we interact with them [32]. Affordances are important in determining how the environment can be designed or manipulated to support (or discourage) various activities and experiences [33]. These experiences and perceived affordances depend on the characteristics of an individual [34]. Yet, affordances do not cause behavior, but rather constrain it or create a possibility for it [32]. Thus, it is important to recognize that the physical environment can facilitate behavior, such as intergenerational interactions, but not shape it completely [35]. In addition, affordances that are designed into a specific place, such as a park, also interact with other factors, such as programed activities, cultural norms, weather and seasonal differences, and user characteristics. Within this framework, it stands to reason that parks would include visual cues to indicate which actions are possible within a park. The intergenerational interactions we identified are considered actualized affordances within each setting.

1.4. Setting

In Australia, as in other parts of the world, the suburban landscape is shifting. With rapid population growth due to births and international migration, as well as longer life spans, residential areas are also expanding to accommodate these numbers. From 2016 to 2017, Queensland, Australia experienced the third-largest population increase (79,580 people) of all the Australian states or territories [11]. This study took place in the Moreton Bay region in South East Queensland.

Within Queensland, the Moreton Bay region is one of the fastest-growing areas. According to the 2016 census, 88% of housing in Moreton Bay comprised single-family homes, with another 10% as medium density [36]. A single family home comprises 1 to 2 stories and covers 50% of the lot, with a traditional lot being approximately 18 × 25 m. The area remains predominantly low to medium density with a high-quality of life. Medium density comprises multiple 1 to 3 story dwellings on narrow lots (7.5 × 25 m) with decreased private outdoor space, which is dependent on the lot size and building height [36]. This growth puts increased demands on critical infrastructure, including parks and open space. In addition, a critical factor impacting intergenerational interactions is that the suburbs may lack specific opportunities for residents to socialize due to increasingly busy lifestyles and a lack of public space designed specifically for community gatherings, as compared to urban areas. Suburban neighborhoods are characterized by low density, low rise housing with detached dwellings as the predominant form of housing, whereas urban neighborhoods are characterized by the densest (attached medium density) forms of housing within the region. They are generally located within easy walking distance of a large range of services and activities and/or frequent public transport services [36].

1.5. Aims and Objectives

To better understand if and how public parks in residential neighborhoods can foster social sustainability, this study employed an intercept survey approach with key open-ended questions of park users. To elicit clearer responses from the park users, we selected a specific activity for them to consider an activity that could allow for shared experiences. We chose to focus on physical activity, as partaking in this behavior provides clear health benefits, in addition to the well-being benefits provided by fostering relationships. Flora and Faulkner [37] suggested that the "examination of physical activity serving as a contextual experience for enhancing communication between generations" is in its infancy and remains an untapped area of research to promote intergenerational active living.

Currently, many public parks in residential neighborhoods within the study area do not incorporate features that encourage intergenerational interactions (or social sustainability more broadly). Extant research has demonstrated how and why different generations utilize parks. For example, greater park use for adults has been linked to good access, the provision of quality signage, seating, and toilet facilities [38]. For children, wide pathways connecting activity areas and open areas are important for park use, especially vigorous physical activity [39]. For adolescents, challenging environments which afford adventurous activities may be attractive [33].

These generational differences highlight the critical importance of understanding which park features are most utilized and enable intergenerational interactions within a neighborhood park setting. These findings are relevant to park design and can inform future best practice. Therefore, two research questions were posed to focus this investigation:

Research Question 1. *What intergenerational interactions occur within the parks?*

Research Question 2. *Which park areas and features are most utilized, particularly by adults accompanying children?*

The next sections describe the methodology, methods, and findings. The paper concludes with a reflection on designing for intergenerational interactions within public parks to promote social sustainability in residential neighborhoods.

2. Materials and Methods

We used brief intercept surveys with adult park users visiting 12 pre-determined parks within a Regional Council area in South-East Queensland, Australia. The parks were selected to ensure a cross-section of park users was reached, based on three criteria: geographical area (five areas across the Region), park classification (local, district, or regional), and age of park equipment (old, new, or combination), all parks had at least one playground and field area. A mixed-methods approach of park audits and systematic observation of park users' physical activity levels were undertaken and recorded as part of a broader study but is reported elsewhere. The data presented within this paper was obtained via intercept surveys with questions aimed at identifying adults' motivations for visiting the park, their perceptions of the park design and physical activity opportunities, and intergenerational interactions within the park setting. Four trained research assistants conducted the face-to-face intercept surveys over a four-month period during the Australian summer months (i.e., December 2017–March 2018). Each park was visited on four days (two weekdays and two weekend days), between 7:00 a.m. and 6:30 p.m., except for one park that was visited on three days.

2.1. Materials

The multi-disciplinary research team, comprising social scientists, landscape architecture and planning researchers, and health researchers, developed the intercept survey. During the development process, the research team discussed the survey questions to ensure suitability, clarity, and relevance. An iterative review process was undertaken by the research team, which resulted in minor changes and additions to the survey questions. Furthermore, during the review process, consultation was held with key stakeholders with historical knowledge about design concepts of the parks (i.e., urban planners and landscape architects working within the Council), and the park users.

The intercept survey comprised five sections; the park users were asked questions about their park visitation, perceptions of the park design, physical activity opportunities (affordances) at the park, intergenerational interaction at the park, and demographics. The park visitation section comprised nine closed-ended questions to gauge the reasons for visiting the park, and with whom they were visiting the park, particularly whether they were at the park with children or not. Further, a subjective measure of their perceptions of park design comprised closed and open-ended questions, including two items ascertaining satisfaction with the design of the park and amenities present within the park using a five-point Likert scale (1-very dissatisfied, through 3-neutral, to 5-very satisfied). The perceptions of physical activity section enquired about the areas in the park the respondent felt they were most active, as well as the areas their children were most active (if visiting with children), and they were asked to explain the factors that allowed for these activities (open-ended question). The intergenerational interaction section was only administered to those parents/caregivers visiting the park with a child/ren. This section comprised three open-ended questions aimed to uncover the type of interactions that typically occurred across generations when at the park. Demographics collected included age category, gender, and the number of girls and boys visiting the park with them in three age categories (i.e., 0–5 years, 6–12 years, and 13–18 years).

The questions were uploaded to an online software program (Key Survey) and administered by research assistants using an iPad. The surveys were also audio recorded to capture verbal responses to open-ended questions and allow transcription of these responses.

2.2. Recruitment

During the park visits, the research assistants approached adult park users and provided a brief description of the purpose and nature of the survey and asked them if they would like to participate. If the park user was interested in participating, they were provided with a paper-based "Participant Information Sheet" and those still interested in participating provided verbal consent to the research assistant. The research assistant then confirmed whether the participant was willing to have their responses audio-recorded, and if so, commenced with the audio-recording.

2.3. Participants

A total of 417 adult park users participated in the survey. However, 31 (7%) of the respondents did not agree to have their responses recorded, and thus, their survey responses could not be included in the qualitative analysis. The final sample comprised 386 adult park users who completed the survey and agreed to have their responses audio-recorded. The majority were female (n = 234; 61%), and between 25 and 44 years old (63%). A large proportion were visiting the park with a child or children (n = 263, 68%). Figure 1 provides the data on the total number of participants by age category as well as the number of adults at the park with a child/children, broken down by gender.

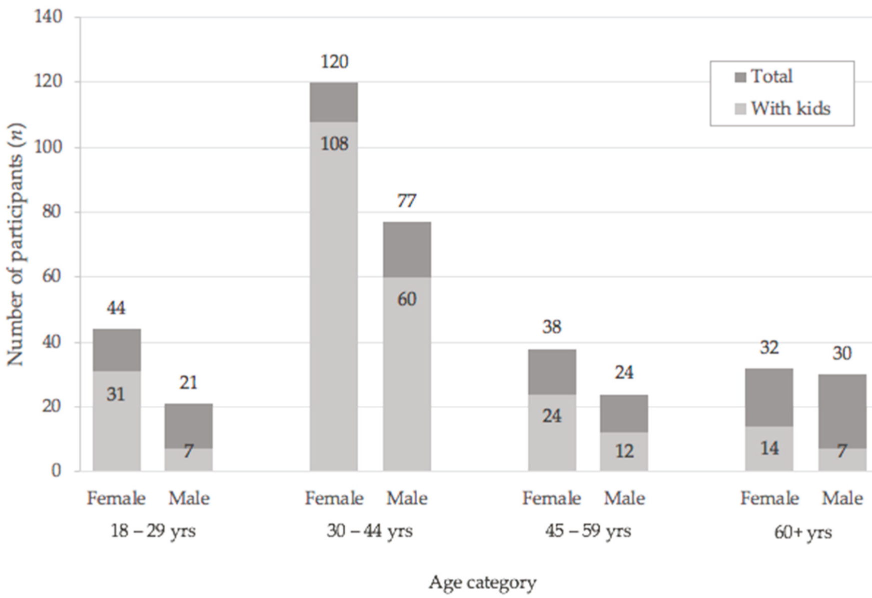

Figure 1. Total number of participants visiting the park overlaid by number of participants with child/ren, by age category and gender.

2.4. Data Treatment

All recorded responses were transcribed verbatim and uploaded into Nvivo for data analysis. The analysis was conducted in line with Braun and Clarke's (2006) phases of thematic analysis [15].

For Phase 1: Familiarization with the data; a sample of 20 transcripts were reviewed by three members of the research team, and initial ideas for coding were proposed and discussed.

Phase 2: Generation of initial codes; researchers used an inductive approach as no pre-existing codes were identified, a priori. After the generation of initial codes (based on a sample of 40 transcribed surveys), a research assistant was then trained to code the remaining transcripts. The surveys were coded with the relevant codes, thus resulting in some extracts with numerous codes assigned. Throughout the coding process, a small number of new codes emerged. Survey transcripts analyzed prior were reread to allow for the new codes to be applied. Thus, an iterative coding process was employed. To enhance the reliability of the analysis, 65 (17%) of the survey transcripts were independently coded by two members of the research team. Subsequently, the transcripts were subjected to inter-rater reliability analysis using Cohen's k statistic to determine if there was moderate agreement between the independent coders (k = 58).

Phase 3: Searching for themes; following the coding of the dataset, analysis was performed to identify the themes within two streams of interest (in line with the research questions posed). The two streams of interest included: (1) Descriptions of adult-child interactions, and (2) Descriptions of park areas utilized.

Phase 4: Reviewing themes, the extracts coded with the potential themes in Phase 3 were reread to ensure they formed a cohesive theme. The biggest adjustment made was with the 'adult-child interactions' stream, after it was identified that the potential theme "assisting" was not providing valuable unique information as the extracts were often also coded with either "playing" or "teaching", both of which typically captured the meaning of the extract better.

Phase 5: Defining and naming themes was undertaken for both streams of interest. The three key themes within the 'adult-child interactions' stream were: (1) observing, (2) playing, and (3) teaching.

Three themes were identified within the 'park areas' stream, these were: (1) playgrounds, (2) open fields, and (3) pathways.

3. Results

The participants were asked to indicate the main reason/s they were visiting the park. The top reasons identified were: for children to play (47.7%), dog exercise/recreation (22.5%), and walking (10.6%), followed by meeting friends (3.9%), and basketball (3.4%). The participants were also asked to indicate the expected duration of their visit to the park. Figure 2 indicates that 41% of the participants intended to visit the park for between 30 min and 1 hour, and one-quarter intended to stay for less than 30 min.

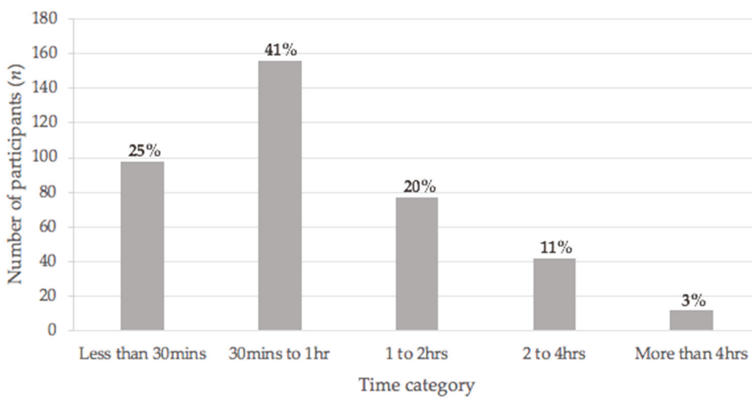

Figure 2. Number of participants, and percentages, by time category of expected duration of park visit.

3.1. What Intergenerational Interactions Occur in the Park?

Three key themes were identified within the thematic analysis: playing, observing, and teaching. Since the respondents were adults, we describe these actions from the perspective of adults, rather than children. Figure 3 shows the relative proportions of these three activities, and the proportion of overlap. Of note, 31% of the responses were coded with all three themes suggesting that the type of interaction that occurs at the park varies across the duration of the visit. The key themes will be discussed in turn.

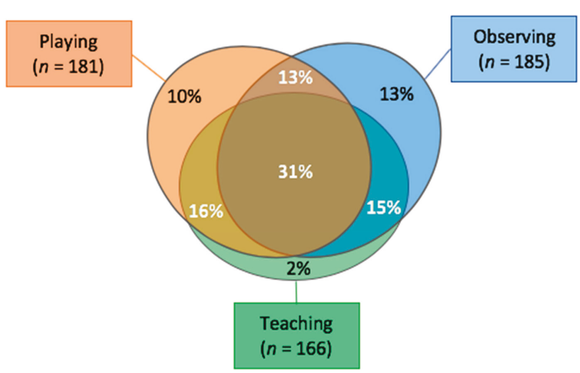

Figure 3. How are adults and children interacting?

3.1.1. Playing

A large number of caregivers indicated that they almost always played with the children when at the park, with typical responses such as: "We play together" (R232), and "No, we play together. Never just sit and watch" (R174). This most often occurred on the playground equipment and within the playground area, "I do play. He was asking me to play with him before . . . Just on the playground equipment" (R226). The playgrounds appear to provide affordances for the children, as well as the adults, to interact through play at the child's level, such as being silly: "We're not really a sporting family, but we'll come to the playground. The little fellas just love to get on it, and especially take some friends as well and kids. I'll be a bit silly on the playgrounds as well" (R344). For many of these caregivers the act of going to the park, with the assumption that the adult and child/ren would play together, demonstrates a unique social dynamic occurring in outdoor space that may not occur during other times of the day or week: "(We) Play together... you go to the park to interact, don't you?" (R328).

Of note, caregivers with younger children (i.e., typically those under 5 years of age) were 'always' playing, with comments such as, "(We) Play together because they're so tiny" (R180; Boy 0–5 years, Girl 0–5 years), and "We play. We interact with her because she's so little" (R211; Boy 13–18 years, Girl 0–5 years). One explanation was that the children needed their assistance physically: "Generally, when I take them to the park, especially if you've got a younger one, you're helping them to climb stuff and push them on the swing, and things like that" (R306; Boys 5–12 years and 13–18 years, Girl 0–5 years). It is also likely that these preverbal children (2-year-olds and younger) lacked social skills to engage in interactive play with other children or initiate games with peers. The parents/caregivers were likely also playing with the younger children for safety reasons, due to the children's lack of understanding of risks and limited assessment of their physical capabilities, as explained by one caregiver: "Because he's little, I like to be there, especially the climbing things, just in case he falls or whatever" (R123; Boy 0–5 years). For these caregivers choosing to visit the park with younger children, there appears to be an acceptance or understanding that they will be interacting with the children through play:

> "We play together. We always play with her. We can't let her just run off by herself. She's a bit young." (R405; Girl 0–5 years)

> "Play together, I don't really get to sit and supervise. We've got a few more years before that." (R380; Boy 0–5 years, Girl 0–5years)

As suggested by R380 (above), this expectation of interacting with children through play at the park appears to dissipate as the children get older. Furthermore, interestingly, some caregivers who indicated they engaged in a combination of playing and observing also indicated that they were reducing their playing time as the children got older and needed them less, which will be further discussed in Section 3.2.2.

3.1.2. Observing

Similar to the playing theme, within the observing theme many parents/caregivers indicated that they mainly observe, which was also described as watching or supervising the children whilst at the park: "I mostly watch when they come down here, now that they're a bit older," (R099; Boy 0–5 years, Girl 6–12 years). A key subtheme that emerged, as alluded to in the prior excerpt, was that older children (i.e., typically those over 5 years of age) were observed more than younger children. Conversely to within the playing theme, it was suggested that the older children did not need their caregivers for entertainment or physical assistance as much as the younger children, "Most times, I sit back and let them play, only because of their ages. Sometimes, I get in and play, but I don't find I need to" (R077; Boy 0–5 years, 2 Girls 6–12 years). This shift from playing to observing as the children got older was clearly identified by some caregivers: "25, 75: 25% play, 75% watch. Now they're older, when they were little, it was more like the opposite way" (R016; Boy 0–5 years). There was also a suggestion that in addition to the older children or teenagers not requiring adult assistance (physically or socially), that they would prefer to do their own thing, as suggested by these caregivers: "I watch them. He's more a teenager, so it's a bit different" (R070; Boy 13–18 years), and "They're a bit old. They don't want to play with me. Walk the dog. I usually don't come. The kids will do it themselves. They're kind of old enough to do their own thing. They'll ride there on their BMX on their own" (R296; 2 Boys 6–12 years).

As illustrated in Figure 3, there was notable crossover between caregivers' descriptions of interactions at the park being coded with observing as well as playing, for example: "Probably three-quarters of the time I play with him, then a quarter of the time I let him play by himself, too" (R123). One explanation for observing at times was to allow the children to demonstrate or develop their skills without direct input from the caregiver, "We play, but sometimes I take the time to just sit down and watch them, see what they're doing. I like being able to sit down and watch them play. That's nice to see as well" (R177). As children are constantly developing their social and physical skills, taking time to observe the children can be a passive yet insightful way to determine some potentially new ways to engage with the children in future interactions. In addition, observing rather than contributing towards children interacting can provide great opportunities for the development of their social skills with their peers. Some caregivers explained that they play but often sit back and observe the children when they had other children to play with, for example, "Well, they've brought some school friends, so we mostly watch them play" (R288), and "It depends how busy it is. If it's quiet, I'll play with them, but if it's busy, I'll sit and watch" (R107). Even though this observation is not typically facilitating social interaction between the adult and child, it is allowing social interaction between the children while at the park.

One interesting subtheme that emerged was that people with lower physical capacity (e.g., has an injury, of retirement age) were observing the children rather than playing. For example, one caregiver who currently has an injury said, "It depends. As I'm busted up at the moment, I'm not skateboarding. I normally skateboard with them, which is how I did this, incidentally" (R153), A caregiver of retirement age said: "I supervise. I, unfortunately, cannot play much, I've got problems with hips and knees and all that" (R138, Age category: 75+ years). It is positive that these adults were still coming to the park with children to allow them to get out into nature and potentially be physically active. However, it would be beneficial to identify ways in which these people could still socially engage with the children, if they wish, and are not designated to simply observe.

There were caregivers who suggested that they use their time at the park to allow the children to have fun and entertain themselves, while the caregivers stole some moments for themselves. These moments were for individuals, "I mostly just supervise. I mean, he'll come and sort of check in, but yeah, mostly I'm just watching him play and reading my book" (R386), as well as for couples or groups, "They do their own thing which sort of gives us our time" (R260). This could have a positive impact on the well-being and mental health of caregivers, particularly as these moments are occurring within the natural environment. In addition, being able to observe the children whilst interacting with other adults can be a great method of social engagement for the adults, "Yeah, it's often a good time for my husband and I to have a talk as well, because the kids are happy and sorted—and they're getting a bit older now, so we can sit down and catch up ourselves" (R418).

3.1.3. Teaching

The caregivers were directly asked if they had taught the children any skills while at the park. Although these interactions involved both teaching and learning, we have focused primarily on the adults "teaching" children, based on the responses that we analyzed. The examples provided were predominantly physical skills, however, amongst these were a few references to social skills as well. In terms of social skills, the parks afforded opportunities for children to interact with other children and learn about prosocial behaviors. These descriptions typically focused on the playground equipment and the need to learn to take turns and not push in, and show respect to others:

> "I think one of the best things in the park is like developing their social skills, so they will meet with other kids and they learn to share toys and play together." (R414)

> "I've probably been more like trying to instruct him to be careful and sort of watching out for little kids, more than anything else." (R386)

These opportunities arise when there are multiple people wishing to use limited resources, such as when there is only one slide or swing available, "Yeah, just trying in an open and safe environment you know teach him about other kids come, we take turns on the swing . . . " (R019). Learning patience, respect, and cooperation are invaluable social skills for the duration of a person's life, and it was valuable for caregivers to identify these learning opportunities for children while at the park.

The main physical skills taught that emerged from the data were bike riding, ball skills, swinging, and climbing skills. The caregivers' responses suggest that the parks afforded these teaching and learning opportunities through the provision of facilities not often available in their backyards. Teaching and learning how to ride a bike occurred on pathways: "I think we brought them here when they were new at learning to ride their bike, because it's got the concrete path all around" (R240). Teaching and learning ball skills (football and cricket) often occurred in open grassy spaces: "Yeah. Kick the football around. How to kick the ball around and how to catch the ball actually" (R072). Teaching and learning climbing skills and swinging oneself occurred on playground equipment: "The rope climbing, teaching them just to look up and hold something higher when they're going up, just the basic stuff, and just yeah, maneuvering around ropes and telling them to look and place their hands, just the basics," (R388), and "(Taught) How to push themselves on the swing" (R175). It was valuable to identify that these were the main skills being taught at the park, as these facilities were also identified as the areas of the park that were most utilized for physical activity, as will be discussed in the following Section.

3.2. What Park Areas Are Being Utilized?

As the focus behavior of the study was the engagement in physical activity at the park, the respondents were asked to indicate the areas of the park in which they felt they were more physically active, and where their child/ren were physically active (for those accompanying children). The results from the participants accompanying children are presented in Table 1. A follow-up question posed to all participants enquired about why these areas allowed for greater physical activity. The key themes identified within the thematic analysis will be discussed in turn.

Table 1. Park areas perceived to have the greatest levels of physical activity for caregivers and child/ren (n = 263).

Park Area	**Adults** *n*	%	**Park Area**	**Child/ren** *n*	%
Playground	114	(43.3%)	Playground	216	(82.1%)
Pathway	54	(20.5%)	Open fields	45	(17.1%)
Open fields	52	(19.8%)	Pathway	36	(13.7%)
Not active	38	(14.4%)	Basketball court	19	(7.2%)

Note: Participants were able to select up to three options for this survey question.

3.2.1. Playground

As indicated in Table 1, the playground area was the top selected park area for physical activity for both caregivers and children. As adults typically do not utilize the playground unless they are accompanying children, it is likely their engagement with this area of the park is dictated by their child/ren's engagement. The caregivers suggested that the variety of playing opportunities was an important element for their child/rens engagement and physical activity levels at the playground, "I don't know, just getting the options, different climbing things to do, slides, swings, you know running around, spinning things. There's a lot more options here." (R416). Some caregivers explained that the variety of equipment helped maintain their children's attention and interest, which helped prevent the children from getting bored:

> "The main thing is if you've got different variety of different types of play equipment because I know that we've taken them to playground parks before when there's only been two or three different things to play on. He gets bored in half an hour, whereas here he's quite content just roaming around, different activities, different swings, climbing apparatus, and different colors is always a good thing as well." (R351)

Some parents/caregivers also suggested that the variety of equipment allowed the children to try out a range of physical skills, which is another method of maintaining engagement, for example: "Maybe the scope of the equipment that is there. There's climbing, there's balance activities, and there's lots of different stuff to do, to keep him engaged" (R123). In addition, some playground areas provided an ideal space for the children to run around, move and exert some energy among the equipment they are typically drawn towards, "I think because it is spread out it gives the kids a chance to run between the spaces" (R299). Overall, the presence of a variety of playground equipment that provides numerous options for use, which include the need to use a range of physical skills, is more likely to engage children for a longer amount of time as perceived by their caregivers.

3.2.2. Open Fields

A key factor for engagement within the open fields appeared to be the provision of a grass lawn area that provided sufficient space to play ball games, kick, throw, and hit balls around. The parents/caregivers also suggested that the open area provided more room to run around, and that is what they did, "Our backyard is quite small, and the open area is only minimal, so you have more space to have a decent run (here)" (R087). Even though the only 'facility' provided was well maintained grass and at times a cricket pitch, it was suggested that this was sufficient due to their ability to bring props to utilize within the spaces, as indicated from this caregiver: "They can just bring everything down, and they can do whatever they want. It's a decent size" (R152). For this community, it appeared that having access to balls and other sporting equipment was common, they just needed the space to use their equipment: "The grassy space is great because they can either bring equipment, or two of my daughters are cheerleaders so they'll often run and do flips because it's such a nice big space" (R404). Open and empty fields (e.g., without goalposts or a cricket pitch) typically do not provide many affordances for use, however, when the potential use of ball games is identified and utilized, the potential for social interaction and social engagement is high due to the reciprocal nature of these games.

3.2.3. Pathways

Of the 123 participants who were visiting the park without children, 46% indicated that they were active on the pathways (which was the most selected park area for this subsample). Thus, the pathways were utilized by both park users accompanying children (as indicated in Table 1), as well as those who were not with children but typically with another adult, their dog, or on their own. The key positive descriptors to explain their engagement with the pathways were long, wide, and smooth, for example: "Because of the nice footpath they can have a long walk" (R285), and "I saw lots of people cycling on it, so, obviously the smooth surface of the pathway," (R345), as well as, "It's nice and wide, and it's nice and smooth" (R252).

The pathways were ideal for park users across all ages because they allowed for a safe environment for walking, bike riding, and scootering, in particular. Wide pathways were described as ideal to allow safe passing by others on the path. Smooth pathways were important for older people with mobility issues who were concerned about tripping while walking:

"Well, they're wide, and they're fairly recently done, so there's no tripping traps . . . Yeah, it's very evenly—it's all very nicely done, very smooth walking." (R274, Age Category: 70 to 74 years)

"Well, you've got a path to follow, and at this stage, it's kept up. [. . .] There's not many things you can slip over on. It's pretty safe. When you get a bit older, you need to have something that's—and they're wide." (R253, Age Category: 65 to 69 years)

Moreover, smooth pathways were important to allow young children to safely ride their bikes or scooters while their caregiver walked, as explained here: "This is a great pathway for me to walk, and then for the girls to come on their scooters as well," (R249). A long pathway within the parks, in conjunction with constant visibility of the pathway, was also viewed as a positive safety aspect, "It's fantastic, because my daughter can go around on the scooter, I can visually see her," (R418). These long pathways afforded opportunities for children to ride longer distances off the roads and within their caregiver's line of sight, providing an optimal space for these physical activities: "Obviously the ability to ride their bikes safely off the roads" (R417). Overall, long, wide, and smooth pathways that are perceived to be 'safe' appear to provide affordances for a range of activities that can be undertaken by multiple generations simultaneously. Therefore, engagement with well-designed and maintained pathways within parks can facilitate intergenerational social interactions.

4. Discussion

In this study, we investigated the type of intergenerational interactions that currently occur within public suburban parks, as well as the park areas that afford these interactions. We identified that playgrounds, open spaces, and pathways were important park features that afford playing, observing, and teaching opportunities for caregivers and their children. This is in alignment with Moore and Cosco's findings, where they found generous pathways linking different elements and areas within a neighborhood playground supported easy and active use by children and their carers [39]. This indicates that, when these park features are designed to promote these affordances, public parks within residential neighborhoods can provide valuable opportunities for intergenerational engagement to contribute to social sustainability. As an important component of residential landscapes, which may lack community engagement opportunities often seen in urban areas, designing these spaces to accommodate and attract intergenerational users is one way to promote general health and well-being.

Within our study, we observed a large proportion (70%) of caregivers playing with their children, particularly within the playground. Our findings suggested that this area of the parks provided affordances for play for children, which was not surprising, but also affordances for adults to interact through play. We also identified that children were perceived to remain engaged with the playground for longer when there was a variety of equipment that afforded numerous options for play (for both interest and physical challenge). This is line with previous findings that challenging environments are attractive to adolescents [33] and adds to the knowledge regarding the design of parks to enhance longer engagement.

The caregivers within our study were commonly playing with young children while at the park, especially when the children needed physical and social assistance or guidance. However, interacting through play appeared to diminish as the children got older, and assistance was no longer required. Even though older children do not necessarily need physical or social assistance when at the park, it may be a missed opportunity for social interaction between caregivers and older children. Particularly so when the "older children" age range starts at 5 years of age, which is when children in Australia typically start attending school. As found by Kessler [12], teenagers who work through life lessons with older adults tend to exhibit more pro-social behaviors than those working with peers. Thus, suggesting that children and teenagers can learn important social skills with the guidance of older people and adults. For those attending school and spending a large amount of time with peers, going to a park with an adult could provide a valuable opportunity for positive intergenerational interactions, if these interactions occur.

As the caregivers in our study reported interacting less with older children, it may be beneficial to include affordances for adults to "play" and interact with these age groups. For example, playground designs could include equipment for older children that requires or encourages assistance from caregivers, which would promote adult-(older) child interactions. As found in an intergenerational intervention program in a Canadian school, enhanced social interactions can occur through socially engaging activities and an energetic atmosphere [1]. It would be valuable to identify if this can be translated to parks. In addition, placing seating within playground areas rather than in surrounding areas, may facilitate greater interactions between caregivers and children. This could accommodate adults and older adults with mobility issues who suggested they were relegated to only 'observe', but may enjoy the opportunity for greater interaction with the children when at the park.

Approximately two-thirds (68%) of adult participants visited the park with one or more children. This suggests that park visitation can enable social interaction between adults and children. Our study also found that children are able to build social skills at the parks since it is often a place where different families can come together -"I think one of the best things in the park is developing their social skills, so they will meet with other kids and they learn to share toys and play together." (R414). The park, and predominantly playground environment, assisted the children to learn the prosocial behaviors of taking turns, not pushing in, and showing respect to others. While variety within playgrounds appears important to maintain interest and challenge, having limited numbers of specific popular equipment appears to be valuable for children to learn important social skills and the concept of taking turns.

Within our study, 75% of the participants planned to visit the park for 30 min or longer. In addition, 75% of the caregivers reported interacting with their child/ren in more than one way when at the park (e.g., playing and observing). Taken together, these results suggest that the amount of intergenerational interaction that occurs at the park varies across the visit. Thus, even though caregivers observing children are not directly interacting with the children, it appears to be an opportunity for adults to interact with each other. For example, adult family members could 'take the time to catch up', or caregivers could forge social connections with other caregivers. However, our results did not provide insight into whether it was a good social space for adults to meet other adults. Past research indicates that this may vary in different cultural settings. A study comparing six public park playgrounds in the United States and Denmark, and the cultural similarities and differences, found the Danish respondents considered it most important to be together with their families, while the American respondents thought it was most essential that their children were physically active while being at the park [23]. Despite the differences, all respondents stayed at the park longer and visited more often if they liked the social atmosphere of the playground. This suggests that ensuring there are spaces and seating in and around playgrounds to facilitate social interactions between those observing the playground is an important design element to promote social sustainability.

Even though our study primarily investigated intergenerational interactions that involved children, it is important to acknowledge the potential intergenerational utilization of public parks with generations other than children (e.g., adults and older adults). We found that almost half of the participants who visited the park without children indicated they used pathways. Older adults like long, wide, and smooth pathways for walking, and children need these same attributes for learning to ride and practicing on their scooters and bikes. Ensuring pathways are designed with these considerations can encourage utilization by the individual generations. In addition, as suggested by caregivers within our study, adults, as well as older adults, could walk while children ride bikes or scooters. This could allow for conversations and explorations together, and in turn, enhance the social connections between the generations.

The teaching and learning of physical skills can provide a great opportunity for adults and older adults to give back to the younger generation, and for children to appreciate the knowledge and skills of their elders. This is a chance for the generations to engage in mutual interests as well as value the assets of other generations [27], an important step in promoting social sustainability. A public residential park can provide unique opportunities for this social interaction. Within our study, we identified several affordances for physical skills taught and learned at the park, including bike riding, ball skills, swinging, and climbing skills, and which occurred on the pathways, open fields, and playgrounds. The inclusion of these park features is commonplace. However, their value for intergenerational social connection may not be fully appreciated to date. The continued inclusion of these park features appears important to allow the teaching and learning of valuable physical skills, particularly in light of the smaller backyards typical of new suburban neighborhoods. To further enhance this unique intergenerational social interaction at parks, the provision of cues that encourage the teaching of these skills could add value.

The results reported here only include surveys conducted with people already accessing the public parks in residential neighborhoods. A limitation is that it does not provide information from the perspective of people who do not access the included parks. Additional phases of this research will include a survey of non-park users to better understand the barriers they may face for accessing the parks.

5. Conclusions

This study contributes to the knowledge on the use of public parks in residential neighborhoods and the intergenerational interactions that occur within the Australian suburban context. Key results show that intergenerational interactions occur when caregivers/parents are teaching, playing, or observing the children. These results demonstrate the importance of park design and its influences on teaching and learning opportunities. Playgrounds with pathways allow for teaching and learning of bike riding and handling skills, and grassy field areas encourage gross motor skill development and hand-eye coordination, through ball sports. Playground equipment allows for risk-taking and independent learning while under observation by the caregiver/parent. These teaching and learning opportunities allow for intergenerational and social interactions that may not otherwise occur within the respondents' residential setting.

With playgrounds that are more appealing to accompanying adults in a number of ways, there is a chance that children will come more often and stay longer. Time spent in public parks has the potential to increase social sustainability within residential suburban areas. Current trends in society often separate the generations and keep people indoors. Yet, connecting different generations within neighborhood community parks may be an option to ensure social sustainability in the suburbs.

Public parks in residential neighborhoods have demonstrated specific areas for intergenerational physical activity and segue for social engagement, hence social sustainability. This type of social engagement within parks may be affording unique opportunities for caregivers to allow and witness their child/ren making decisions and taking risks and foster valuable parenting/caregiving opportunities as well as learning opportunities for the children. The provision of these opportunities could encourage different and potentially greater social engagement than those opportunities provided at home. In addition, these interactions can be complementary to developing the foundation of solid social engagement within families, rather than just simply existing within the presence of one's family that may occur in today's busy lifestyles.

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Review

A Conceptual Framework for Urban Commoning in Shared Residential Landscapes in the UK

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Abstract: This paper uses ideas central to the notion of urban commoning to develop a conceptual framework that can be used to inform the design and management of shared residential landscapes in the UK. Shared residential landscapes provide an important backdrop for everyday social interaction, chance encounters and mutual understanding. A recent revival of the commons concept within the urban context has brought forth new ideas for the design and long-term management of shared urban resources through participation and collective action. However, despite the potential benefits of urban commons for improved quality of urban living, there remains a disconnect between commons and spatial theory, obstructing effective application. Of particular significance are the role of physical space and the design professions in enabling or hindering the collective practice of urban commoning. To address this, this paper reviews the evolution of the commons, the implications for applying them to the urban context, and spatial theories in developing a conceptual framework for their application within the UK residential sector. Finally, the example of cohousing in the UK is drawn upon as an illustration of the urban commons framework. The framework creates a foundation for further research on the design and long-term management of shared residential landscapes as urban commons to benefit the everyday social lives of residential communities.

Keywords: urban commons; residential landscapes; spatial theory; cohousing; governance; shared resources; territory

1. Introduction

In recent years, a significant amount of attention has been focused on the sustainable development of urban landscapes [1–4], with notable focus on residential settings [5,6]. This coincides with a growing understanding of the opportunities offered by urban commoning [7–10], an emerging concept describing the collective governance of shared resources in the city by communities [11,12]. The term 'urban commons' has gained momentum in recent years as part of a wider 'new commons movement'. This has seen the reinterpretation and broader application of the traditional commons concept within contemporary contexts [13,14]. However, the novel and diverse use of the word 'commons' presents its own challenges, in particular, in that it has become "*a term frequently applied yet rarely defined*" [13] (p. 3). Despite the term resonating with an emerging sharing culture within cities [15] and participatory approaches to designing the city [16], the term urban commons remains ambiguous and difficult to pin down. In particular, conceptualising city spaces as urban commons, highlights a need for a spatial understanding [17,18] and a stronger connection between the concept and urban spatial theory. The current paper argues that there is potential to align commons thinking with urban spatial theory in order to strengthen its applicability. This will focus on the context of shared residential landscapes, where the commons concept offers potential to encourage a more socially sustainable and bottom-up approach to participatory placemaking. While new community-led practices are emerging and calling for greater collaboration with urban professionals, there remains a gap in the theory to underpin how the ideas of urban commons relates to the residential context. In response, this paper highlights the need for a place-based understanding of the urban commons concept to enable the sustainable design and management of shared residential landscapes as urban commons.

In pursuit of bridging this gap, the current paper will focus on addressing the need for a spatial understanding of commons in the context of urban residential landscapes by developing a new conceptual framework for urban commons that strengthens the connection between the emerging concept and spatial theory. To achieve this, a review approach will draw upon and organise existing commons and urban spatial concepts to build a preliminary conceptual framework within the context of recent UK cohousing research. The purpose of this preliminary conceptual framework is to lay the theoretical groundwork for future empirical research on urban commons specific to residential landscapes and substantiate more broadly the spatial theory surrounding urban commons. In the process of bridging spatial and urban design theory with urban commons, attention is also brought to the role of the design professions and how professional input can be accommodated within the community-led process of urban commoning.

2. Background and Context: Shared Residential Landscapes and Urban Commons

In 2017, the UK Government set out plans to build 300,000 new homes a year in England in an attempt to tackle ongoing issues around the affordability and availability of housing [19] (s.5.3). The concern from a social sustainability perspective is how, in the long-term, these new homes will contribute to the everyday social lives of the communities that will live there. In particular, how the spaces between buildings can provide an opportunity for social interaction and engagement.

Shared residential landscapes are socially valuable spaces that form the backdrop to everyday routines, social encounters and community identity [20]. The characteristics and qualities of these spaces, shaped by their design and maintenance over time, have a significant influence on the social aspects of a neighbourhood [21–23]. Aligned with this is the understanding that people's direct interaction with the surrounding environment can provide opportunities for expressing identity, receiving recognition from others and developing a greater sense of belonging [24]. Resident control over shared outdoor spaces also allows potential for residents to shape their common surroundings in a way that is beneficial to them, providing agency over the way they live [25,26] and increasing opportunities for social interaction [27].

A way of encouraging greater potential for communities to have a decision-making role within the make-up of their residential environment can be seen within the community-led housing sector [26,28,29]. Even though profession-led top-down approaches remain the predominant model for new housing development in the UK, community-led housing is growing in popularity, something that has been recognised in the UK government's 2018 announcement of the £163 million Community Housing Fund [30]. Community-led housing challenges some of the limitations within contemporary housing development by generating a new bottom-up approach that shifts residents' roles from end users to engaged participants in aspects including anything from site acquisition to management.

Cohousing is a particular model of community-led housing characterised by its combination of individual private dwellings with shared facilities and resident-led decision making during the design, development and occupation phases [31,32]. Examples of cohousing in the UK are located in both urban and rural contexts and built with a range of densities and layouts [33]. Although cohousing developments are spatially diverse, they are based upon similar design and organisational principles that promote collaborative ways of living [6]. Subsequently, residents have high levels of involvement in the maintenance and management of communal spaces, organisation of social activities and the decision and rule-making process of the community [6,34]. A review of recent research suggests multiple benefits associated with cohousing, including decreased energy use, affordable living costs, enhanced connection to place, improved self-awareness, strong community relations, mutual support and knowledge sharing [34–38]. Cohousing, therefore, provides a useful illustration for the potential of collective participation in residential placemaking.

Notable within the increasingly popular community-led housing sector, and resident participation in shared residential landscapes more generally, is the emerging concept of urban commons. While the evolving meaning of the term commons has created a usefully flexible concept applicable to various resources in different contexts and at multiple scales, it remains conceptually challenging in its vagueness [13,17]. In applying the commons concept within the urban context, the theoretical implications are yet to be fully explored. Furthermore, a polarisation between top-down and bottom-up approaches to urban development in the UK presents additional challenges of integrating commons as a bottom-up approach within the top-down guidelines and practices of urban professions [34,39]. Therefore, even though the broadening of the commons concept to include shared urban resources has stimulated a reconceptualisation of collective governance in cities generally, challenges remain surrounding clarity in its definition, understanding the spatial implications, and the role of urban professionals in its implementation. These limitations in understanding the urban commons create challenges to appropriately applying the theory in urban residential contexts.

To address these challenges, this paper aims to develop a new conceptual framework for urban commons that strengthens the connection between the emerging concept and spatial theory. This is realised within the following objectives and methodological steps for a literature review of existing commons theory, urban spatial theory and UK cohousing literature (as illustrated in Figure 1). Firstly, (1) a review of recognised commons literature is undertaken to highlight the defining components of commons in both traditional and urban settings. Secondly, the contemporary urban commons literature is reviewed to identify the implications arising from the application of the commons idea within urban settings. Thirdly, (3) relevant concepts within urban spatial theory are drawn upon to explain and underpin the implications identified within the urban commons literature. Fourthly, (4) a preliminary conceptual framework is outlined to draw together the key concepts that connect urban commons with urban spatial theory. Finally, (5) the concepts are pre-emptively illustrated within the context of residential landscapes using examples from recent cohousing research in the UK.

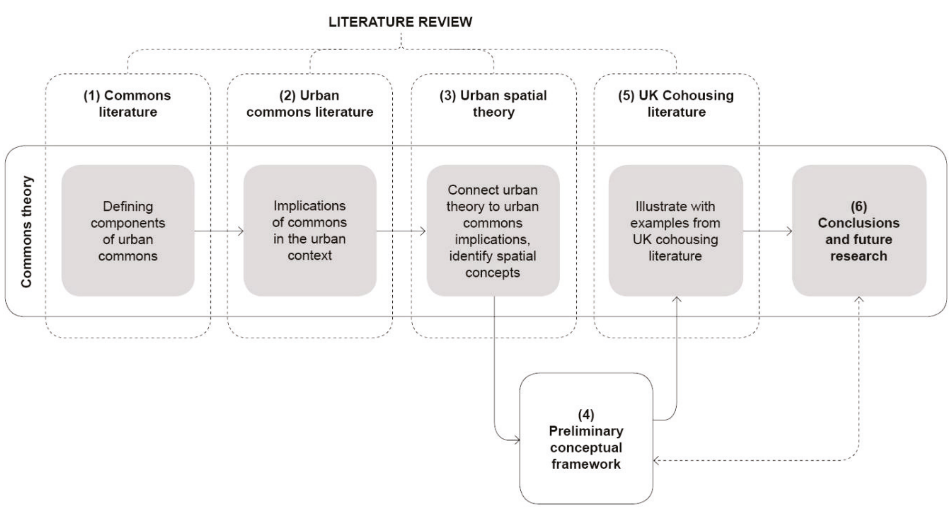

Figure 1. Diagram illustrating the methodological flow for developing and illustrating the conceptual framework from the literature review.

3. Urban Commons: A Review

The urban commons is a concept evolving from the economics theory of common-pool resources [12] and subsequently applied to the context of the city [7–10,40]. This paper draws on the idea of urban commons to conceptualise resident participation in the governance of shared residential landscapes. This section reviews the emerging concept of urban commons and explores its varying interpretations to develop a common definition that can be more readily applied within urban design professions. In doing so, the review highlights a number of implications, as a result of applying commons theory within the urban context, which form the basis for the conceptual framework.

In the UK, a commons is traditionally associated with historical areas of uncultivated land allocated with shared rights such as grazing and foraging. This was the image that Hardin [41] had in mind when he argued that natural resources, such as an open access field shared by unrestricted numbers of people, are inevitably exploited by those working in their own self-interest, leading to the resource's eventual demise. He called this the 'tragedy of the commons', a phrase that formed the argument upon which commons were stripped of their common rights and transformed into private or public access land through successive acts of enclosure. Although the tragedy of the commons is a useful analogy to describe the exploitation of natural resources witnessed today on a global scale, the idea that all commons were destined for self-destruction was successfully challenged by Elinor Ostrom [12]. She highlights that the open access and vulnerable resources that Hardin based his argument on are defined by two key characteristics: subtractable—the ability for a resource to be depleted by consumption—and nonexcludable—difficulty in restricting access to a resource. Ostrom subsequently used the term common-pool resources to describe resources particularly vulnerable to practices of over-use and exploitation. Though common-pool resources reinforce Hardin's idea of a commons defined as a type of shared natural resource, Ostrom's extensive game theory modelling and empirical observations of commons revealed important yet previously overlooked social dimensions. Ostrom identified cases of common-pool resources around the world that demonstrated enduring and self-sustaining qualities. In endeavouring to identify the characteristics that enabled sustainable resource management of common-pool resources, Ostrom discovered that these shared resources were restricted to a defined group of people who actively participated in outlining their own rules, boundaries and agreements, enforcing sanctions and resolving conflicts. The findings, summarised in the design principles for long-enduring common-pool resource institutions [12] (p. 90), outline the need for resource users to have a participatory role in the governance of a shared resource. In doing so, Ostrom's theory contributes essential social and organisational dimensions in defining successful commons, in particular, the need for a defined community of end users and their ability to collectively participate in the governance of a shared resource.

Thus, research on common-pool resources conjures additional meaning for the commons. The term simultaneously describes a shared resource, a social process, collective activity and rules of governance. In searching for a definition of the commons, three essential components are identified from the theory of common-pool resources: 1) a shared resource, 2) a community of resource users and 3) collective governance. Specifically, the relationship between these components is key to defining what make a commons. As Harvey later describes, "*The common is not to be construed, therefore, as a particular kind of thing, asset or even social process, but as an unstable and malleable social relation between a particular self-defined social group and those aspects of its actually existing or yet-to-be-created social and/or physical environment deemed crucial to its life and livelihood*" [40] (p. 73). Harvey reinforces the idea that although a physical shared resource is an essential component of a commons, without its integral social relationship with a defined community of end users and their collective participation in its governance, the shared resource cannot be sustained as a commons. Maintaining a bottom-up approach in the governance of commons is, therefore, a key aspect to their existence, and without the latter aspect of collective autonomous governance, the resource becomes subject to potential tragedies [11,12,40].

Ostrom's early work, based largely in the rural context, validated the commons idea as a sustainable governance approach and established the theoretical stronghold of commons within the discipline of economics. In doing so, her work paved the way to expand the application of the commons concept and its theory to a range of new resources, both physical and intangible, including knowledge [42], the Internet [43], culture [10], and the city [9,17,40,44]. Ostrom's theory and rules for common-pool resources were developed in primarily localised rural contexts, and so the dense human-made environments of the city brought new socio-political contexts for commons to exist within. Hess notes the reinterpretation of commons within a 'new commons movement', denoting a societal desire to take back control of public resources in response to "*increasing commodification, privatisation, and corporatisation, untamed globalisation and unresponsive government[s]*" [13] (p. 3). The movement suggests an expansion of the idea of commons as a form of sustainable and collective resource management to include broader political debates on social justice and promote inclusive open access within the city's spaces. This evolving use of the term commons within the urban context is underpinned by Lefebvre's idea of 'The Right to the City' [45] and later reinterpreted by David Harvey [40]. Harvey emphasises that 'the right to the city' encapsulates not only an inclusive right of access to the cities spatial resources but importantly, includes a right to remake those spaces to suit the needs and desires of those that live there. The argument is formed on an integral relationship between people and their environment. Harvey describes this "*as a right to change ourselves by changing the city*" [16] (p. 23), echoing the words of Berleant, "*what we do in environment, we do to ourselves*" [46] (p. 121) and Alexander et al., "*that towns and buildings will not be able to become alive, unless they are made by all the people in society*" [47] (p. x). Harvey, Berleant and Alexander's words acknowledge the agency afforded to those who are given the opportunity to change their surroundings in deciding how they wish to live and the places they live in.

Harvey recognises an agency over one's environment as being an explicit right. In doing so, he also recognises that within the compact environment of the city, there is a collective right whereby an individual's actions in remaking the environment should consider the impacts upon others. This raises some interesting tensions between the idea of inclusion and exclusion within urban commons. Where Ostrom's common-pool resources are formed around defined communities and enclosed shared resources protected from outside exploitation, Harvey presents a more public vision for urban commons that have inclusive access, collective participation and a shared understanding on a wider scale. Within the urban context, the tensions between insider and outsider, inclusion and exclusion, become all the more apparent due to increased demand for resources and contestation for space. In some cases, enclosed types of urban commons that restrict access or use within urban public spaces, can exhibit characteristics similar to privately owned public spaces, whereby trade-offs are imposed on public use and access [44,48]. Clarifying this apparent conflict between urban commons and public space, Harvey explains: "*There is an important distinction here between public spaces and public goods, on the one hand, and the commons on the other ... While these public spaces and public goods contribute mightily to the qualities of the commons, it takes political action on the part of citizens and the people to appropriate them or to make them so*" [40] (p. 72). In searching for a definition for urban commons and untangling their relation to public space, Harvey highlights that public space is not to be automatically equated with urban commons. Instead, he acknowledges that public space can become an urban commons if a collective, and often political, movement takes ownerships of them. This collective movement can often represent the initial stage in instigating collective governance of a shared resource. It is important to recognise that there is often an inherent tension within urban commons, between public and private, or inclusion and exclusion, and to be aware of who the urban commons is for.

The definition of an urban commons incorporates new ideas of inclusivity beyond the smaller scale, localised communities of traditional commons. As such, they become encapsulated within a political and activist context of 'the right to the city' that calls for equal recognition of all citizens and their influence on one another at the city scale. Despite the addition of broader political debates and social justice discourses, the urban commons retain a relationship between the three essential components previously identified within the definition of a commons. In the urban context, these components can be recognised as 1) the city and its urban spaces as a shared resource, 2) the city's residents as a community of resource users and 3) residents' participation in the city, through political movements or resource management, as a form of collective governance. While the defining components remain broadly the same in the urban context, the unique characteristics of the urban in comparison to the rural suggest that urban commons have distinct differences from their traditional counterparts. In reviewing the evolution of the commons and the 'new commons movement', several differences and implications for the urban common are revealed. Firstly, the differing social dynamics and characteristics that exist within urban settings call for urban commons to form within dynamic, temporal and disconnected populations [49,50]. Secondly, in highlighting the relationship between people and their environment at the city scale, a spatial dimension becomes more apparent within the density of the city, something that has thus far been underexplored in the urban commons literature [18]. Thirdly, the literature suggests that urban commons play a potential role in the production of urban place or city-making [17,40]. Finally, urban commons are implemented within the institutional, legal, and planning frameworks of the city, and thus, commoning groups often require partnerships with various professions, organisations or institutions to negotiate these frameworks [17]. Therefore, this paper echoes the call for a conceptual framework for the commons that deals with the urban, in particular, a spatial and place-based understanding to enable the design and management of shared residential landscapes as urban commons.

4. Developing an Urban Commons Framework

To provide a new urban, spatial and place perspective on the urban commons concept, this paper frames the concept of urban commons around the four implications identified. These include 1) the need for a relatively disconnected and dynamic urban population to work toward a common interest, 2) to understand the spatial manifestations of urban spaces as shared resources, 3) the process of commoning as a potential production of place and 4) the need for commoning communities to work with external professionals and within institutional frameworks. To develop an urban perspective on these implications, the following discussion spatialises commons theory by drawing upon the ideas of informal urbanism, territory, placekeeping and partnerships.

4.1. Working Together as Strangers

To explore the spatial implications of urban commons, the framework begins by looking at what drives their initial formation. Ostrom marks the success of commoning as relying on communities that "*share a past, and expect to share a future*" [12] (p. 88). Therefore, the relatively close-knit and stable characteristics of rural communities compel individuals to work together in anticipation of long-term mutual benefit and trust. In contrast, the city is characterised by a dense saturation of people living as relative strangers [50,51]. Urban commons emerge without the default commonality and established trust of rural communities—a prerequisite to commons formation. Examples of urban commons in recent research demonstrate emergence in response to privatisation and limitations on urban life [52], tenants in danger of eviction [50,53], campaigns against demolition and in support of neighbourhood revitalisation [54] and movement against climate change [55]. These examples suggest that instead, urban commons form in response to a threat, need, desire or ideology. Huron [50] highlights in her research that within the city, there is a dialectic relationship between commons and community formation that differentiate urban commons from their rural counterparts. Community is not a prerequisite to urban commons formation, but rather a simultaneous process of commoning and community formation triggered by a particular urban condition that drives a common mindset.

The organic and emergent nature of commons formation, centred around a common mindset, can be further explained through the idea of a sharing culture [15] and the understanding of the urban context through complex-adaptive assemblage theory [56]. Sharing culture is defined as a shared goal to "*co-produce, manage, and shared resources . . . based on solidarity and reciprocity rather than economic profit*" and "*relates to social networks that grow informally within a region between diverse stakeholders*" [15] (p. 430). Katrini highlights that a sharing culture is triggered in reaction to wider contextual changes, such as a withdrawal of public services, and makes use of and adapts available resources and materials. The city, therefore, provides both a context and a driver for sharing practices, produced from ongoing changes in the relationship between multiple urban influences. Complex-adaptive assemblage theory provides a useful way of conceptualising informal urbanism, considering the city as a larger 'whole' assembled from underlying connections between multiple components that exist in a constant state of change or 'becoming' [56]. Put more simply, the city is a collection of connected elements, such as "*buildings, houses, shops, signs, cops, shoppers, cars, hawkers, rules, sidewalks, goods, trolleys, etc. all come together to become the street* ... " [56] (p. 353). Within the assemblage of elements, of particular importance are the connections between them, "*the relations of buildings to sidewalk to roadway; the flows of traffic, people and goods; the interconnections of public to private space, and of the street to the city.*" [56] (p. 353). The assemblage itself, its components and relationships are dynamic and ever-changing and therefore, the interactions and outcomes unpredictable. Therefore, complex adaptive assemblage thinking helps explore the dynamics of interactions between the many components that make up the city and the emergent nature of informal urban phenomenon. It describes a relationship between parts that are at once independent and unpredictable, yet interdependent, so when a change occurs in the assemblage, all the other parts adapt in response. Practices of sharing culture emerge as a form of adaption in response to other changes within the assemblage of the city and exist within reactive cycles of emergence, stabilisation, release and re-organisation [56]. The common mindset can be understood as a form of self-organised and informal adaption in response to shifts within the urban assemblage, such as the components of housing affordability, vacant land, and privatisation.

So what does this mean for the application of urban commons in the residential context? Significantly, urban commons are not easily predetermined, or in other words, they cannot be readily designed. This is problematic for urban professionals, such as landscape architects, seeking to implement such ideas within residential landscapes through traditional top-down means. In understanding a common mindset as an emergent phenomenon, urban professionals play an important role in recognising and validating the ideology or goals of a group and putting in place available services and frameworks that enable those goals to be achieved. Thus, they aid in reducing friction along the routes towards establishing an urban commons by identifying the barriers and understanding what can enable or support such practices. Overall, what this section of the framework emphasises is firstly the need to recognise and understand the common goal underlying urban commons formation and secondly the supportive, but not determinate, role urban professionals play in it. The ways in which this might happen are explored in the following three sections of the framework.

4.2. A Spatial Understanding of Urban Commons

Urban contexts bring together both social and spatial considerations. The previous section outlines the implications of some of the social characteristics of the urban, living amongst strangers. The current section will now explore the spatial implications. The 'urban' describes a size, scale, density, diversity and temporality [57], all of which are descriptors of the city's physical form. Urban commons, by the definition of what is urban, have spatial as well as social implications [15,40]. To define what is meant by space, this paper looks toward a multi-faceted understanding outlined by Lefebvre: the abstract mental construction of space, the production of physical space, and the experience of living in and through space [45]. Through this understanding, urban commons are recognised simultaneously as being spatially perceived in the minds of commoners, physically conceived through collective action and experienced through everyday occurrences. Urban commons are at once a product of the city and a producer of urban space, concurrently experienced by commoners [45]. Therefore, the implication for the theory of urban commons is that our understanding is not limited to a spatial form created by collective action nor solely a social organisation produced from a spatial resource; rather they emerge from the reciprocal relationship between both—a socio-spatial manifestation. Such a mindset inherently places significance upon the linkage between such social and spatial considerations, which, when viewed within the context of commons thinking, can be reflected upon in terms of territory.

Territory is a form of control that explains the relationship between the social and the spatial. In other words, territory describes a spatial extent, the area within a set of physical limits, and a social scope, demarking who is allowed within the space and what norms are expected within it. Yet, territory differs from formal legal ownership and rights in that it portrays a perceived sense of belonging to a space [58]. A territorial awareness, therefore, not only helps to distinguish between what is mine, what is someone else's and what is shared, but also strongly relates to an individual's awareness of self, self-esteem and position within society. In other words, through their collective actions, commoners can manifest their common mindset, rules and norms into something physical, such as the adaption of boundaries, placement of objects and physical occupation of space. In witnessing this physical expression, it allows individuals to become aware of their own mindset and, furthermore, their position within society by recognition of their actions by others. Honneth [59] considers recognition of self-identity and status within a mutually supporting community as essential for human fulfilment. Landscape theory highlights that achieving this human fulfilment for recognition requires it to occur within a spatial context or territory [24].

Territory, as a manifestation of the relationship between people and their environment through its control is, therefore, expressed both spatially through the adaption of boundaries, placement of objects and occupation, and socially through the rules, sanctions and norms applied to those spaces. The idea of territory, while not explicitly mentioned in commons theory, is highly relevant to urban commons and the common mindset, particularly in relation to territories that express a shared sense of belonging. This perceived sense of shared belonging is described within the MYTO territorial framework [60] as 'ours'. Where 'mine' describes an individual's perception of space over which they have sole control—such as a private garden—and 'yours', a space controlled by some other known person—such as a neighbour's wall—'ours' delineates a space controlled by a group of people of which an individual feels they belong—such as a shared entrance to a block of flats or a community allotment. 'Ours', therefore, represents a terrain requiring cooperation, a consciousness of others and a common understanding and, in doing so allows individuals to feel a greater sense of belonging to a group of people and the place in which they live [60]. 'Ours' as a shared territory provides opportunity for the spatial expression of the common mindset, recognition of an individual's position within the community and developing a shared understanding.

The spatial dimension of urban commons as a form of shared territory lies within the understanding of how 'ours' is spatially defined and what types of spatial infrastructure enable a sense of 'ours' to be expressed more readily. Within the residential landscape, proximity of 'ours' to 'mine' may have several advantages in creating a balance between expressing self-identity in 'mine' and overcoming excessive introspection and settling of differences in 'ours' [58]. In placing shared territorial landscapes near the frequently occupied spaces of private dwellings, there is a provision of more frequent opportunities for territorial expression through natural surveillance, defensible space, physical occupation and appropriation. The spatial configuration of the boundaries between 'mine' and 'ours' enable a balance between privacy or maintaining a sense of self-identity, with publicness, sharing and commonality. The spatial characteristics that enable this balance are described by Martin [61] as 'hide and reveal', a phenomenon observed in residential back alleys that enables a porosity between preservation of privacy and opportunities to be more readily situated in open and social spaces. In this respect, Martin's 'hide and reveal' resonates with Appleton's theory of 'prospect and refuge' [62] in highlighting the importance of spatial arrangements that afford simultaneous opportunity for people to feel protected whilst maintaining surveillance.

A similar relationship, thereby, exists between shared spaces as a form of 'ours' and the wider public realm, a larger scale of 'ours'. The thresholds that define the edges of shared territories are important in defining what kind of relationship urban commons have with adjacent territories. Thresholds can be expressed in several ways, including physical boundaries, symbolic representation, the placement of objects [58], physical occupation [63], maintenance, the temporary adaption of space [64], social norms and group membership [12]. The idea of thresholds crops up in several ways within the commons literature. Firstly in Hardin's conception of the boundless grazing field in danger of exploitation, and then in Ostrom's first rule for common-pool resources—"*clearly defined boundaries*" [12] (p. 90), referring both to the individuals with access and the resource itself. These references suggest the need for defined territorial boundaries surrounding spatial shared resources. However, the more recent 'new commons movement' promotes a shift away from processes of enclosure associated with privatisation and commodification and thereby advocates the removal of physical barriers and restrictive thresholds. The balance between openness and enclosure within urban commons is not a straightforward contradiction to solve. Harvey suggests that not all forms of enclosure are negative and can be necessary in the protection of certain types of shared resources in the complex, often competitive and contested nature of the city [40]. It is important to understand the level of inclusion and openness required in relation to different types of urban commons in spatially configuring territorial boundaries. Residential urban commons, in particular, may require territorial thresholds that define space in relation to the specific community of residents, yet enable wider interaction with the broader neighbourhood. Subtle attention to the height, depth, transparency, porosity and flexibility of territorial edges expresses potential balances between complete enclosure from the outside and undefined openness. The adaptability of such edges also enables commoning communities greater temporal control in expressing not only who is allowed access, but also when. The opportunity for the placement of symbolic markers and physical occupation of territorial thresholds is increased where the spatial depth of a threshold is increased. Described as a 'transitional edge' [60], 'soft edge' [22] or a 'margin' [58], the depth of a threshold can provide additional opportunities for resident participation, shared control and social inclusion.

Whilst some of the spatial concepts mentioned here, such as soft edges [22,60] and defensible space [65] are well recognised within the theory of residential urban design, there application to the urban commons concept is less established. Therefore, careful consideration needs to be given to territorial arrangement in relation to urban commons and how territorial thresholds are best expressed to reflect relationships with surrounding urban contexts. The challenge within the application of this idea into the residential context is who is in control of deciding how territory is arranged and defined. Territory is at once related to a very personal expression of belonging, largely out of control of the urban professional. Examples have shown how territory can be very difficult to assert without the presence of some spatial infrastructure or cues to indicate where individual and shared control begins and ends. Therefore, the role of the urban professional is to determine not only the spatial arrangement of territory and thresholds but also to understand what level of intervention is required of them and what understandings are already in place within the common mindset.

4.3. The Production of Urban Commons as Placemaking

To date, in its evolving definition, urban commons are considered as both a long-term process of sustaining a shared resource [12] and a short-term goal of reclaiming spaces in the city [50]. Huron, identifies that within the urban context, following successful reclaiming of urban resources, there is a need for that resource to be maintained through long-term governance. The adaption of urban spatial resources through their initial acquisition and longer-term governance to suit the everyday needs of urban residents, therefore, influences the spatial, social, political, cultural and material dimensions of that resource. Place is a word that can be used to describe the coming together of the multiple dimensions associated with urban spatial resources. Dovey [56] highlights that place distinguishes itself from space by describing a measure of intensity, such as vibrancy, activity or other qualitative characteristics that the dimensional measures of space cannot portray. In the case of urban commons, place is a useful term to describe the developing product between an urban spatial resource and the social dimensions of collective governance and the process of commoning. Placemaking describes an approach to delivering places in a way that strengthens the connections between people and place [66] and placekeeping is a term that emphasises the role of long-term and ongoing practices of maintenance, management and governance in the creation of place [67]. Together, placemaking and placekeeping describe the process through which urban commons are realised spatially through the everyday activities, perception and participation of end users through collective governance.

The factors that influence *placemaking* are complex and multiplicious. Franck and Stevens [68] use the term 'loose space' to summarise the characteristics that enable people to appropriate and adapt space to meet their needs and desires. 'Looseness' relies largely upon individual people's belief of what is admissible or allowed a belief in their abilities, skills and recognition of new possibilities. Therefore, loose spaces provide physical opportunities for looseness, people's perceived potential to create place, to be fulfilled. According to Franck and Stevens [68], the characteristics of loose space relate to spatial diversity, physical disorder and affordance. Firstly, greater spatial diversity, the variation in physical form, creates increased possibilities for how that space can be inhabited and adapted and by whom. Secondly, physical disorder relates to a lack of regulation, lower surveillance, visible physical deterioration and ambiguity in the control of space that allows individuals increased freedom to take ownership of space. Lastly, affordance describes the ability for physical features to provide multiples uses, the occupation of space enabled by graduated transitions at thresholds and moveable, flexible and malleable elements. While spatial diversity, physical disorder and affordance hinge on increased flexibility and reduced definition, a lack of spatial elements and too much openness can also restrict opportunities. Dovey describes this as a tension between stable, enclosed territories and the absence of defined territorial boundaries [69]. He describes a tension within place that is constantly shifting with spaces having the potential to accommodate new and unpredictable forms of placemaking that stabilise in time toward enclosed territories until the cycle begins again. The crux of loose space and the encouragement of placemaking through forms of urban commoning centres on the provision of spatial form that can be readily adapted and the relinquishment of some level of control, definition and prescription in favour of flexibility, adaption and the unknown.

4.4. Partnerships and collaborations

The urban context creates several challenges for bottom-up movements, such as commons, to take hold, due to the difficulties in navigating its numerous top-down frameworks, such as planning and legal systems [34]. While some urban commoners may utilise knowledge from within their group where they comprise members with professional positions and specialist knowledge, many require support, partnerships, collaborations or consultation with external professions and organisations to negotiate such frameworks. This may be in the form of support, guidance and open-mindedness from housing associations, tenants and residents associations and local councils, or advisory roles and participative approaches from design professions. Within urban commons, there is a shift away from traditional client-professional relationships towards a collaborative or supportive partnership between bottom-up and top-down actors. The placekeeping conceptual framework [70] describes a shift away from a single universal governing body toward a liaison among a variety of stakeholders in the delivery of place. Successful approaches to place governance combine local knowledge, skills, time and resources with external resources, professional expertise and public enablement. Despite these benefits, there continues to be several barriers to community involvement in the design and maintenance of urban residential spaces. A contributing factor to this problem is the polarisation between top-down and bottom-up approaches to design, implementation and management in urban development [25,71]. The predominant top-down approach to residential placemaking in the UK today creates barriers to people focused placemaking and a disjointed and uncoordinated approach to its long-term place maintenance and management [70].

A recent political shift toward localism, alongside austerity measures and local authority withdrawal from the public realm in the UK [55] has created regulatory slippages [17] in top-down placemaking provision that community-led approaches have been able to occupy [72]. Research into this phenomenon, described as 'improvised', 'interstitial' and 'makeshift' urbanism (amongst others) [72], demonstrates a number of potential benefits, including improved quality of space [54,73], social interaction and community cohesion [74], and individual wellbeing and expression of self-identity [75]. However, such examples also demonstrate significant barriers to bottom-up participation in placemaking within institutional, legal and design frameworks [54], a lack of empowerment to influence external authorities and relations [52], and a limited capacity for resources, skills and time [75,76]. Ostrom's last principle for common-pool resources attempts to address issues of scale and power through the implementation of multiple layers of nested institutional rules [12] that enable both top-down and bottom-up approaches to work together. Thus, the success of urban commons relies on maintaining open communication channels from the bottom to the top to enable a common mindset to extend beyond internal relationships to include external professions, organisations and institutions.

The emergence of commons within the urban context not only calls for collaborations between communities and urban professionals but a new facilitating role to enable such change to happen. This can be explained using Arnstein's ladder of participation [77]. The participative relationship between urban commons communities and professions, organisations and institutions is positioned on the top three rungs of the ladder of participation (citizen control, delegated power, and partnership; see Figure 2). Any position lower down the ladder would hinder the commoners' ability to maintain collective participation in devising, monitoring, sanctioning and resolving their own rules [12], a defining characteristic of a commons. Therefore, the role of the urban professional needs to shift to reflect this new relationship, from client-profession to one of supporter, facilitator and partner. This requires a willingness of urban professions to relinquish some level of control and a preparedness to work with the unknown.

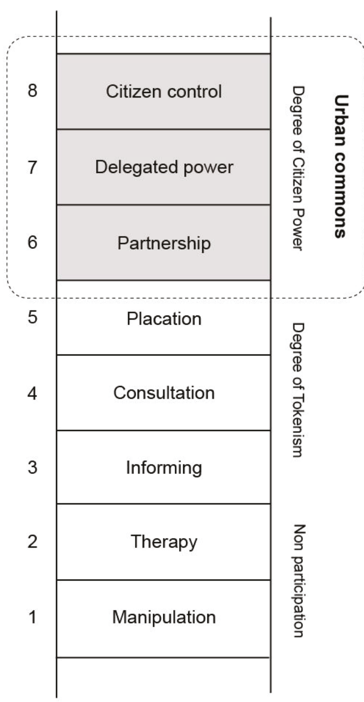

Figure 2. Urban Commons are defined by the collective ability of commoners to participate in its governance, situating them on rungs 6-8 on Arnstein's ladder of participation. Below these rungs, in the zones of 'Tokenism' and 'Non-participation', commoners lack the necessary control to define their own rules, and therefore their status as a commons. Adapted from Arnstein's ladder of participation [77].

4.5. A Conceptual Framework for Urban Commons in Residential Landscapes

This paper defines commons as a shared resource, collectively governed by a community of end users that maintain a bottom-up and inclusive approach to participation. A review of urban commons literature reveals several spatial, social and institutional implications of applying commons theory within the urban context. These include 1) understanding the spatial implications of sharing resources within the city, 2) the enablers of collective governance between strangers in the city, 3) the impact of collective governance on the creation of place and 4) the need for community groups to work within institutional urban frameworks. A preliminary conceptual framework for applying commons theory within an urban residential context (see Figure 3) draws upon various spatial theories in addressing some of these implications. In doing so, this paper outlines four preliminary concepts for applying commons theory to the urban context 1) the emergent common mindset in a complex-adaptive assemblage, 2) a spatial arrangement that reflects a shared territorial perception of 'ours', 3) opportunities for adaption and occupation of space as placemaking and 4) the reorientation of professional roles in delivering urban commons.

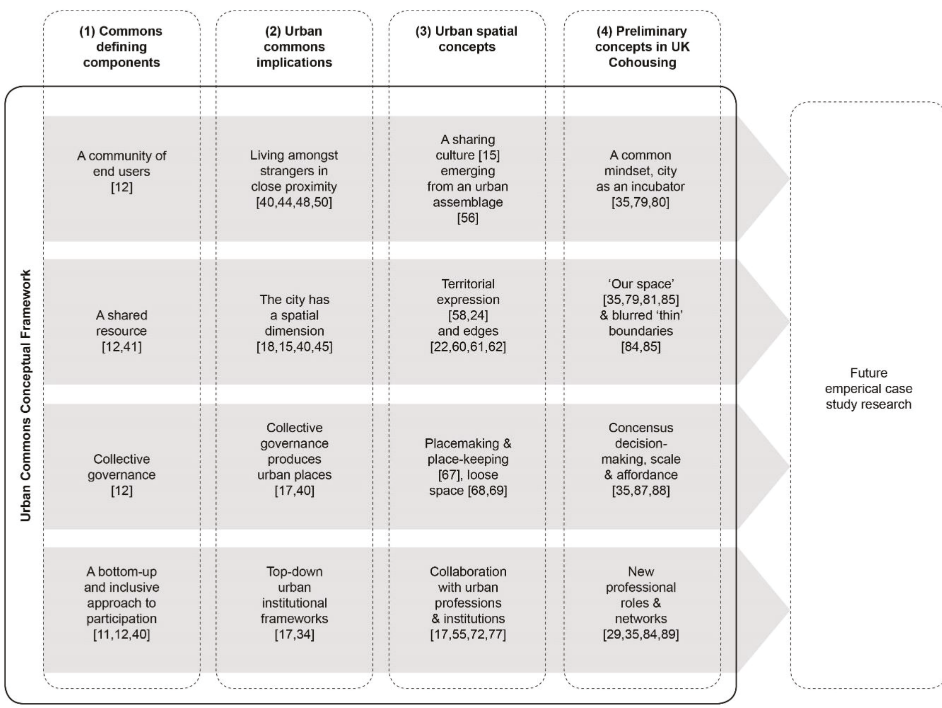

Figure 3. The urban commons framework consists of (1) the defining components of a commons, (2) the implications for these components in the urban context, (3) the relevant spatial concepts and theory in addressing the urban implications and (4) the key spatial ideas for the application of the urban commons in residential landscapes

5. The Community-Led Housing Context

The conceptual framework developed draws together multiple theories in addressing the urban implications of commons situated within the city. The purpose of this current section is to illustrate how this may be achieved in the residential landscape context and reinforce the preliminary framework developed through examples of recent research. The growing sector of community-led housing in the

UK is drawn upon as an example of urban commoning in residential landscapes because it exemplifies high levels of resident participation in the instigation and governance of the site [31,39]. Specifically, this paper looks pre-emptively towards cohousing, a small but growing example of community-led housing, as an example of urban commons within the residential context. This section reviews recent UK cohousing literature to identify examples of how the urban commons framework could manifest within the residential landscape context.

5.1. Cohousing and Its Emergence from a Common Mindset

To understand the *common mindset* concept within the context of UK cohousing, this section first refers to the wider cohousing movement. It is important to understand the broad drivers for cohousing's emergence through a series of similar but contextually responsive ideological movements across the world. According to Meltzer [78], the first wave of cohousing began in Northern Europe (Denmark, Sweden and the Netherlands) in the 1960s and 1970s, propelled by two central beliefs: a communitarian desire to increase a sense of community and a feminist ideology to lighten the load of housework on women and improve the lifestyles of working parents. Transferred across to the USA in the 1980s and 1990s, the borrowed cohousing concept was driven by a striving for stronger social connections and an awareness of the need to build resilient neighbourhoods. This second wave of cohousing saw a number of developments adopting a significant environmental focus and utilising new sustainable building technologies. Cohousing did not begin to emerge in the UK until the late 1990s and has taken longer to establish itself than in other countries [34]. However, a recent revival of cohousing in the UK has seen a broader uptake of the idea. This most recent wave, whilst sharing some of the earlier social and environmental ideologies of cohousing seen in Europe and the US, also highlights a pragmatic economical response to unaffordability and the UK housing market. The overview of cohousing's global emergence suggests that the drivers and ideologies on which cohousing are founded have gone through various iterations, evolving to suit local contexts.

One such case from the literature review that demonstrates a collective response to these varied drivers, in the form of a common mindset, is LILAC cohousing in Leeds, UK. A recent paper [35] describes how LILAC was founded from initial discussions, covering a variety of individual views and expectations that were subsequently concentrated into a single vision for the project. The vision was based upon three core values: low-impact living, affordability and community. Chatterton [35] explains, "*This led to the creation of the acronym 'Lilac' which summed up the social, economic and ecological ambitions of the project*" (p. 1658). This quote suggests that LILAC emerged from similar responses to the global driving forces of previous waves of cohousing, but with a distinct socio-economic focus, endeavouring to ensure that housing remained affordable in the future. Chatterton describes the group's response to housing affordability in the UK as "*the need to challenge an unsustainable housing model and develop an alternative based on economic equality among residents, permanent affordability, demarketization, nonspeculation and mutual co-ownership.*" [35] (p. 1662). LILAC, alongside broader observations of global cohousing movements, emerged from an underlying commonality, a collective desire to work together in response to both global and context-specific social, ecological or economical drivers. The common mindset not only appears to drive forward the project but also functions to attract new residents with similar values; "*its name and values are directive enough to attract residents with a strong commitment to social and environmental justice*" [35] (p. 1665). This quote from the paper describing the lessons learnt from LILAC, reinforces the idea that a shared ethos can help to invite like-minded residents to maintain a common mindset.

Sargisson describes such groups as intentional communities or "*groups of people who have chosen to live (and sometimes work) together for some common purpose. Their raison d'être goes beyond tradition, personal relationships or family ties. They are places where people try to live their dreams on a daily basis*" [79] (p. 34). Intentional communities begin with an initial forming phase [80,81], where a common purpose or common mindset is first outlined. The outlining of common values and goals within LILAC during the initial stages reinforces the idea that the foundations for a common mindset are made during the forming phase of the project. The value of the urban context in providing a significant resource pool for connecting together the necessary people and resources within the same common mindset is also mentioned in the paper: "*Leeds offered a critical mass and a fortunate series of encounters, opportunities and informal networks to bring together active individuals and groups to kick start the idea*" [35] (p. 1659). This highlights a distinct characteristic of the urban context in providing a 'critical mass' and coming together of individuals previously unknown to each other around a shared mindset.

The case of UK cohousing suggests that the common mindset is not a static element, but something that evolves through the phases of cohousing development and occupation. Establishing a common goal at the initial forming phase can play an additional role in creating social bonding, focusing group values and goals [80], reducing community conflicts and enabling harmonious decision making [82]. Research on UK and US cohousing case studies by Ruiu suggests that a common mindset is cultivated among residents' during their collective participation in the design process, also known as the storming phase. " … *residents of communities involved in the research strongly believe that their participation in the designing process promoted more intimate relationships among members and increased their social capital in comparison with their previous situation. This led cohousers to know each other and solve conflicts that arose during the process due to their diverse points of view and needs … spending a long period of time working together contributed to creating their community in both material and immaterial terms*" [80] (p. 405). The evolution of the common mindset continues during the performing phase where shared goals are reinforced, renegotiated and adapted through the self-managed governance of the project. Within LILAC, the evolving shared agreements within the community are recorded by " … *a number of community agreements … devised to provide guidelines for members' individual behaviors, their interactions with others, and the use and management of shared spaces.*" [35] (p. 1661). Ongoing decision-making processes within cohousing ensure that decisions are made collectively and demonstrate how a common mindset might be preserved and adapted over time.

5.2. The territorial Arrangement of Cohousing Centred on a Sense of Ours

Cohousing characteristically combines both private individual dwellings and shared spaces [83], producing an intentional matrix of private, shared and public territories that allow an expression of both *ours* and *mine*. This makes cohousing an interesting case to explore the territorial arrangement of shared residential landscapes as urban commons and the resulting spatial boundaries between the individual, shared and wider public. Although each cohousing development has its own unique layout to suit the characteristics of the site and resulting from the community's input into the design process, cohousing developments share some distinctive spatial features. Many cohousing developments follow key design principles developed by US architects McCammant, Durrett and Hertzman [83] and are based on three typical layouts: linear street developments, clusters of houses around a central space or courtyard, or single buildings with internalised shared spaces [83]. Common to all of these layouts is the central positioning of shared spaces, inward-facing buildings and car parking at the peripheries, as illustrated in Figure 4. These spatial arrangements are based on principles that increase the use of shared spaces and encourage social interaction [6]. Devlin et al. [84], described this in an older women's cohousing where the "*positioning of the entrance hall and common room as the focal point of the whole site and of arranging circulation routes so that paths cross and people are drawn together was fundamental*" (p. 191). This results in a proximity of spaces perceived as 'mine' and 'ours' (Figure 4, (1)), and centralised car-free landscapes that increase the likelihood of social interaction (Figure 4, (2)). To further encourage the utilisation of shared spaces and social interaction, private space (and a sense of 'mine') is reduced [83]. In cohousing landscapes, this is achieved by reducing the size of private gardens in favor of shared space (Figures 2 and 4 (3) and (2)). Some communities found that negating all private space in favor of shared was not desirable, as in the case of the older women's cohousing in a study by Devlin et al. *"But we are all individuals and it was equally important that each separate flat was as private and self sufficient at possible, with its very own little bit of outside space if at all possible.*" [84] (p. 191).

As such, small areas that act as private space are positioned between private dwellings and shared open spaces as a buffer (Figure 4, (1) & (4)).

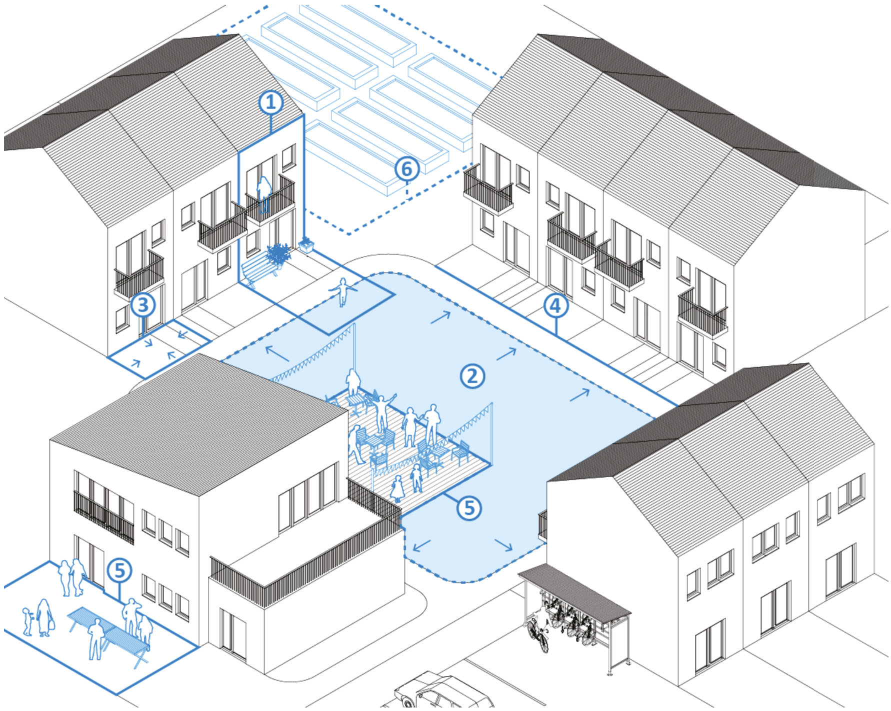

Figure 4. A diagram of a typical 'cluster' cohousing development illustrating the key spatial principles of residential urban commons: (1) proximity of 'mine' and 'ours'; (2) central shared landscape as our space; (3) reduction in private space; (4) thin boundaries between 'mine' and 'ours' (no hedges or fences); (5) flexible shared spaces that afford public events; (6) loose space left for community self-finish.

The central positioning of shared communal space surrounded by private dwellings, typical of most cohousing developments, creates distinct private-communal gradients, similar to, yet distinct from, the public-private gradients within most conventional housing developments (Figure 4, (1)). Ruiu [85] and McCammant et al. [83] observed that the boundaries between the private and communal spaces in cohousing are uniquely thin or soft in comparison to conventional public-private residential gradients (Figure 4, (4)). Higher levels of social interaction, participation in community life, trust and familiarity between residents allow the definition between cohousing residents' private spaces and communal spaces to become more ambiguous. In cohousing, the social blurring between communal and private is reinforced spatially by community agreements that ensure that members keep their front gardens unfenced or free of hedges and gates.

Several authors have highlighted that the cohousing arrangement produces a new kind of territorial realm that is public to residents yet private to outsiders [79,81,85]. The communal spaces within cohousing developments produce a territorial realm that simultaneously represents an 'ours' to cohousing resident and a 'theirs' to those in the wider neighbourhood. Some cohousing groups, attempt to mitigate this feeling of 'theirs' by making facilities available to the local community, running community events and holding open days [35]. This suggests that communal space within cohousing has the ability to become temporarily public through a kind of territorial slippage [69] (Figure 4, (5)) and that the boundaries between 'ours' and 'theirs', shared and public, have a certain permeability. A number of authors reinforced the need for further understanding of the territorial and spatial understanding at the collective scale [81] and its relation to the wider urban public scale [31,86]. Further empirical research on cohousing could provide insight into the spatial and temporal definition of 'ours' and how it can become spatially integrated within surrounding urban neighbourhoods.

5.3. Cohousing Governance as Placemaking and Placekeeping

Cohousing demands high levels of resident participation in the development stages, everyday decision-making and long-term governance of the place in which they live [31,32,39]. In this sense, cohousing residents can be understood to be taking part in a process of placemaking and placekeeping. As well as resident involvement in the design process at the forming phase of cohousing development [80], residents continually adapt and create place through their involvement in its long-term governance. Longer-term aspects of everyday governance are achieved in cohousing through the adoption of specific resident roles within the group, contributions during community workdays and shared meals, group meetings and decision-making processes [35]. Many cohousing groups utilise consensus decision making to formalise the collective governance process, a process by which a potential decision is put forward to a group of people, discussed and then adapted to address individual concerns, until full consensus is reached. As a result of the collective decision-making process, the LILAC paper [35] mentions the production of various community agreements that outline the "*expectations and limits on different aspects of community life*" (p. 1665). "*Members are free to propose a community agreement and it is put forward as a proposal for discussion, amendment and then ratification. These cover areas such . . . management of green spaces . . .* " [35] (p. 1665). In this example, written community agreements demonstrate a more formal approach to addressing decision making around placemaking and placekeeping. While consensus decision making ensures that individual concerns are addressed, gaining consensus within large groups can be time consuming. "*For example, the initial centralised 'Development Group' worked well in the initial years but as the Society grew it could not manage with increased workloads.*" [35] (p. 1665). To address this issue, LILAC developed "*Eight self-directed and participatory task teams [to] undertake routine decisions based on a preset remit in areas such as membership, landscaping, finance, maintenance, publicity, process, community outreach and learning/research.*" [35] (p. 1665). This example stresses the challenge of scaling up decision-making, which is well documented within urban commons literature [11,12,40,87,88]. Similar to Ostrom's theory of nested decision-making within larger scale and institutional commons [87], LILAC demonstrate an approach to the challenge of scale by creating tiered and informal decision making for routine aspects of the project within working groups.

Building in opportunities for placemaking in the residential landscape is an important role of the design profession in cohousing and urban residential landscapes more broadly. One approach in enabling high levels of resident participation in placemaking in cohousing is by incorporating looseness through a self-build or a partial self-finish approach. A self-build approach, where residents take the role of contractors and take on responsibility for the full build, often requires too large a time and resource commitment and high levels of skills and expertise for most residents. Self-finish provides a potential option for those residents by leaving aspects of the development purposively unfinished in agreement with residents to allow participation in the making of their own homes and surroundings. Self-finish is a phrase that usually refers to the provision of an unfinished but structurally integral shell of a house for residents, but could also include leaving the building and planting of landscapes unfinished (Figure 4. (6)). Fishponds road cohousing in Bristol is one such cohousing example that took on a self-finish approach. In a published interview with one of the development's residents [89], the collective self-finish process is described as having social benefits, but also challenges surrounding the balancing of expectations, time, input and guidance. Residents of Fishponds road cohousing addressed some of these issues with 'sweat equity', a term used to measure individual contributions, in the form of building equity or reduced rent, in return for the hours spent in finishing the project.

The above example demonstrates one way in which a balance between community autonomy and professional input can be achieved, however, further understanding is required to address the challenges faced in this area. Hammond [90] begins to address this lack of understanding by exploring ways in which flexibility can be incorporated in his collaborative 'spatial agency' approach to design with an older people's cohousing group in Manchester. He discusses how flexibility in the design of spaces to afford changing uses over time were important to the group he worked with. "*Rather than pre-determining the functions of these spaces, they felt it more important to create spaces with different spatial characteristics that they could appropriate for different uses as they emerged. This position was in recognition that the group's needs would inevitably change as they grew older, but that the types of shared activities the group might want to undertake in the future are unknown to them at present*." [90] (p. 10). Hammond emphasises a need for an understanding of cohousing groups' desire to be involved in landscape management and maintenance from the outset, so that a more collaborative role can be adopted by design professionals and community ideas can be incorporated into the overall design.

5.4. Cohousing, Partnerships with Professionals and Working within Institutions

UK cohousing groups, in comparison to other European countries, have been slow in establishing themselves due to a tendency for new groups to reinvent the wheel [34] and the challenges presented in negotiating top-down frameworks. This is something that Chatterton [35] highlights in LILAC's experience of implementing their social, economic and ecological goals: "*To deliver its objectives simultaneously requires working across a set of complex institutional and governance frameworks and scales, including legal, financial, planning, ecological, community liaison, design and governance issues. The ability to do this is extremely difficult as it challenges conventional wisdom in terms of the functioning of housing markets, land ownership, building fabric choices and community self-governance, which is reinforced by the silos and specialisms that most professions, especially central government departments and large volume housing builders, operate within. The challenge is to strategically build governance frameworks that promote holistic approach*es" (p. 1667). A review of cohousing literature reinforces this call for more widely adopted planning, financial and institutional infrastructures to support cohousing and collaborations between local councils, social and private developers, lenders and cohousing groups [34].

With the rise in popularity surrounding cohousing in recent years, the establishment of several pioneering cohousing examples in the UK, and the community-led housing fund, a collaboration between cohousing communities and outside professionals is emerging to enable groups to overcome these barriers. This has led to the specialisation of some professions in dealing with cohousing groups using participatory approaches to cohousing design and development. For example, the recently completed Marmalade Lane cohousing [91] was built on a collaboration between the local council, a custom-build housing developer, a Swedish sustainable development consultant, architects, and the K1 cohousing group. The emphasis on collaboration, rather than a traditional client-profession relationship, highlights a need for equal input and partnership between the cohousing community and professions, in an attempt to balance power relations. This new facilitating role and emphasis on collaboration and partnership rather than traditionally professional procurement is explored in Hammond's reflection on his facilitating role with the older people's cohousing group in Manchester. He highlights, that whilst cohousing groups are actively involved in creating a collective identity and ethos, they "*are disempowered from exploring the spatial implications and possibilities of these ideas*" [90] (p. 4). Hammond investigates a method for overcoming this disempowerment by developing a new architect—cohouser relationship that enables the social identity of the cohousing group to develop alongside the spatial design development. He emphasises that the design professional be involved at the earliest opportunity and for them to adopt a facilitating and interpretive role.

Working with professionals presents a number of benefits to cohousing groups. For example, Devlin, Douglas and Reynolds [84] highlight the important role professionals have in communicating and negotiating the community's vision within planning frameworks. In addition, partnerships with external organisations and institutions may provide opportunities for broader inclusion of people from a range of backgrounds [85]. Despite these benefits, Ruiu [80] highlights that engagement with top-down processes within cohousing may result in a loss of community control and an erosion of the common mindset that it is built upon. The challenge within cohousing, as in other types of urban commons, is maintaining a pathway for bottom-up communication, a sense of collective control and identity, while at the same time collaborating with external organisations to negotiate urban frameworks. Part of the answer to this challenge may lie in the development of intermediary networks and organisations working on a national scale to support communities, such as the UK Cohousing Network and Community Led Homes organisation [33,92]. LILAC worked with a number of outside professions and networks in order to break these barriers. These included "*the local Green Party who brokered a meeting with the leader of the Council, grassroots organizations such as the Permaculture Network, the Co-operative Development Agency, and Sustainable Futures Leeds who provided early support, as well as founder members who had built up experience in housing cooperatives and community organizing in the city*" [35] (p. 1659). This suggests that intermediary networks and existing contacts from cohousing members play an important role in negotiating the barriers created by institutional frameworks and the groups' ability to maintain community control.

5.5. Summary of Provisional Findings

Up to now, chapter 5 discusses examples found within UK cohousing literature to illustrate the key concepts outlined in the conceptual framework for urban commoning in shared residential landscapes, derived from a literature review. This illustration reinforces the four key concepts within the framework and elaborates upon them to suggest a number of preliminary findings and areas of interest for future research. The UK cohousing literature provides an illustration of the conceptual framework for residential landscape urban commons in a number of ways:

A common mindset and the city as an incubator: Through the initial group discussions that collectively outlined the group's values and goals and cemented them within the project name acronym, LILAC highlights the group's formation from a common mindset. The process of developing shared values and goals establishes a common mindset that enables a diversity of people within the urban context to work together in pursuit of a common goal. This idea is echoed by Huron [50] and Sargisson [79] and helps to explain how urban commons establish the community of end users component within the context of the city that consists of relatively diverse and transient populations. In addition, the LILAC example suggests that the common mindset acts as a magnet to attract residents who share the same values. Chatterton's description of the city providing "*a fortunate series of encounters, opportunities and informal networks"* (p. 1659) suggesting that the city itself acts as an incubator for the common mindset by providing a critical mass of like-minded individuals and potential for dynamic connections and networks. This is reinforced by Dovey's understanding of the city as a dynamic and networked urban assemblage [56].

Our space and thin boundaries: The cohousing literature discussed outlines a number of spatial and territorial ideas around the concept of our space that is central to the common mindset concept. This provides new spatial insight into urban commons as residential landscapes, which is illustrated in Figure 4. Firstly, typical cohousing layouts emphasise spatial arrangements that encourage social interaction, such as a proximity of 'mine' and 'ours' (Figure 4, (1)), central shared landscapes (Figure 4, (2)), a reduction in private space (Figure 4, (3)) and internalised pedestrian circulation routes. This emphasises that spatial layouts that encourage both social and spatial interaction in shared spaces are important for residential urban commons. Secondly, investigation of cohousing research suggests a blurring of territorial clarity between private and shared in cohousing landscapes [83,85]. These boundaries have been described as being particularly thin, something that is both socially and spatially reinforced in some cohousing agreements (Figure 4, (4)). Finally, the research on cohousing highlights a tension between public and shared spaces, which parallels the tensions between open and enclosure within urban commons literature. The cohousing examples suggest a temporal fluidity in shared-public boundaries enable residents' flexibility to briefly open up shared spaces to the wider public, while retaining a sense of community privacy and shared ownership (Figure 4, (5)). These findings are supported by urban spatial theory [22,58,60] that suggests a need for soft transitional edges between territorial boundaries.

Scales of decision-making and affordance: UK cohousing use processes of consensus-decision making, tiered organisation and participatory design processes to enable placemaking and placekeeping in governing urban commons. Larger groups and time required can be barriers to collectively achieving the decision-making required in placemaking. Initial examples suggest smaller working groups and a combination of formal and informal agreements may be required to tackle these challenges. In addition, new ways of building in looseness into the design, such as self-finish approaches, could enable residents to have greater participation in the landscape and balance the need for professional design input and guidance (Figure 4, (6)).

New professional roles and networks: The UK cohousing illustration suggests institutional frameworks and top-down processes remain difficult for urban commons groups to negotiate. Intermediary organisations and networks, horizontal knowledge sharing and design professionals play an important role in negotiating those frameworks and processes. Within the urban context, where institutional frameworks are more prominent, collaborating with professionals may be more important than in traditional rural commons. The LILAC example also demonstrates the necessary support that intermediary networks and existing contacts provide in negotiating urban institutional frameworks. This calls for a new role from urban professionals to facilitate the negotiation. Hammond [90], in particular, suggested that professionals need to be involved at an earlier stage in the process during the development of the common mindset.

6. Conclusions

This paper presents a new conceptual framework that situates urban commons inside the broader discourse of sustainable residential landscapes. This deepens the spatial understanding of urban commons and creates a foundation for further research. To clarify commons terminology, this paper investigates the reinterpretations of the commons concept to provide a single overarching definition comprising of the relationship between four essential components: a community of end users, a shared resource, collective governance and inclusive participation. In doing so, this review also demonstrates the limitations of commons theory in understanding the new urban context in which it is emerging, in particular, a need for an urban and spatial understanding for implementing the idea in shared residential landscapes. This need is addressed by looking toward existing urban spatial theory and examples of UK cohousing research to situate the concepts within the urban residential context.

The findings of this review highlight the potential of the urban context in providing a critical mass of like-minded people and a dynamic potential for networks and connections to drive forward projects involved in collectively managing shared residential landscapes. A number of spatial concepts common in urban spatial theory, such as our space, thin territorial boundaries, loose space and temporality, are connected to residential urban commons to provide new spatial insight into the emerging idea. Finally, this paper also highlights the tensions between bottom-up processes of placemaking and placekeeping with the need for professional collaboration in negotiating the complex institutional frameworks within cities. In observing the emerging practices and limitations highlighted within the UK cohousing literature, it is suggested that a new collaborative role for urban professions is required to facilitate the converging of top-down and bottom-up processes, alongside new intermediary organisations and networks.

The implications of these findings are relevant for residential urban commons groups (cohousing communities specifically), potential external partners, such as planners and urban designers, and researchers. For urban commons groups, this conceptual framework provides an awareness of the common mindset and its purpose, utilising the connections and networks afforded by the city, and the importance of working collaboratively with external organisations. For external partners, this paper highlights a new facilitating role required to carve out new types of relationships with urban commoning groups that preserves their collective identity and ability to self-govern. It also highlights a number of spatial concepts specific to residential urban commons and cohousing that design professionals should be aware of.

The framework itself (Figure 3) lays out the groundwork in joining previously disconnected theories related to urban commons in residential landscapes and guides new lines of inquiry into the spatial dimension of urban commons (Figure 4). The lack of empirical research on this topic to draw on highlights the preliminary nature of the findings developed from a solely review-based approach. By emphasising the lack of spatial understanding within urban commons theory, this paper lays foundations for further empirical investigation surrounding commoning within the urban residential context building from the conceptual framework developed. In particular, the conceptual framework offers a foundation for more comprehensive case-study-focused research that can highlight specific empirical responses to the urban implications highlighted in this paper. For researchers, these preliminary findings open up new lines of inquiry relating to urban commons in residential landscapes. This may include longitudinal research on the establishment, development and potential fragmenting of the common mindset, more detailed empirical evidence of the spatial concepts outlined in this paper, and how these spatial concepts and new top-down roles can be implemented in design practice and in a wider variety of residential contexts. Finally, the broader potential and application of the conceptual framework should be explored. In particular, urban commons have previously been linked as a potential component in building resilient cities [93–95] and therefore, the framework has potential for application to wider urban challenges.

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Comparing the Residential Sustainability of Two Transformation Models for Chinese Urban Villages: Demolition/Relocation Market-Oriented and New Rural Construction

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Abstract: In China, large-scale urban village transformation has profoundly influenced the residential sustainability and interests of indigenous villagers. Local governments have widely adopted a demolition/relocation market-oriented model (D/RMM) for transformation of most of the urban villages (UVs) in China. During the D/RMM process, the interests of indigenous villagers have generally suffered to a certain extent. Originally, the new rural construction model (NRCM) was only used to improve rural development and sustainability. However, it has now occasionally been applied in the UV transformation process to safeguard and guarantee the interests of the village collective and villagers. Given the considerable difference between the two transformation models, we explored the sustainability and impact mechanisms of residential landscapes in terms of housing condition sustainability, community environment sustainability, and livelihood sustainability, through the cases of Beimiantan New Village (BNV) with NRCM and Xiaoyantan Village (XV) with D/RMM in Lanzhou, Gansu, China. The research findings reveal the differences in institutional design and social influence, and changes in the redistribution of benefits between the two transformation models. Overall, the residential sustainability of NRCM is higher than the D/RMM's. Meanwhile, the influence factors in the residential sustainability of the two transformation models can mostly be attributed to three aspects: (1) Land development rights allocation models and earning redistribution fundamentally affect villagers' housing condition sustainability; (2) The collective economy and the informal economy are the potential drivers of sustainable village community transformation; (3) Informal institutions and village social networks protect and continue the social capitals in village. Specifically, the NRCM in BNV has the following advantages in improving residential sustainability: (1) Collective land assets can be further activated; (2) Villagers' vested interests are largely safeguarded; (3) The main role of social low-rent housing and informal employment places in the original village is optimized to a larger extent; (4) The original villagers' social networks remain stable and intact. In summary, villagers' rights are maintained and enhanced via informal institutions, informal economies, and original social relationship networks are completely preserved through NRCM in BNV, as much as possible. Therefore, NRCM can maximize the villagers' interests, that may be conducive to residential sustainability in the transformation of China's urban villages.

Keywords: urban villages transformation; residential sustainability; new rural construction model (NRCM); demolition/relocation-oriented market model (D/RMM); sustainable livelihoods

1. Introduction

The residential landscape, the environmental landscape of residential zones [1–3], includes residential buildings, residential artificial environment landscapes, natural environmental landscapes, and facilities (i.e., the external space environment). In a broad sense, residential landscape sustainability refers to the livability of the residential environment [4,5]. In a narrow sense, it also includes the improvement of residents' housing conditions and the sustainable livelihood issues supporting their quality of life [6,7]. The latter is an important aspect of the residential sustainability of residents, because good residential landscape reconstruction must balance the relationship between residents' public guarantee needs and individual livability needs [6–9]. However, from the perspective of urban village transformation, existing research on residential sustainability remains scarce. The insights gained from the "urban renewal movement" with respect to large-scale transformation have long been a focus for scholars in Western countries [10–13]; while the landscape of the urban village (UV) is unique in China, the research into it has long been on a limited scale. Against a background of urban suburbanization, industrial decentralization, and rural urbanization, many rural settlements and communities have passively been involved in industrialization and urbanization in China. Original rural settlements are surrounded by urban construction land, resulting in mixed communities with a typical urban-rural dual structure, known as urban villages (UVs). The UVs' economic form is embodied by the exogenous rental economy based on self-owned houses and collective properties, and the social structure is an acquaintance society based on consanguinity, kinship, and informal institutions. In reality, their essence is still a traditional rural social settlement.

Current UV transformations are mainly characterized by three models in China: market-oriented, government-oriented, and village collective-oriented. Most UVs have been transformed based on the market-oriented model in China since the opening and reform in 1978. Firstly, the opening and reform was a national economic reform policy in China that was initiated by Deng Xiaoping (a famous leader in China) in December 1978, and included internal reform and external opening up. The internal reforms mainly involved the adjustment of relationships of production, whereby the state established the household contract responsibility system in the villages and decentralized the state-owned enterprises' autonomous management rights in the cities. External opening up to the world refers to the establishment of a socialist market economy and a special economic zone in Shenzhen and the subsequent implementation of special opening policies in Guangdong and Fujian provinces by the government. Since then, an open pattern comprising the special economic zone, coastal open cities, coastal economic open zones, and inland has formed in mainland China. Through the implementation of the above measures, urbanization and marketization in China have been promoted. Accordingly, the UV phenomenon is a prominent product of China's rapid urbanization. As the frontier of China's economic reform, the eastern coastal zone, especially the Pearl River Delta, is the most representative region of China's UV phenomenon, because it is the first region to have experienced the reform and opening up policy and rapid urbanization in China. For example, Qianshan village in Guangzhou and Yangji village in Zhuhai were successful in attracting developers of UV transformation, by means of the circulation of collective land through bidding and auctioning. Since then, other provincial governments across the country have followed this model. However, due to the lower marketization level in the less developed western regions in China, the transformation effect is not ideal in the regions. The government-oriented model is traditional, mainly referring to the fact that the community resident committee replaces the community villager committee, such as in rural-to-residential apartment construction. However, due to the limited financial resources of the local government, this model sometimes faces a bigger capital investment problem. As a result, this has only been implemented on a small scale. The village collective-oriented model means that the village collectives undertake transformation work alone; they determine the compensation standard and resettlement rate for demolition, and raise funds for completing the transformation. Until now, a few cases with sufficient investment capacity of villagers have appeared in small-scale villages. Although these villages have independent development paths and organizational structures, they are all based on the accumulation of collective economic means, regarding the redistribution of rights or interests and the transformation of governance models as the turning point of sustainable community transformation. This provides development opportunities for rural industrialization in rural areas. A typical example is what are known as the "industrial villages", which rely on township and village enterprises in the Yangtze River Delta. Additionally, the villages with these transformation characteristics are also called "new collectivist villages" because they have preliminarily carried out village unitization during the UV transformation. Obviously, the new rural construction model (NRCM) introduced in this paper belongs to the third model. However, different from the previous transition of industrial villages, the model promotes the transition of commercial villages through a rental economy.

Traditionally, the large-scale demolition/relocation market-oriented model (D/RMM), predominantly applied by developers, was the mainstream method of UV transformation [14]; however, this is an unsustainable reconstruction model. Should UVs be removed? UVs have played and will continue to play an important historical role in the urbanization process in China [15,16]. First, UVs provide a lower threshold of access for the rural floating population than living in cities. With the rapid urbanization of China, much rural floating labor has flowed into the city, yet the government is unable to cover the demand for low-rent housing for such a large low-income group. As a consequence, the low living costs of UVs absorb a large amount of the rural floating population, making UVs the main absorber of the rural floating population, bearing the huge social costs of the high-speed urbanization process in China. Second, the prosperous rental economy and informal economy provide a power source for the accumulation of livelihood assets for indigenous villagers in UVs [17], creating the basic material conditions for their ultimate transformation into urban residents [18]. Therefore, UVs cannot be artificially eliminated, but the government and some related stakeholders should spare no effort in promoting their sustainable development. We assume that the issue of sustainability in UV transformation not only refers to the improvement of the living environment, but also to achieving livelihood sustainability for the villagers. The following key issues must be considered: (1) How to realize the employment and resettlement and social guarantee of landless villagers? (2) How to maintain the healthy follow-up development of the original village economies? (3) How to continue the main role of low-rent housing and informal employment places played by the original UVs?

In November and December 2018, and in February and March 2019, we conducted, respectively, a preliminary investigation and a formal investigation in villages included in the UV transformation project of Lanzhou in 2018. These villages had been, or were about to be, transformed, and most of the villagers were resistant to the involvement of developers or had different degrees of dissatisfaction or concerns about their life and work conditions after the transformation. Only villagers in Beimiantan New Village (the original village was named Beimiantan Village, and the village following the transformation was renamed Beimiantan New Village) were highly satisfied with their overall production and living conditions. Even many women who had married people outside the village brought their families to settle down there. This phenomenon interested us greatly. Through further investigation, we found that the village adopted a new rural construction model that the village collective and villagers spontaneously organized against a background of land expropriation. Although this model was proposed by the Chinese central government in 2005, it has mainly been applied to administrative villages and outer suburb villages far from cities, and it rarely appears in UV transformation. UV transformation mainly adopts a market-oriented model in China, and the new rural construction model (NRCM) has not been applied in the past. Therefore, the purpose of this study is to compare and analyze the residential sustainability of NRCM and D/RMM, focusing on the transformation model based on the power of the people, and to further fill the gap in previous studies, which have mainly focused on the role of the government and developers in UV transformation. In this context, we aim to answer the following questions. In urban village transformation, which model has higher residential sustainability: NRCM or D/RMM? Which aspects of residential sustainability are embodied in the two models, respectively? What are the impact mechanisms behind them? Moreover, in future UV transformation, more attention should be paid to the relationship between citizens, indigenous villagers and the floating population. To ensure productive resources integration and property rights privatization, the government should establish supporting laws and regulations that are conducive to defining land property rights. For example, some specific issues should be the focus, such as how the collective land enters the market and how to legalize the construction of houses with limited property rights and so forth. Promoting transformation with the help of non-market folk society power is a sustainable method and a valuable tool for future research.

2. Literature Review and Theoretical Construction

2.1. Analysis Based on the Theory of Sustainable Livelihoods

The term "sustainable livelihoods" was first introduced in the report of the World Commission on the Environment and Development in 1991. The most universal concept proposed by Chambers and Conway [19] refers to the ability of individuals or families to earn a living based on capabilities, assets (including reserve stocks, resources, right of request, and ownership rights), and activities to improve their long-term living conditions. Scholars from several research institutions such as the University of Sussex Development Institute (IDS) have made remarkable contributions to the livelihood issues [20–22]. The livelihood framework focuses on the micro-level on the complex local vitality of livelihood structure as well as the diversity and initiative of people's livelihood channels [20,23,24]. It focuses on rural development issues from the dimension of poverty reduction [25]. The theory incorporates interdisciplinary concepts and elements such as neoclassical economics and new institutional economics, with particular attention on the effects of the institutional process on adopting strategies and achieving goals for human beings. In practice, the farmer's household is usually regarded as the research unit [26,27].

2.1.1. Rural Areas: A Field of Livelihood Construction

Globally, rural areas have high incidence of poverty and livelihood inequality [28]. The sustainable livelihood approach represents a change in rural development concept and discourse, advocating the creation and promotion of local capacity, vitality, and competitiveness through local resource mobilization [29,30]. In the livelihood framework, the village or community is the field of livelihood construction. It not only provides the background for livelihood development, but it is also the space for production and reproduction of various livelihood assets. Rural ecology, geography, complex institutions, and other conditions have not gained enough scholarly attention yet, but these factors have implications for people's livelihood strategies and paths [20]. With China's rapid urbanization spreading to rural society, the UV phenomena and the rural floating labors are common. Therefore, villagers' sustainable livelihoods are no longer confined to rural areas and the use of local resources. The strategy of cross-regional livelihood construction concerning rural and urban areas will become mainstream [31]. To a certain extent, this is a manifestation of a new rurality that may better guarantee the sustainable livelihood of villagers.

2.1.2. Villagers: Actors to Adopt Multiple Livelihood Strategies

The livelihood framework focuses on the initiative of villagers. From the perspective of structuralism, such as Marxism or New Institutional Economics, villagers are usually regarded as passive subjects who are always being sacrificed [32]. In actors theory, villagers are regarded as social actors who have initiative and can use various resources to actively construct livelihood strategies [33]. The livelihood framework also focuses on the heterogeneity of villagers and dynamic changes in their livelihood strategies. This perspective concentrates on how villagers can maintain rural life and small-scale peasant economy through livelihood diversification. For landless villages in UVs, their sustainable livelihood has the following characteristics: (1) Continuity, the current state can extend to the future and have ability to develop and change in the future; (2) Development, it is the fundamental aspect of sustainable livelihoods. Only when the livelihood of landless villagers develops can their living conditions be improved; (3) Justice, because landless villagers make contributions and sacrifices for urbanization—only by guaranteeing their livelihoods can they improve the residential sustainable in UV transformation.

2.1.3. Homestead: The Most Important Livelihood Asset of villagers

An important aspect of the livelihood framework, villagers rely heavily on various assets, and the accessibility of these assets has substantial influences on their livelihoods [25]. The homestead is an important asset, and is vital for the diversity and sustainability of villagers' livelihoods. Specifically, from the perspective of livelihood, land issues are reflected in the following dimensions: First, livelihood framework analysis is concerned with the roles of institutions, organizations and policies, exploring the impact of social structure on access to land resources [34]. Second, from the perspective of actor initiatives, the focus is on the micro-practice of land resources' allocation, combination and utilization, and the related power and political relationship [20]. Local features and complexity cannot be ignored in UV transformation. Additionally, attention should be paid to the impact of land marketization on villagers' livelihood [35]. The low-rent housing economy and informal economy in UVs are important livelihood assets of landless villagers.

2.2. Demolition/Relocation Market-Oriented Model of Urban Villages

D/RMM is a mainstream model based on overall demolition and reconstruction in current UV transformation, and reflects the capital operation logic. It is guided by the principle of "who invests, benefits". Firstly, the local government expropriates the village collective land and converts it into nationalized urban construction land. After that, the government adopts a thorough marketization path by circulating land use rights, namely, all land parcels are publicly tendered and auctioned, and sold to real estate developers [36]. In the transformation, the land is divided into three types: The first type is the construction land parcel, which is mainly used for real estate development. The second type is the rebuilding land parcel, for constructing villagers' resettlement houses; meanwhile, developers will provide one or two sets of "rebuilt houses" for each household of landless villagers. The third type acts as public financing land for UV transformation. The government identifies the land transferee, and raises transformation funds through collective land use rights transformation. However, as a result of the transformation, low-rent houses in the UVs disappear and are replaced by a large amount of high-price commercial houses, from which the real estate developers profit. This has considerably increased the living cost of landless villagers and the floating population. Subsequently, these low-income groups are forced to lose their guarantee of survival, and UVs are stripped of the benign social function of providing low-rent houses [37,38]. Moreover, D/RMM has a negative attitude toward UV chaos and disorder—it advocates one-off large-scale demolition and reconstruction and emphasizes functional zoning and use purification. Additionally, the model lacks villagers' participation and decision-making in planning and implementation, and reflects the tenure goals formulated by government departments, even ignoring the actual situation in UVs and landless villagers' actual needs to some extent [39]. This model is not conducive to the sustainable residential development of the villagers, which is manifested in the following ways: (1) The original economic operation mechanism of UVs is destroyed. The low-rent housing economy and the informal economy in UVs provide living space and employment opportunities for local residents. Single large-scale demolition and reconstruction deprives landless villagers of the opportunity to obtain income from collective land and their homestead in the urbanization process. This means that the model deprives them of a stable income source. Self-employed commercial shops, which provide income for low-cost operators in UVs, are largely demolished and has caused economic depression in UVs and surrounding areas, which destroys the economic vitality of original villages. Subsequently, massive amounts of low-income groups face unemployment. (2) The original social capital of UVs is reduced. UVs have accumulated a large amount of social capital, mainly through the social relationship networks of villagers, informal institution and the interpersonal trust environment built up by local villagers over a long time; it is the best soft asset for landless villagers in terms of maintaining sustainable livelihoods in the passive urbanization wave. China's villages are acquaintance societies based on the village-community relationship networks. Consequently, the social capital of UVs mainly comprises relationship resources that depend on the original acquaintance circle, whose traditional logic is an informal institution that is maintained by traditional ethics, family networks, interpersonal relationships and folk credits. Chinese traditional villagers are characteristically ill-informed and conservative; they are more willing to maintain strong ties based on consanguinity relationships, geographical relationships, and kinship than to develop external weak ties. In addition, landless villagers, rural floating population, low-cost operators and consumers take what they need from the social capitals of the UVs. Hence, UVs provide an indispensable living space for low-income groups. This stable supply–demand relationship also represents the vitality of existence and development in the UVs. No matter which form is adopted to demolish UVs, the original village social networks are damaged, which means that landless villagers are unable to obtain the necessary buffer and protection against the rapid impact of passive urbanization [40].

2.3. Construction of a New Socialist Countryside

China has attempted to improve the rural settlements and villagers' residential sustainability. Before the reform and opening up, the most influential government efforts included the rural construction movement and the new socialist countryside construction in 1950. These strategies aimed to improve villagers' living quality, rebuild community organizations, and adjust rural production relationships through the agricultural cooperation movement, and promote productivity development [41]. When Chinese worker–peasant and urban–rural relationships entered a new process that needed to be restructured [42–45], the Fifth Plenary Session of the 16th Central Committee proposed strategic measures of a new socialist countryside construction in the outline of the 11th Five-Year Plan in 2005 [46]. The biggest difference between the reaffirmed concept and one in the past is that this construction focus on resources reintegration and the residential sustainability of villagers.

The main characteristics of new socialist countryside construction are embodied in centralized human power, material resources, and financial resources, and uniform planning and implementation. The whole construction follows the principles of "villagers oriented, village collective undertaken, town government led" [46]. The specific implementation methods are as follows: (1) Before the implementation of the project, the village committee conducts a uniform opinion poll of the villagers in the villagers assembly, and the agreements are signed for dismantling old houses and building new houses; (2) The town government conducts uniform planning and construction. The town government uniformly formulates new rural construction planning and deploys the project implementation tasks. There are two construction strategies. First, the villagers build their own houses according to the uniform plan. The government subsidizes housing construction funds and allocates building areas. Generally, the building area of each household is 100 m^2, and the type is three-storied. The villagers pay for the expenditure by themselves beyond the scope of the amount of the government subsidy. The surrounding greening, water, and electricity infrastructure are equipped by the government. Second, the government organizes housing construction and then sells houses to villagers at a lower price with certain subsidies. This strategy is mainly used for relocation planning of poverty alleviation. In brief, the above two situations do not change the nature of the villagers' land ownership, that is, the land is still owned by the villagers collectively; (3) The town government provides and divides homesteads for villagers. The town government, as the planning department, reasonably determines the locations and scales of house construction, defines the building standards and homestead areas in strict accordance with the relevant regulations of the all levels of government; (4) The construction units build a uniform infrastructure for new villages. The construction unit shall be determined by public bidding. The successful bidder for the construction units subsequently builds public infrastructure such as roads, power grids, water, and sewerage in the new villages; (5) The village committees uniformly conduct the homestead arrangement. After the demolition of the old villages, the village committees sort the homesteads of the old villages into cultivated land.

The current new rural construction still has the following problems in terms of villagers' residential sustainability: (1) Many young and middle-aged laborers from villages live in cities for their job, then rural hollowing appears [47]. Driven by economic marketization and the urban–rural income gap, many young and middle-aged laborers flow into cities for jobs, and the people remaining in the new countryside belong to vulnerable groups such as the elderly and children. (2) Many villagers are more inclined to move to a city and buy a house than to move into a new rural community due to the value increase of house in cities, whereas rural houses have little space for appreciation; (3) The atmosphere of local rural life is insufficient. Formalist planning neglects village diversity, which results in the phenomenon of "thousands of villages having similar faces", in which villagers lack the traditional local rural atmosphere, and even the original rural life form is difficult to maintain, due to the loss of the young and middle-aged population. Above all, this affected rural development sustainability. (4) Economic driving forces are lacking, and investment and financing channels are blocked. The new rural construction mainly aims at relatively poor outlying villages, where collective economic strength is weak. As a result, most villagers leave the villages for jobs in the cites; hence, the impetus of planning and construction impetus in village is insufficient.

3. Materials and Methods

3.1. Case Study Area

In Lanzhou, UVs are mainly distributed in the four municipal districts, that is, Chengguan, Anning, Qilihe and Xigu, forming a dual-nuclear cluster center, Chengguan-Anning, and several secondary centers. With rapid urbanization and integration of construction land in the urban area of Lanzhou since 1990, a total of 83 UVs are divided into four types needing to be transformed: transformation on the original site, transformation on the relocated site, partial transformation, and comprehensive transformation. Among these, transformation on the original site is the most common, followed by transformation on the relocated site. Yantan (YT), subordinated to the Chengguan District, is one of the places where the land value-added benefits increased the most in Lanzhou, and has a superior location. Before 1990, it was only an important agricultural area in the suburbs of Lanzhou City, with growing of vegetables and apples being its main industries. Subsequently, with the establishment of the Lanzhou High-Tech Industrial Park in 1992, the land of Yantan was quickly expropriated as urban construction land, resulting in a rapid increase in land values. Meanwhile, the rapid urbanization of Yantan also produced 15 UVs, including Beimiantan New Village (BNV) and Xiaoyantan Village (XV). When the regional renewal development and UVs transformation are placed on the agenda, these UVs may face the dilemma of land expropriation, house demolition, and resettlement compensation of indigenous villagers. This study selects BNV and XV as case studies because of the two villages' unique characteristics. First, they are both located in the core area of Lanzhou, where land value-added benefits are huge. The distribution of land value-added benefits has attracted the attention of different stakeholders, including the local government, real estate developers, the floating population, and indigenous villagers. Second, the two villages have similar characteristics in terms of population distribution, family structure and occupational composition, which makes residential sustainability comparable. Third, both villages have detailed data that can be obtained, and thus, they are relatively complete transformation samples.

In China, BNV is a rare "UV" that was experimentally transformed by adopting the new rural construction model in the city center. Located to the northeast of Yanbei Street, Yantan (Figure 1), the village covers an area of 51.89 hm^2. In around 2004, the BNV village committee assigned some members to Xi'an and other places to investigate the experience of new rural construction, especially to learn how to activate collective land assets in new rural construction. Then, village committee cadres entrusted the Gansu Urban Rural Planning and Design Institute with planning the first and second new villages and signed house building agreements with the villagers. By 2006, the villagers were under uniform supervision to build new villages on the original site. In 2007, faced with disputes over the lack of homesteads for the married women in the village, the village committee established a third new village for them. This village is mainly inhabited by married women and their families, who are still registered as permanent residents in the BNV, so it is also called the Women Village. In 2007, the community village committee was transformed into the community resident committee, administrated by the Yanbei Street Office. The new village promotes community economic cooperation, the joint stock institution, village-owned enterprises such as the Yantan Pipeline Market, the Beimiantan Heating Station and Beimiantan Commercial and Trade Co., Ltd. (Lanzhou, China). These enterprises not only create employment opportunities for villagers, but their demand for space also further expands the market, renting the first floors of villagers' houses as warehouses. The transformation parcels were divided into three parts. After some of the village's land parcels had been expropriated by local government, villagers used land expropriation compensation as a new rural construction fund. The second part comprised villagers' homesteads, which were used as the uniform new rural construction parcels. The surplus parts were used as reserved collective land parcels to promote collective economy development and to provide a guarantee for the villagers' future life. This transformation model is greatly reliant on the willingness of landless villagers, namely, that they wish to be resettled on the original site and acquire the same residential area as before the transformation. Nowadays, villagers rely on informal economies such as self-owned house rental and self-employed commerce to create considerable profits. This economic structure has undergone a transformation in marketization towards "making money by the rental economy".

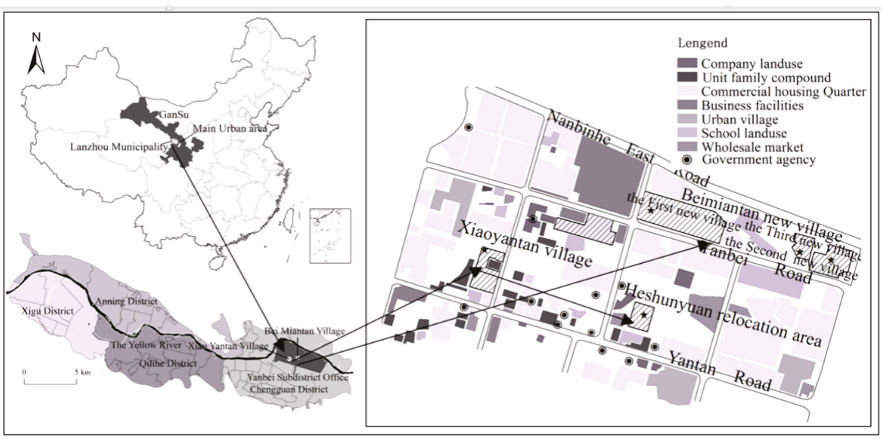


Figure 1. Location and spatial elements of the urban surrounding of the two urban villages.

XV is a community under the jurisdiction of Yanbei Street, Yantan, Lanzhou City (Figure 1), with an area of 46.83 hm^2. Although XV has the same transformation background as BNV, local villagers made a living in a completely different way from the villagers in BNV before capital entry. The village underwent two rounds of farmland expropriation in 2005 and 2010 due to government road construction demand. By 2014, the village had become a village without agricultural production, and villagers earned money by renting self-owned houses, as well as the village collective storefront rental market. Once the economic rationality of villagers was awakened [48], they rebuilt and renovated their self-owned houses to expand the rentable house areas and obtain greater benefits. The Lanzhou Yantan secondhand goods market is also a typical example of the village collective outsourcing land to outside contractors. The village committee established a market on this land, and then rented the market storefront to merchants everywhere, from which they collected rent. The village is one of the earlier urbanized villages; meanwhile, it is the most difficult urbanization area in Yantan. The transformation faces difficulties because the interests of the different stakeholders with respect to demolition compensation are hard to balance. The village's developer is Lanzhou Jinhang Hongyan Real Estate Development Co., Ltd.(Chengguan district, Lanzhou, China), and the construction of the resettlement area is divided into two phases. At present, the Heshunyuan residence zone, which is the phase I resettlement area, has been completed, and 902 villagers whose houses had been demolished have been resettled. The phase II project is still in progress.

3.2. Survey Design and Data Collection

This study examines residential sustainability in UV transformation through field research and factor analysis method. The sustainability scale design for the two models is an important research foundation. Although there is no flawless survey scale currently available for this topic, the related research provides references that could help us to advance this work [49–63]. On the basis of relevant research and discussion, we propose a conceptual framework for the evaluation of residential sustainability based on housing conditions, the community environment, and livelihood. With respect to sub-indicators of housing conditions, we referred to relevant studies on the housing conditions of rural floating populations and indigenous villagers in UVs [49–54], supplementing the sustainability content with previously available indicator structures. As for sub-indicators of community environment and livelihood sustainability, we specify indicators on the basis of precedents related to the evaluation of satisfaction in UV transformation [53–63]. A household questionnaire survey method was used, combined by further interviews with 13 villagers and 5 village committee cadres to gain in-depth understanding of the relevant background context. Beginning with a preliminary investigation in November 2018, we officially completed the formal research work in February and March 2019. It is a common phenomenon that many relatives with consanguinity and kinship live intensively in large families in China's villages. Although large families underwent relocation, villagers disengaged from their original family and made up new families after UV transformation, still living in the same resettlement area. Against this background, in order to reduce the possibility of selected objects belonging to the same large family, we firstly obtained a list of household heads' names with the help of village committees. Then, we conducted a household questionnaire survey and adopted an equidistant sampling method according to family address, and randomly selected households to ensure that there was an equal probability that every household could be selected. Meanwhile, we asked for the household heads' names, and noted them on the list in case of repetition. The content and structure of the questionnaire included basic family situation and a residential sustainability survey of the villagers. After the transformation, BNV comprised 670 households, with a permanent population of 2280; XV comprised 634 households, with a permanent population of 2120. Therefore, 134 and 127 questionnaires, respectively, should be distributed in the two villages, in accordance with the standard ratio of 1:5. A total of 260 questionnaires were distributed and 252 were recovered, of which 240 questionnaires were valid, representing an overall effective recovery rate of 95.2%. The following is a detailed explanation for the residential sustainability scale indicators.

(1) Interpretation of indicators of housing condition sustainability

We selected five indicators to reflect the housing condition characteristics in this study, the specific weighting and assignment methods of each indicator are shown in Table A1. (1) Housing ownership index (HOI). Property rights of houses and housing source are selected as its sub-indicators, wherein the property rights of houses define the owner's right to possess, use, benefit and dispose of the property, with housing source also reflecting the property right relationship, to a certain extent. (2) Housing crowding index (HCI). We use per capita residential area (m^2) and housing structure to measure this. The division method of per capita living area refers to *GB 50180-93 standard of the Code for Planning and Design of Urban Residential Areas*. The housing structure is measured based on the whole set rate of the building. Generally speaking, the higher the number of complete sets in newly built houses, the higher the quality of the houses. (3) Housing privacy Index (HPI). We adopted housing privacy and housing function to measure this index. In general, if the houses' privacy is high and the houses only carry out a residential function, the villagers' residence will be disturbed to a lesser degree. (4) Housing facilities index (HFI). On the basis of a method of measurement found in the literature [54], we establish three sub-facility indexes to measure HFI. The overall level of HFI is the sum of following three sub-indices: basic facility index, intermediate facilities index and advanced facilities index (Table A1). Notably, we updated facility items according to the difference in the housing conditions of the resettled communities. The 7 items belonging to the former index cover basic facilities (including tap water, power facilities, natural gas, heating, flush toilet, water heater, water supply and drainage facilities), and each item scores 1 point. Items 8–14 are intermediate facilities (including lighting, fire fighting, elevator, parking lot, garbage collection, gate guard and monitoring, broadband network), and each item scores 2 points. Items 15–21 are advanced facilities (including fitness and entertainment venues, cultural and sports facilities, educational facilities, community parks and squares, medical facilities, business services, landscape and sitting-out areas), and each item scores 3 points. Specifically, we listed the above 21 housing facility items in our questionnaire; respondents then selected the corresponding facilities possessed by their families, or with which they were equipped in the community. Afterwards, we calculated the total scores of each questionnaire based on the rules and the calculation method provided in Table A1. All index values ranged from 0 to 1. The higher the number, the better the facility configuration. (5) Housing quality index (HQI). We measured HOI based on three sub-indicators: building quality, housing ventilation effects and lighting condition, and residential area. Then we asked the villagers their satisfaction with these three aspects. The degree of villagers' satisfaction was expressed as a numerical value using a five-point Likert scale, the responses in which were classified as 'not at all satisfied', 'slightly satisfied', 'moderately satisfied', 'very satisfied' and 'extremely satisfied', with the corresponding values of 1, 2, 3, 4 and 5, respectively. The specific calculation method was as follows:

$$HQI = \sum_{i=1}^{n} HQ_i \quad (1)$$

where: HQI is the sum of three sub-indicators, and its value ranges from 1 to 15. According to the equidistance method, housing quality is divided into three degrees: when HQI < 5, the quality of housing is "low quality"; when HQI ranges from 5 to 10, housing quality is "medium quality"; when HQI > 10, housing quality is "advanced quality". The method for assigning weights and classifying the hierarchical structure for indicators is based on the literature—the evaluation method of the socio-economic status of the floating population in UVs [55].

(2) Interpretation of indicators of community environment sustainability and livelihood sustainability

The residential environment and livelihood sustainability are essential factors affecting living quality. We selected 19 sub-indicators from 6 dimensions evaluating community environment and livelihood sustainability, and their operational definitions are as follows (Table A2). Community planning and environment includes property management (X_1), support for public facilities (X_2), landscape greening (X_3), community security (X_4), and places of public activity and facilities in the community (X_5). The location condition of resettlement areas not only has an important impact on villagers' daily commute, but plays a role in potential market thrust in terms of stimulating tenants' rental behavior. Therefore, we selected the convenience of public transport around (X_6), distance between the resettlement area and the city center (X_7), and commuting status (X_8) as sub-indicators. The economic situation after the transformation is not only directly related to villager livelihood, but also indirectly reflects their occupational class. We selected stability of income source (X_9), work intensity and tiredness (X_{10}), and income increase or decrease situation after transformation (X_{11}) as sub-indicators. As many scholars have stressed the importance of social networks and their impact on the lives of villagers [57,58,63], we selected friendliness and support of community members (X_{12}), scope for making friends in the community (X_{13}), the degree of reservation in the acquaintance society

(X_{14}), and the impact of social networks on livelihood sustainability (X_{15}) to measure neighborhood attachment. Social guarantee situation reflects social equity, and is one of the most important ways for villagers to deal with emergency situations. Thus, we used coverage level (X_{16}) and guarantee level (X_{17}) of the villagers' social insurance to evaluate this. Given that the villagers have turned to non-agriculture households since UV transformation, we only considered urban insurances that villagers had already enjoyed (i.e., old-age insurance, medical insurance, unemployment insurance, employment injury insurance and other social insurances), and exclude rural insurances. Additionally, psychological willingness is also an important aspect for evaluating residential sustainability. We choose degree of satisfaction with resettlement compensation (X_{18}) and willingness to reside and enter old-age care in the resettlement area for a long period (X_{19}) as its sub-indicators. The degree of residential sustainability for each of the above factors was obtained through investigation, and is expressed in numerical form by a five-point Likert scale. Villagers' subjective feelings or views in response to these issues were classified as 'completely unsustainable', 'somewhat unsustainable', 'neither sustainable or unsustainable', 'completely sustainable', 'somewhat sustainable', with corresponding values of 1, 2, 3, 4 and 5, respectively.

To avoid there being too many indicators, the dimension structure was merged using the factor analysis method. These main factors can represent most of the original factor information, and also show the structural dimension of residential sustainability in UVs. They are converted into values between 1 and 100 points based on a standard score, using main factor variance contribution rate as the weight. The composite score was subsequently calculated. New factors were transformed in the same way to obtain the specific scores for each dimension. The main expression equation of factor analysis is:

$$X_i = u_i + a_{i1}F_1 + a_{i2}F_2 + a_{i3}F_3 + \cdots + a_{im}F_m + \varepsilon_i \quad (2)$$

where: X_i represents the original indicator variable; F_m ($m < i$) represents the unobservable common factor, which synthesizes the original i indicator information; and ε represents the information part that is not included as a special factor.

Among the 240 valid questionnaires received from the two villages, males and females in BNV accounted for 63.33% and 36.67%, respectively (Table 1), while they accounted for 45.32% and 54.68%, respectively, in XV. In terms of age, samples from both villages were dominated by middle-aged and elderly people. The educational level of villagers in both villages was low, mainly at the level of primary or junior middle school. Respondents were from the following several types of family. In BNV, 43.33% and 31.67% were from extended families and joint families, respectively. In XV, respondents were predominantly from nuclear families and extended families (28.33%, 40.00%). The size of the families tended towards miniaturization. As for occupational types, the villagers mainly worked as general staff, or had left the village for jobs and self-employed jobs. In addition, employees of township organs, organizations and departments also accounted for a relatively high proportion of the villagers in BNV, mainly belonging to the staff of village collective organizations.

Table 1. Demographic characteristics of samples (N = 120, per village).

Variable Name		Percentage (%)	
		NRCM(BNV)	**D/RMM(XV)**
Gender	Female	36.67	45.32
	Male	63.33	54.68
Age	19~30	21.03	25.38
	31~45	48.67	51.33
	46~60	30.30	23.29

Table 1. *Cont.*

Variable Name		Percentage (%)	
		NRCM(BNV)	D/RMM(XV)
Level of Education	Primary school and below	45.00	42.50
	Junior middle school	28.33	39.17
	Secondary technical specialized school, or senior high school	23.33	11.67
	Junior college, or undergraduate and above	3.33	6.67
Family structure	Empty nest family	3.33	5.00
	Nuclear family	21.67	28.33
	Extended family	43.33	40.00
	Joint family	31.67	26.67
Career structure	Unemployment, or waiting for employment	35.83	55.83
	Freelancer	5.00	7.50
	General staff, or leaving village for jobs	19.18	28.33
	Self-employed household	21.66	6.67
	Staff of township organs, organizations, and institution	18.33	1.67

4. Results

4.1. Sustainable Measurement of Housing Condition

In terms of the housing form, the houses in BNV were built by the villagers themselves through transformation at the original site. The XV resettlement area (Heshunyuan residential zone) contains affordable housing built by the developer through transformation at the relocated site. The resettlement compensation in BNV was mainly currency resettlement (68%), supplemented by currency and material resettlement (32%). with the combination of currency with material resettlement as a supplement was mainly applied to families with many people but fewer homesteads. If their residential area was not sufficient, they could buy the building area at 1298 yuan/m^2 below market price and in this manner could ensure that the per person building area was not less than 64 m^2. Every household was allowed to build four floors under the allocation policy of the building area, reconstruction households could build an area of 140 m^2 × 4 if they had sons in their family, and they could build an area of 72 m^2 × 4 if they had daughters in their family. The area of the newly built house could not be less than that of the original house. The villagers in BNV mainly consist of joint families or extended families, and the distribution policy was able to protect the vested interests of the villagers. The resettlement compensation in XV was dominated by housing resettlement (54%), supplemented by surplus housing area discount currency placement (46%). The area replacement ratio from one to three floors was 1:1; that is, the original housing area was equal to the corresponding area in the resettlement area. As concerns the relocated households with more than three floors of the original housing, resettlement was adopted in the three floors, and the resettlement pattern in parts exceeding three floors was adopted at a price of 6500 yuan/m^2. There are significant differences in the total housing area before and after transformation in the two villages. In BNV, the households with a significant increase in total housing area accounted for 98% of the total samples, of which area growth ranged from 0 to 600 m^2, accounting for 84%, with unchanged areas or decreased areas by only 1%, respectively (Table 2). In XV, the increased, unchanged and decreased areas accounted for 53%, 8% and 39%, respectively. Furthermore, the area growth range of all sample households was less than 300 m^2, but the area reduction scope is obvious, and varies from 0 to 900 m^2 (Figure 2a).

Table 2. Economic situation and housing sustainability under the two reform patterns.

	NRCM(BNV)		**D/RMM(XV)**	
Total (household)	120		120	
Housing form	Self-built houses by villagers		Affordable housing	
Total housing area after reform	Increased	98%	Increased	53%
	Unchanged	1%	Unchanged	8%
	Decreased	1%	Decreased	39%
Resettlement and compensation pattern	Currency resettlement	68%	Housing resettlement	54%
	Combination of currency and physical resettlement	32%	Surplus housing area discount currency placement	46%
Income condition	Increased 93%	Decreased 7%	Increased 28%	Decreased 72%
Consider the source of income that promotes income growth	House rental economy	93%	House rental economy	82%
	Leaving village for jobs	4%	Leaving village for jobs	12%
	Village organization employment	3%	Self-employed shop stalls	6%
Exist leasing economy and revenue situation	Existing	100%	Existing	73%
	Exist, increased in revenue	97%	Exist, increased in revenue	34%
	Exist, decreased in revenue	3%	Exist, decreased in revenue	66%
Housing status sustainability	Average value	Standard deviation	Average value	Standard deviation
HOI	4.00	0.21	3.80	0.41
HCI	5.18	0.81	5.40	0.85
HPI	6.12	0.76	5.62	1.03
HFI	0.83	0.54	0.63	0.87
HQI	12.63	1.57	10.52	2.89

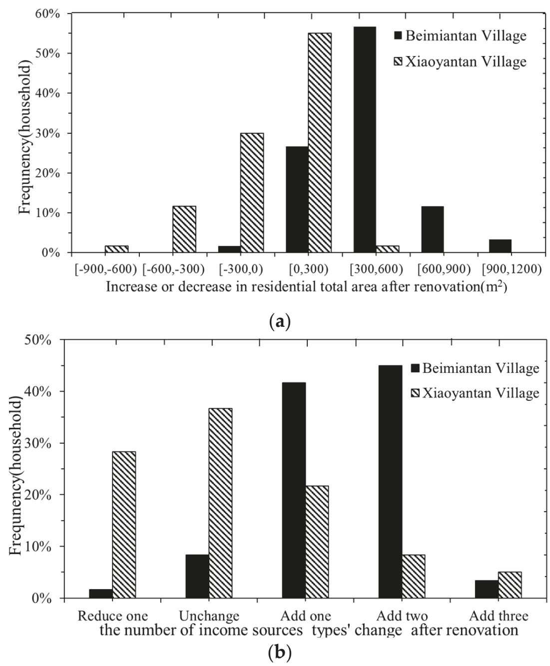


Figure 2. Villager's residential area compensation and occupational income status. (**a**) The change in total residential area after the transformation. (**b**) The change of income source types after transformation.

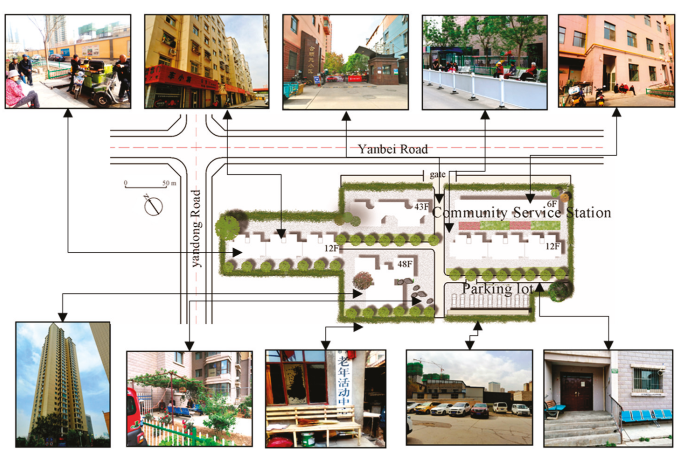
Compared with income status before transformation, 93% of villagers in BNV state that they think that their income has increased. Among the villagers who think that their income has increased, they think that the main means of promoting income growth was the house rental economy (93%), followed by leaving the village for jobs, and employment with the village collective (this refers to the village committee and village-owned enterprises that provide jobs for villagers). Income source channels have increased by 90%, and the channels have tended to diversify (Figure 2b). In comparison, only 28% of villagers in XV stated that they think their income has increased, either due to self-owned house rentals (82%), leaving the village for jobs (12%), or self-employed shop stalls (6%). Income source channels have increased by 35%, and the channels have tended to remain single. When comparing the income structure proportions before and after the transformation (Table 3), villagers in BNV received their income mainly from agricultural farming and leaving the village for jobs before the transformation. After the transformation, the income structure was largely converted to self-owned house rentals, and village collective shares and dividends. Additionally, the village collective employment portion also increased significantly. Before the transformation, XV's income structure comprised self-owned house rentals, and shares and dividends of village collective. Additionally, very few agricultural plantations still existed on non-expropriated cultivated land. After transformation, agricultural farming stopped. Furthermore, the proportion of self-owned house rentals decreased, and the proportion of village collective shares and dividends did not change much, although the number leaving the village for jobs increased significantly compared with the number before the transformation, which reflected the increased livelihood pressure faced by landless villagers. The main driver promoting the two villages' income growth was self-owned house rentals, but initially, it was unclear why there was such a wide gap in the degree of income improvement between the two. In further investigations, we found that every household in BNV was involved in self-owned house rentals (100%), and 97% of villagers thought their income had increased as a result of this factor. However, only 73% of households in XV still had maintained self-owned house rentals, among them, only 34% of households held that their income had increased due to this factor. It shows that the retention degree and income status of the rental economy in XV are not as good as before, mainly due to the substantial decrease in rentable housing area per household following the transformation. Conversely, the sharp growth in the tenant market in BNV should be understood in terms of increasing rentable area and rent. On the one hand, the area allocation policy of BNV ensured that the building area per household increased, and that the villagers would have the rest of their house to rent (villagers usually live on only one floor, with the other three floors being rented as houses, storerooms and storefronts). On the other hand, the uniform planning of the new rural construction promotes village landscape urbanization and external benefits, in comparison with the low-rent housing provided in other UVs. The village's environmental optimization, self-sufficient service industry clusters, location and transportation improvement are able to provide a better residential environment for tenants, thus, above all, greatly increasing the housing rental market.

Table 3. Proportion of income structure before and after transformation.

	NRCM(BNV)		D/RMM(XV)	
	Before	**After**	**Before**	**After**
Self-owned house rentals	3.33%	96.67%	61.67%	61.67%
Leaving village for jobs	15.75%	19.17%	17.35%	70.23%
Village collctive employment	2.50%	21.67%	1.67%	1.67%
Village collective shares and dividends	1.67%	85.83%	3.33%	85.00%
Government subsidy	1.67%	5.00%	1.67%	23.33%
Self-employed shop stalls	3.33%	21.24%	1.67%	15.20%
Agricultural planting	76.67%	0%	65.00%	3.33%

Housing sustainability indicators show that the HOI and HPI values of BNV are higher than those in XV, and the HCI value is lower than that in XV. The houses in BNV were self-built by the village collective and villagers. Thus, villagers have their own house property rights. The relocation area of XV is state-owned land, the second-phase project is still in progress, and issuance of the real estate license is not fully in place. Therefore, the HOI is generally low. The HPI is related to the HCI, housing area allocation policy, and family structure factors. XV has more people with fewer homesteads, and the original villagers built additional illegal buildings with four or five floors to increase rent-seeking space. The compensation policy for demolishing one house and rebuilding another is limited to houses below three floors; surplus house floors fall under the discount currency placement policy, and the resettlement price is far lower than the Yantan land market price. After the transformation, the villagers of XV mainly consisted of nuclear families and extended families. To maximize the rentable area in a limited housing area, a large family will often live intensively in one or two suites, with surplus rooms being used for renting. Therefore, the current residential status of more people but a smaller residential area in XV has aggravated the unsustainable housing conditions. The overall HQI scores are 12.63 in BNV and 8.92 in XV. The residential area of the villagers in BNV increased by a large margin, with no reductions being observed. The villagers themselves selected the engineering team to build their own houses, and the construction process was conducted according to construction drawings and uniform planning. Hence, the construction quality met the villagers' own residential requirements. Each unit of a building is a household, and each household can build four floors. Then, villagers can choose to live on floors with relatively good ventilation and lighting. Conversely, XV's resettlement area was uniformly built by real estate developers. Residential floors were allocated according to the villagers' relocation order, and villagers had no choice regarding building quality, ventilation, lighting, or residential area. The HQI in BNV is higher than that in XV. The overall HFI scores are 0.83 in BNV and 0.63 in XV. With respect to the three sub-facility indexes, firstly, the scores for the basic and intermediate facilities indexes are generally equivalent in the two villages. The advanced housing facilities index is 0.43 for BNV and that of XV is only 0.14, which is significantly different. BNV is equipped with fitness and entertainment facilities, cultural and sports facilities, a community park plaza, landscape greening, and resting places. Villagers can conduct activities in relatively abundant open space. The residential areas on the first floors of each household are rented out as commercial storefronts, and the cluster of self-sufficient commercial facilities has increased the vitality of the community and resulted in greater convenience for the villagers (Figure 3a). Apart from the tall tower buildings, XV's relocation zone lacks cultural and sports facilities, landscape and leisure places, and commercial facilities. Villagers' daily activities mostly consist of gathering to be in the sun, and chatting in the downstairs areas of residential buildings. Thus, XV is extremely lacking in activity spaces, and the vitality and sustainability of the community are generally low (Figure 3b).

(**a**)



(**b**)

Figure 3. Plane map and corresponding photos of the two villages' resettlement areas (Source: the plane map was drawn according to the investigation and community introduction data; photos were taken by the author). (**a**) Beimiantan New Village (BNV). (**b**) Xiaoyantan Village (XV).

4.2. Sustainable Measurement of Community Environment and Livelihood

Before using factor analysis to construct the structural dimension of residential sustainability, a Pearson correlation analysis of 19 indicators of residential sustainability was conducted. We found that all indicators were significantly correlated, indicating that the selected indicators did not need to be excluded. Subsequently, statistical tests are conducted to determine whether the indicators were suitable for factor analysis. The Kaiser–Meyer–Olkin (KMO) test value was 0.603, and the Bartlett test of sphericity's approximate Chi-square value was 345.112, with a significance level of 0.00. Hence, the correlation coefficient matrix was considered to be significantly different from the unit matrix. Both tests indicated that the 19 indicators described above were suitable for the factor analysis model. According to the calculation, there are six dimensions of residential sustainability structure in the relocation area (generally, factors with a characteristic value greater than one are chosen as principal components in statistics), and the main factors are represented by F_1, F_2, F_3, F_4, F_5, and $F_{6,}$ respectively. Compared with F_1, the eigenvalues of F_5 and F_6 are much smaller than that of F_1, which means that their factor naming lacks explanatory power. The variance maximization method was used to rotate the factor loads orthogonally, and the post-rotation load value and its structural dimension factor score are shown in Table 4. At present, there is no uniform standard for the measurement of residential sustainability, so the social integration degree method is used as a reference; the structural factors [64] or factor variance contribution are used as the weight in the existing literature [65,66]. We use the latter to weight the sustainability of the residential environment and livelihood security by using the variance contribution rate of each main factor. Subsequently, the scores of the six new factors are converted to values between 1 and 100 according to the standard scores. The specific principal factor naming explanations and structural dimension factor scores of the two villages are as follows (Table 4).

(1) BVN

The factor loads of X_9, X_{10}, and X_{11} on F_1 (economic status factor) are found to be the highest. From the index expression content, this mainly refers to the occupation and income status of the villagers after the transformation, which is the first main factor. The factor loads of X_{12}–X_{15} on F_2 (social relationship factor) are found to be the highest. These four factors reflect the social relationship networks of the villagers after the transformation. X_1–X_5 have the highest factor loads on F_3 (community environmental factor), which reflects the sustainability of the community residential environment. X_6–X_8 have the highest factor loads on F_4 (location condition factor), and the three factors reflect the location conditions of the new village. X_{16} and X_{17} have the highest factor loads on F_5 (social security factor), which reflects the social security situation that the villagers currently enjoy. X_{18} and X_{19} have the highest factor loads on F_6 (psychological willingness factor), which reflects villagers' satisfaction with resettlement compensation and willingness to live in the community for a long time. Comparing the eigenvalue size of each factor, we find that the eigenvalues of F_1 and F_2 are larger, which indicates that the economic condition factor and the social relationship factor have the most significant impacts on the sustainability of the community environment and the livelihood in the new village, whereas the psychological willingness factor has the weakest effect. Regarding the scores of each factor, the sustainability scores of the structural factors in BNV were ranked in the descending order $F_2 > F_1 > F_3 > F_5 > F_6 > F_4$, which indicates that the sustainability of the villagers' social relationship network and economic status after the transformation are the highest, while the sustainability of the location condition has changed little.

(2) XV

The main explanatory factors for XV were found to be the same as those for BNV, but the ranking of the influences of structural factors on the sustainability of the residential quality was different from that of BNV, as follows: F_1 (economic status factor) > F_2 (community environment factor) > F_3 (social guarantee factor) > F_4 (social relationship factor) > F_5 (location condition factor) > F_6 (psychological willingness factor). Regarding the eigenvalue size of each factor, the first three factors' eigenvalues are the largest, which indicates that economic status, community environment, and social guarantee have the most significant impacts on the sustainable quality of XV's resettlement area. Regarding the scores of each factor, the sustainability scores of the structural factors in XV are ranked $F_3 > F_5 > F_4 > F_2 > F_1 > F_6$, which indicates that the sustainability of villagers' social security and location conditions after transformation are the highest, whereas the sustainability of the community environment, economic status, and psychological willingness are the lowest.

4.3. Analysis of Influencing Mechanisms

4.3.1. Land Development Right Allocation Model and Earning Redistribution

The differences in the land development rights allocation models in the two villages have affected the subsequent pattern of villagers' land earning redistribution [64,66]. BNV takes the village collective as the development subject, whose land development patterns are housing and the collective property rental economy (Figure 4a). This pattern originated from collective spontaneous land circulation behavior, driven by the village collective to pursue the maximization of collective land benefits. The village collective took the lead in setting up a collective joint-stock company and centralizing the scattered homesteads of the villagers as construction parcels for the new village. Subsequently, the village collective led the villagers in constructing a new socialist countryside under uniform planning, and part of the collective land was used as property rentals to develop the collective economy. Eventually, the village collective fed the profits back to the villagers in the form of annual dividends or infrastructure investment. The corresponding land development rights allocation model is the "free transformation model" (Figure 4c). This model circulates the land development rights to the village collective and the villagers, who maintain collective ownership of the land [65,67]. After the transformation, the land development rights, which partially reflect public interests, were handed over to the government. XV introduced real estate developers as the investment and construction subject (Figure 4b). This type of marketization behavior is representative of the most common urban village land development model in China, that is, the land expropriation model (Figure 4d). The local government expropriates collective land from UVs and circulates the land use rights to real estate developers via bidding and auctioning. Subsequently, developers use a portion of the land parcels to establish resettlement areas for the landless villagers. Then, they construct various types of commercial houses using the rest of the parcels, and sell or rent them at higher prices [68]. A common phenomenon is that the local government expropriates collective land from villagers at a lower price, and sells it to developers at a higher price; thus, the government may obtain huge economic benefits as a result of this process. After the government has fully nationalized the land development rights through land expropriation, the government may return some of the land development rights to the village collective for the construction of the resettlement area and the compensation of landless villagers.

The difference between ownership rights and use rights for collective land has had a profound impact on the construction quality of the two villages' resettlement areas and the allocation policy of the villagers' housing areas [68,69]. The land in BNV is still collectively owned, and the rural land property rights belong to the villagers. After the transformation, villagers' residential areas are several times larger than before ones, they build new houses and rent them out for rentals, which considerably stimulate their enthusiasm for the transformation. Villagers are simultaneously given long-term and effective land use rights. Thus, this model protects villagers' land property rights and fundamental interests. The cultivated land in XV was completely expropriated in 2014, and the villagers no longer live on agricultural farms. Nowadays, many homesteads have spontaneously entered the market, and villagers live off house rent and land rent. Land expropriation by the government deprives villagers of an economic foundation for their survival. However, with respect to the compensation to the villagers for land expropriation, other than one-off currency compensation, the government has not calculated or redistributed any potential land income. Additionally, the one-off currency compensation has decreased under the influence of rising prices and inflation. The villagers in XV lost their land, but did not receive considerable resettlement compensation; this also means that they lost their interest in engaging with land use, income redistribution and assets for improving their long-term livelihood conditions.

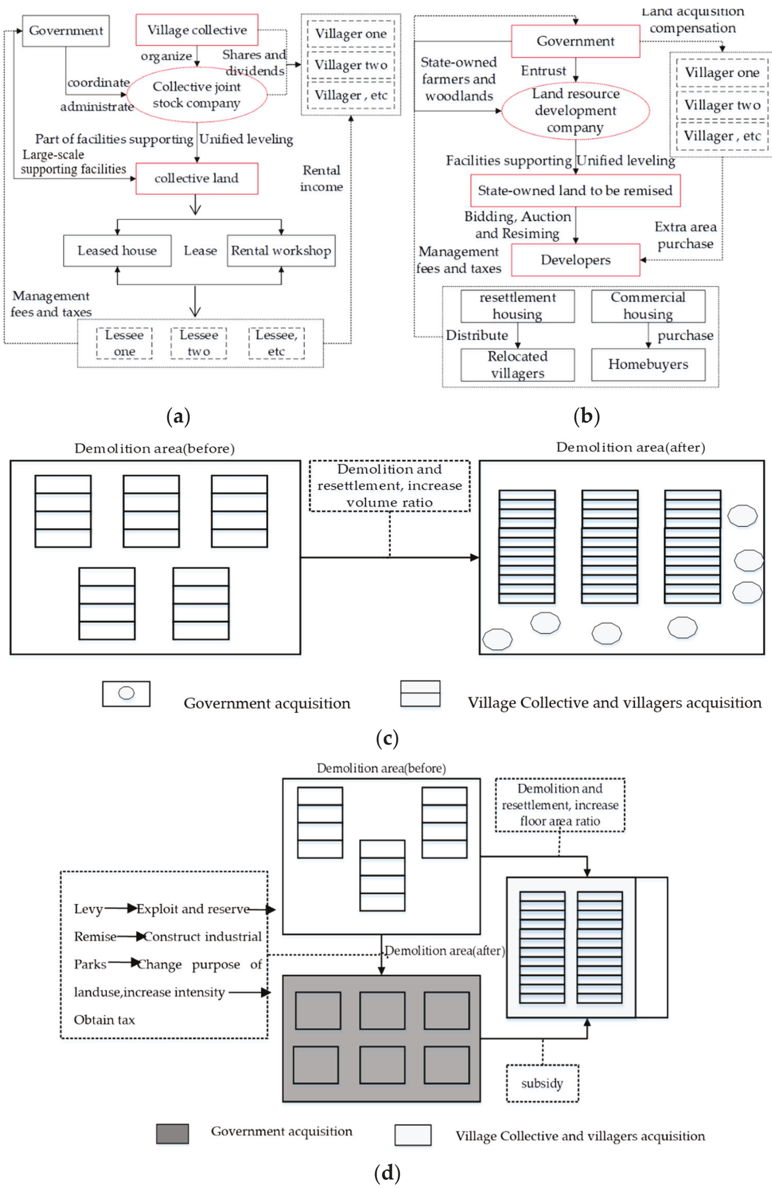


Figure 4. Comparison of the land development right allocation models used in the two villages in the transformation (the dotted arrows represent the flow of funds, and the solid arrows represent the mode of action in (**a**,**b**)). (**a**) Land development and capital flow in BNV; (**b**) land development and capital flow in XV; (**c**) schematic diagram of allocation model based on the "free transformation model"; (**d**) schematic diagram of allocation model based on the "land expropriation model".

Table 4. Factor load matrix and composite sustainability structural factor score.

Independent Variable	Model One. NRCM(BNV)						Model Two. D/RMM(XV)					
	F_1	F_2	F_3	F_4	F_5	F_6	F_1	F_2	F_3	F_4	F_5	F_6
X_1 Realty management	0.346	0.563	0.726	0.115	0.065	0.271	0.554	0.565	−0.203	0.081	−0.218	0.076
X_2 Public facilities supporting	0.663	0.263	0.907	0.413	0.018	−0.2	0.515	0.736	−0.277	−0.085	−0.512	0.141
X_3 Landscape greening	0.631	0.136	0.816	0.048	0.447	−0.325	0.398	0.689	−0.502	−0.245	−0.304	0.028
X_4 Community security	0.268	0.6	0.72	−0.263	0.506	−0.161	0.557	0.551	−0.635	0.276	0.224	−0.142
X_5 Community public places	0.227	−0.461	0.815	−0.183	0.225	0.138	0.046	0.813	0.505	0.635	−0.437	−0.146
X_6 Convenience of public transport	−0.161	0.169	0.666	0.844	0.143	−0.007	0.636	−0.364	−0.265	0.017	0.817	0.026
X_7 Distance from the city center	−0.504	−0.349	−0.205	0.761	−0.156	0.195	0.541	−0.335	−0.429	0.019	0.869	−0.412
X_8 Commuting status	0.372	0.586	0.411	0.886	0.384	0.216	0.427	−0.404	−0.158	0.374	0.927	−0.503
X_9 Stability of income sources	0.701	−0.091	−0.26	0.698	0.153	0.489	0.832	−0.156	−0.039	−0.458	0.441	0.487
X_{10} Work intensity and tiredness	0.799	0.104	0.418	−0.659	−0.056	0.18	0.748	0.134	0.617	0.566	−0.036	0.495
X_{11} Income increase or decrease situation	0.856	0.715	−0.415	0.028	0.591	0.017	0.824	0.071	0.238	0.426	0.433	−0.312
X_{12} Friendliness of community members	0.222	0.738	0.066	−0.178	−0.071	0.482	0.607	0.238	0.545	0.773	−0.046	0.154
X_{13} Scope of making friends in the community	0.17	0.822	0.067	0.288	−0.266	0.153	0.147	0.454	0.316	0.853	0.484	−0.068
X_{14} Acquaintance social reservation situation	0.441	0.801	−0.084	0.371	−0.532	0.013	0.262	−0.354	0.499	0.689	−0.335	−0.231
X_{15} The impact of social networks	0.46	0.769	0.182	−0.188	0.361	0.198	0.454	0.382	0.534	0.824	0.045	−0.123
X_{16} Coverage degree of self-owned insurance	−0.227	0.019	0.284	0.632	0.769	0.185	−0.184	−0.244	0.922	0.347	−0.481	0.424
X_{17} Guarantee level of self-owned insurance	0.368	−0.215	0.342	0.164	0.824	−0.316	0.533	−0.359	0.906	0.105	−0.343	−0.262
X_{18} Satisfaction degree of settlement mode	0.408	−0.282	−0.154	0.112	0.08	0.757	0.469	−0.073	0.413	0.055	0.181	0.762
X_{19} Willingness of residence and old-age care	0.545	−0.431	0.074	0.084	0.054	0.633	0.589	−0.328	0.204	0.009	0.198	0.813
Characteristic value	2.761	2.057	1.561	1.449	1.319	1.26	3.57	2.505	2.034	1.516	1.393	1.23
Variance contribution rate (%)	26.275	18.393	13.548	10.219	8.554	6.63	30.648	20.307	17.077	10.308	8.738	5.721
Accumulated variance contribution rate (%)	26.275	44.668	58.216	68.435	76.989	83.619	30.648	50.955	68.032	78.340	87.087	92.799
Average score (to measure sustainability)	52.112	58.726	34.539	23.676	19.598	28.745	22.541	25.454	50.655	31.448	45.36	15.865

4.3.2. Collective Economy and Community Transformation

There exist differences in the features of collective economy and community transformation between the two villages. Community transformation in BNV is embodied in organic renewal through collectivist transformation. The village still retains many traditional village community structure patterns, but they are embedded in the urban management mechanism after UV transformation. Community transformation in XV is embodied in overall demolition and reconstruction through market-oriented transformation, and the traditional village community has been completely transformed and attached to the urban management mechanism [70–72]. Moreover, different community transformation models have greatly influenced the collective economy in the two villages. In other words, the degree of reservation in the collective economy is quite different as a result of the two community transformation models [71]. The public ownership institutions for rural property, an institutional foundation of the rural collective economy at the present time in China, mainly comprise collective property rights institutions and mutual assistance and cooperation mechanisms. They not only define the property right relationship between collective ownership and individual possession, but also have strong administrative characteristics. In addition, the formation and development of UVs' collective economies mainly depends on collective land resources. Undoubtedly, the shares and dividends of each villager are also closely related to the development of collective economies and collective land resources. To summarize, the collective economy has become a link between industrial production relationships and village community transformation [73].

With the usage value of rural land increasing continuously with marketization, BNV has ensured that rural land ownership still belongs to the village collective under NRCM, and the rural land resources have been re-collectivized. The village's collective economy is generated by the cooperative development and independent management of collective land, which forms a rental property-based economic development model [74]. The early collective income in BNV involved labor-intensive industries set up by the village collective, which had preliminary industrialization tendencies. However, since UV transformation and the monetization and marketization of land rights profits, the village collective's income mainly comes from property rentals and the profits of three major village-owned enterprises. The economic management system of the village collective consists of the economic association and several subordinate organizations known as economic communes. The community share-cooperative economy was established on this basis [75]. The administrative affiliation relationship between the village collective and villagers has gradually been weakened through this process, while the economic property rights relationship between them has been constantly strengthened. Therefore, we hold that the village's collective economy plays the following roles in ensuring villagers' residential sustainability: First, the village collective organizes and undertakes the agency management of the collective property of villagers; second, the collective economy performs a welfare guarantee function for landless villagers. The villagers' shares and dividends have increased since the transformation [76], and with the increasing scale of village-owned enterprises and village committee, villagers gain many employment opportunities from them. Conversely, the original collective-owned land in XV was completely transferred to state ownership through collective land expropriation. The landless villagers' resettlement area is categorized as government-assigned land, and the construction is presided over by developers. If the villagers wish to rent, transfer or co-build the houses on this plot, these activities must be approved by the relevant authorities, which has curbed the development of the rental economy to a certain extent. Thus, the change in collective land ownership in the village has brought the institutions of collective land and housing property rights into the urban real estate market management system. However, the change in property rights is only a unilateral agreement with the city government and does not have approval from the village collective or villagers. It also does not have the bilateral binding force of a common agreement between the two groups. In the present UV transformation, there is a serious lack of public finance and social management on the part of the government. Policy input is mainly used to compensate the cost of land expropriation, which is limited to solving the short-term living guarantee issues of landless villagers. Villagers' long-term education, medical care, old-age care, municipal support facilities, and public service facilities have not been considered in the construction and management of the city. The NRCM in BNV retained the collective economy as much as possible and allowed it to continue to play the above social security functions for villagers. However, with the loss of collective property rights and the depression of the collective economy, the collective economy of XV has been unable to carry out these functions, which has greatly affected the livelihood sustainability of the villagers. Developers might only focus on economic benefits, by increasing the floor ratio excessively in order to settle more landless villagers with fewer rebuilt land parcels, while placing housing quality in the relocation area as a secondary concern. This problem has greatly reduced the residential sustainability of the villagers in XV, and has caused the villagers to strongly resist the deep involvement developers in UV transformation.

4.3.3. Informal Institutions and Village Social Relationship Networks

If a village is compared to a building, the internal structure of the village is like the framework of the building. At first glance, BNV and XV are similar in terms of social composition (e.g., the sex, age, education level, and family structure of the villagers), but societies with similar surficial structures may have fundamental differences. Specifically, the differences in residential sustainability of the two villages are reflected in the informal institutions and social relationship networks [77]. China's societies have always been interpersonal societies dominated by strong ties. China's villages have the social characteristics of independent communities; essentially, they are also acquaintance societies based on village–community relationship networks. The traditional logic of relationship networks is that of informal institutions based on traditional ethics, family networks and interpersonal credits; this is neither the prohibitive rule of hierarchy nor the transactional contract rule of the market, but rather fulfills constructive and protective functions for the development of the collective economy in UVs. During the transition period, the old formal institutions have been broken, while new formal institutions (i.e., administrative institutions and market rules) had not yet been established and perfected in China's villages. For this reason, informal institutions based on interpersonal relationships were more vigorous than the formal institutions in China's villages, where the formal institutions had always been weak.

BNV experienced the re-collectivization process and revitalized land assets in the UV transformation [71]. Furthermore, the complete village social networks in BNV were still complete after the restructuring of the social orders of the village. For one thing, the villagers adopted a sophisticated, expedient, and flexible way of absorbing new things that benefit them; for another, their operation logic still retains the deep characteristics of the original village. Hence, this transformation model causes the reconstructed economic structure to be embedded in the original social relationships [78]. This type of informal institution can greatly protect the operation of the collective economy in BNV. In summary, the operational mechanism includes the following: (1) The operation of vague collective property rights depends heavily on interpersonal trust in the community [79]. NRCM realized the centralization of villagers' residence and the integration of collective land through the transformation on the original site and uniform planning. Therefore, the village has retained a relatively complete acquaintance network with a higher credit guarantee and local attachment. The interpersonal trust among villagers reduced the collective transaction costs and organizational costs and created a benign external environment for collective economy operation [80]; (2) The social relationship networks can operate on a broader scope (i.e., beyond the limitations of family size). The usage efficiency of public assets depends on the ability of community members to solve collective problems. This not only embodies the collaborative cultural tradition of Chinese peasants, but is also a product of the development of relationship networks; (3) The social relationship networks can provide informal protection for collective accumulation. The initial capital of the collective economy in BNV mainly came from the accumulation of collective agriculture in the past. In addition, the preservation of complete social networks and the reforming of stock immobilization can also help to curb the loss of collective heritage [81]. Conversely, the compensation and resettlement method in XV is completely different from that in BNV. Villagers in XV either choose to move into resettlement areas, or they choose currency compensation and now live elsewhere; it can be said that the villagers have been disbanded to some extent since the transformation. At a deeper level, the original acquaintance relationship networks of villagers have been broken, and the rural society structure has become extremely fragmented in XV. The incomplete social network has increased villagers' survival risks and reduced the cohesion of the village community [82]. The villagers are already lacking the ability to form internal social connections and relationships, so they are also unable to form a network of common social assistance.

Granovetter's theory regarding the strength of weak ties shows that weak ties are the bonds between groups, which provide heterogeneous information and act as an information bridge [70–74], while strong ties are the bonds inside the groups, which provide a greater homogeneity of information [83–85]. Based on Granovetter's theory, Prof. Bian proposed a strong relationship hypothesis. It shows that China's society is not a society of weak ties like the United States, but rather it is a society of strong ties. Achieving success in China does not depend on weak ties, but rather on strong ties [86–89]. Prof. Fei found that a sequential structure exists in Chinese village societies [90], whereby individuals are involved in various layers of private social networks from the inside to the outside, relying heavily on the intimacy of interpersonal relationships [91]. Hence, there exist typical strong ties in rural societies in China, which are composed of consanguinity, kinship relationships, and geographic relationships (Figure 5). Specifically, the social relationship networks of the two villages result in different relationship resources. Firstly, landless villagers in the two villages have little possibility of changing jobs and being re-employed. For one thing, the education level and labor skills of landless villagers are generally low, and their ability to participate in market competition and adapt to the market is limited; for another, the desire of landless villagers for re-employment is not strong. Because of land expropriation, they are forced to participate in the process of urbanization. However, in essence, they have been accustomed to a land-based lifestyle and are unwilling to face the highly stressful urban-rural employment markets. Even with the same re-employment background, the influence mechanism is different, due to differences in the social networks between the two villages [92]. Villagers in BNV reside centrally in the new village, and their original circle of acquaintances was not broken up following UV transformation, so the village retains the strong ties of the acquaintance networks and provides more interpersonal resources. The village collective and village-owned enterprises have created many jobs for the villagers, thus solving the employment problems of some villagers internally through community transformation. Other than human capital, the law of interpersonal relationships also plays an important role in the distribution of employment posts [93]. However, following the market-oriented transformation of XV, villagers were not able to realize centralized residence in a geographical sense to the necessary extent, and the acquaintance circle of the original village disintegrated. Relatively speaking, there have been no improvements in the low human capital and landless villagers' employment conditions. Hence, the villagers have faced more serious unemployment problems since the transformation, which worsens their adaptability dilemma.

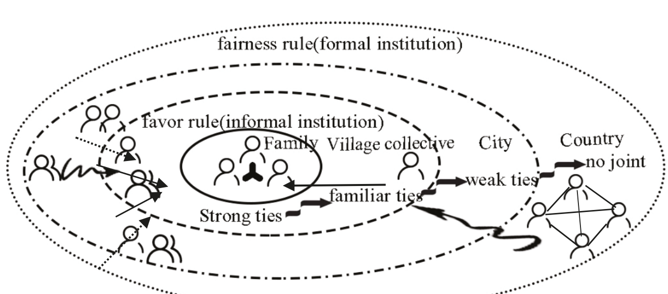


Figure 5. China's rural social network compliance rules under the differential order pattern (solid arrows are strong ties, dotted arrows are weak ties).

5. Conclusions and Discussion

5.1. Conclusion

The residential sustainability of NRCM is generally higher than D/RMM. From the perspective of income situation and income structure, the housing rental economy is used as the main tool to promote villagers' income in the two villages following transformation. Specifically, as a result of more reservations, higher housing rental income, and increasing shares or dividends from the village collective and collective employment of villagers, villagers' income sources have become more diversified since NRCM in BNV. However, since the implementation of D/RMM, the income sources of the villagers have become deficient, the housing rental income has decreased, the number leaving the village for jobs has increased significantly, and the stability of their work has decreased; meanwhile, their working intensity and the livelihood pressure have increased since the transformation. From the perspective of housing condition sustainability, since NRCM, the villagers have a higher overall sustainability with respect to their own housing condition than previously. Specifically, in BVN, Housing ownership index, Housing privacy index, Housing quality index and Housing facilities index are higher than those in XV, and its Housing crowding index is lower than that of XV. This is related to the differences in housing allocation policies, family structures, housing construction, and infrastructure construction between the two villages. As for community environment sustainability and livelihood sustainability, overall, the two items in BVN are higher than those in XV, and the two items in BVN are mainly manifested in the sustainability of the villagers' social relationship networks and economic status. The influence factors in the residential sustainability of the two transformation models can mostly be attributed to three aspects: (1) Land development right allocation models and earning redistribution fundamentally affect villagers' housing condition sustainability; (2) The collective economy and the informal economy are the potential drivers of sustainable village community transformation; (3) Informal institutions and village social networks protect and continue the social capitals in village. In summary, villagers' rights are maintained and enhanced via informal institutions, informal economies, and original social relationship networks are completely preserved through NRCM in BNV, as much as possible. Therefore, NRCM can maximize the villagers' interests, which should be conducive to residential sustainability in the transformation of China's urban villages.

5.2. Discussion

UVs comprise a special type of residential landscape with Chinese urbanization characteristics; the transformation of UV has prompted discussions regarding the fairness of urban spatial resource allocation, as well [94]. Since the reform and opening up, China has adopted a demolition/relocation market-oriented model, which seemingly ends the history of the villages through a one-off transformation, but this radical reconstruction leaves a number of remaining historical problems. For local villagers, the end of the village does not mean that the villagers vanish, and they will face more sustainable livelihood challenges, including the inadequacy of land rights and interests, the difficulty in re-employment channels, the incomplete coverage of social security, and difficulty with urban integration. For the floating population who live in UVs, the demolition and removal of the UVs do not fundamentally solve their living problems. To settle down in the cities, these low-income groups would have to move to other urban villages that have not been demolished, causing a vicious cycle between the generally increasing housing rent in the surrounding areas and the emergence of "new UVs". Thus, the continuing effect of D/RMM is known as the "Tangjialing phenomenon"; proposed by Prof. Gu [95], it is prevalent in UV transformation in China.

Transformation of the original site on the premise of continuity should be one of the current feasible models; specifically, villagers and village collectives conduct urban village transformation at the original site, on the premise of retaining and expanding the rental economy. UVs have very strong local embeddedness, and this is based on consanguinity, kinship, clan, geographic relationships, folk beliefs, and village rules. At first glance, the demolition and reconstruction of UVs and commercial real estate development seem to provide villagers with beautiful and comfortable houses; however, it also results in villagers losing land value-added benefits from the original UVs' locations, which is primarily embodied in the loss of housing rentals, collective properties, and other livelihood opportunities. Eventually, this may lead to the disintegration of the original social networks and the disappearance of the acquaintance society at a deeper level. NRCM is a sustainable exploration; it attempts to promote UV transformation with the help of non-market folk society forces, and has a unique effect on transcending the limitation of economic rationality. If we over-rely on market-oriented transformation, the erosion of market laws and capital profit-seeking are hard to avoid. For example, the volume ratio may be too high in the resettlement area (relatively speaking, it is appropriate that the volume ratio of the residential districts ranges from two to three), and may even be far higher than in the general commercial housing districts. An excessive population density has a lasting negative impact on the sustainability of the community environment and villagers' residences. An additional advantage of NRCM is the revitalization of collective land assets. Moreover, its transformation benefits also lie in activating collective land assets and optimizing the functions of low-rent housing in urban areas by protecting reasonable land development rights of villagers. Therefore, it is necessary to explore the land development right allocation model, which is allocated by the government, village collectives, and villagers, simultaneously. Government should establish a reasonable institution for the gradual transfer of land development rights [96]. Based on the above discussion, the following suggestions are made based on an economic perspective: first, the government should establish supporting policies that are conducive to the economic transformation of the community joint-stock companies in UVs, in order to safeguard villagers' employment. Second, the government should build a special investment and financing platform to reduce the risk of village collectives' independent investment. Eventually, the government should rebuild an interest redistribution mechanism that balances fairness and efficiency. Rural collective land should be granted the same development rights as urban construction land; the establishment of a uniform urban–rural construction land market is one of the directions that China's land institution reform will take in the future. From a social point of view, the government should guide the establishment of community self-governance mechanisms that meet the needs of transformation. Also, the government should guide village collectives to participate in land re-planning. The village collectives should be allowed to develop the remaining land. Eventually, it will be necessary to protect sustainable development of internal industries in UVs, to promote industrial development, and to increase employment.

In the future, the end of villages and villagers will be the final outcomes of UV transformation in China, which will include three aspects: (1) The end of the physical aspect of UVs; this refers to the demolition of houses and the disbandment of villagers; (2) The end of organizational entities by the disintegration of village administrative, economic, and social organizations. In particular, this is reflected in the abolition of the Village Committee System (VCS) and the implementation of the Community Resident Committee System (CRCS); (3) The end of social relationships means the dissolution of the acquaintance society. For instance, villagers either choose currency compensation and have to make their own living, or choose housing resettlement and move into resettlement areas in a different construction phase. Thus, the original villagers are scattered and distributed in different urban spaces, and consanguinity and geopolitical relationships will gradually disintegrate; for this reason, the above dimensions will subsequently emerge in XV. Although BNV will not face demolition in the near future, the villagers still fear that they will face the same fate as XV in the next decade, and their vested interests will not be safeguarded. BNV has expanded its economic boundaries based on its own economic strength, such as rental market networks. Thus, its administrative boundaries have also changed, as the village committee turns into the community resident committee. Based on our investigation, we find that the villagers are increasingly adapting to the urban lifestyle and values; meanwhile, the village value system has gradually diversified. With the trend of further urbanization in the future, the cultural and social boundaries between urban and rural areas will be further blurred.

However, if the government guides and governs properly in the future, BNV may retain its original social relationship networks relatively completely following the termination of the rural housing form.

5.3. Limitations

Although this study provides several new insights into residential sustainability issues in UV transformation, it still has space for improvement. First, this study focused on only two UVs; the diversity represented by different UVs should be considered in further research. However, even if the village case can be studied in-depth, it lacks universal explanatory power on account of limitations in the characteristics of villages. Second, the study mainly focuses on the analysis of residential sustainability from the perspective of indigenous villagers in UV transformation. Future research should focus on floating urban labor and tenants in UVs, because there is a possible difference in residential sustainability between migrants and indigenous villagers.

Author Contributions: Y.Y. conceived the presented idea, proposed the related scientific problems and this paper's structure, verified the analytical methods, and revised and confirmed the manuscript; L.Q. carried out a survey in Lanzhou, wrote and completed the original manuscript, revised the content of manuscript based on the comments of the four reviewers and editors; W.M. is responsible for the language revision and proofreading of the article.

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Appendix A

Table A1. Descriptive statistics for housing condition sustainability indicators of relocation villagers.

Shorthand	Sub Index	Weighting Method
HOI	Housing forms and property Rights	Rented house = 1; accommodation = 2; self-built house = 3; self-purchased house = 4
HCI	Per average housing area(m^2)	>=46 m^2 = 1;36~45 m^2 = 2;21~35 m^2 = 3; <=20 m^2 = 4
	Housing set ratio	Complete set house = 1; incomplete set house = 2; bungalow = 3
HPI	Housing function	Only living room = 2; both life, production and business use = 1
	Housing privacy	The five-point Likert scale: [1 2 3 4 5]
HFI	Basic facility Index	$I_1 = \sum I_a/42$, I_a is total score of the former seven items facilities ownership
	Intermediate facilities index	$I_2 = \sum I_b/42$, I_b is total score of 8~14 items facility ownership
	Advanced facilities index	$I_3 = \sum I_c/42$, I_c is the total score of 15-21 items facility ownership
	Overall facility index	$I = \sum I/42$, I is total score all facilities ownership
HQI	Building quality	The five-point Likert scale: [1 2 3 4 5]
	Ventilation and lighting	The five-point Likert scale: [1 2 3 4 5]
	Residential area	The five-point Likert scale: [1 2 3 4 5]

Table A2. Descriptive statistics for the sustainable quality indicators of relocation villagers.

Index Name	Range of Values	Average Value	
		NRCM(BNV)	D/RMM(XV)
X_1 Property management	1–5	4.07	3.20
X_2 Support of public facilities	1–5	4.08	2.97
X_3 Landscape greening	1–5	4.30	3.02
X_4 Community security	1–5	4.15	3.63
X_5 Community public places and organizations	1–5	3.3	1.98
X_6 Convenience of public transport around	1–5	4.47	4.22
X_7 Distance between the relocation area and city center	1–5	4.32	4.15
X_8 Commuting status	1–5	4.54	4.22
X_9 Stability of income sources	1–5	3.08	2.71
X_{10} Work intensity and tiredness after transformation	1–8	3.72	6.09
X_{11} Income increase or decrease situation	1–2	1.93	1.25
X_{12} Friendliness and support of community members	1–5	4.32	3.62
X_{13} Scope of making friends in the community	1–5	4.53	4.16
X_{14} Acquaintance social reservation situation	1–2	2.00	1.8
X_{15} The impact of social networks on livelihood security	1–5	3.50	3.05
X_{16} Coverage degree of self-owned social insurance	1–5	1.92	2.07
X_{17} Guarantee level of self-owned social insurance	1–5	2.96	3.20
X_{18} Satisfaction Degree of Settlement Compensation	1–5	3.93	2.48
X_{19} Willingness of residence and old-age care in the resettlement area for a long time	1–5	4.38	3.45

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Landscape Performance for Coordinated Development of Rural Communities & Small-Towns Based on "Ecological Priority and All-Area Integrated Development": Six Case Studies in East China's Zhejiang Province

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Abstract: Over the last decade, the Chinese government has focused on addressing development challenges in rural areas. The "Ecological Priority and All-Area Integrated Development" concept was thus developed, and it was found to be crucial for rural areas in Eastern Zhejiang Province. A new comprehensive evaluation system was composed by comparing and synthesizing existing Chinese assessment criteria, and landscape performance metrics developed by the Landscape Architecture Foundation. Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation Method (FCE) were used to conduct post-development evaluation on six cases using the new evaluation system. The results of four cases show that ecology should be considered a high priority when dealing with rural community and small town developments. The other two cases emphasizing infrastructure development verified that "coordinating the development of rural communities and small town area" is crucial for building sustainable and livable rural communities, and avoiding redundancy and inefficiency. The newly developed comprehensive evaluation system integrates existing systems with a broader vision and is more holistic in its objectives for the region. The development-led intervention (based on landscape performance evaluation) is conducive to the implementation of a more scientific and comprehensive development model, with predictable performance.

Keywords: ecological priority, All-Area Integrated Development; coordinated development of rural communities & small towns; landscape performance evaluation; rural landscape architecture

1. Introduction

1.1. Research Background

1.1.1. The Focus of Rural Development in the Current China Context

For decades, the Chinese government has led a series of development schemes in rural areas to meet the challenges of eco-environment destruction, population outflow and aging, decline of traditional industries, and rising demand for regional tourism services. A rural revitalization process that emphasizes the development of rural area was integrated with traditional urban development strategies.

1.1.2. Policy Guidance on Rural Construction Development of China over the Last Decade

The Chinese government began to emphasize rural construction in 2002. In 2014, the "New Urbanization" idea was introduced to orient the development of rural areas at the macro level to deal with the developmental inequalities between urban and rural areas, especially in areas of environmental management, infrastructure, public services, etc. [1]. In 2015, the "Construction of Beautiful Rural Villages" was carried out [2]. In 2018, the "Rural Community Environment Improvement" scheme was posted [3], focusing on the improvement of rural living environment, followed by the "Rural Revitalization" program, which stressed on the comprehensive development of rural areas [4]. Such rural policies evolution indicates that the guideline has evolved from focusing on rural material production to a comprehensive system of rural industry, living and ecology integration.

Because of the different regulating departments, the above rural policies focus on different concerns for different related topics. The basic contents seek to address the resolution of rural life, development of rural industry, and improvement of rural human settlements. However, systematic guidance for rural eco-environment protection, environment resource sharing, and all-area development coordination has been lacking. Under the new requirements of rural construction, it is imperative to propose the new comprehensive evaluation system. This new comprehensive evaluation framework can address more inclusive assessment of post-development and effective adoption in the Chinese region.

1.1.3. Research Brief on Rural Development of China over the Last Decade

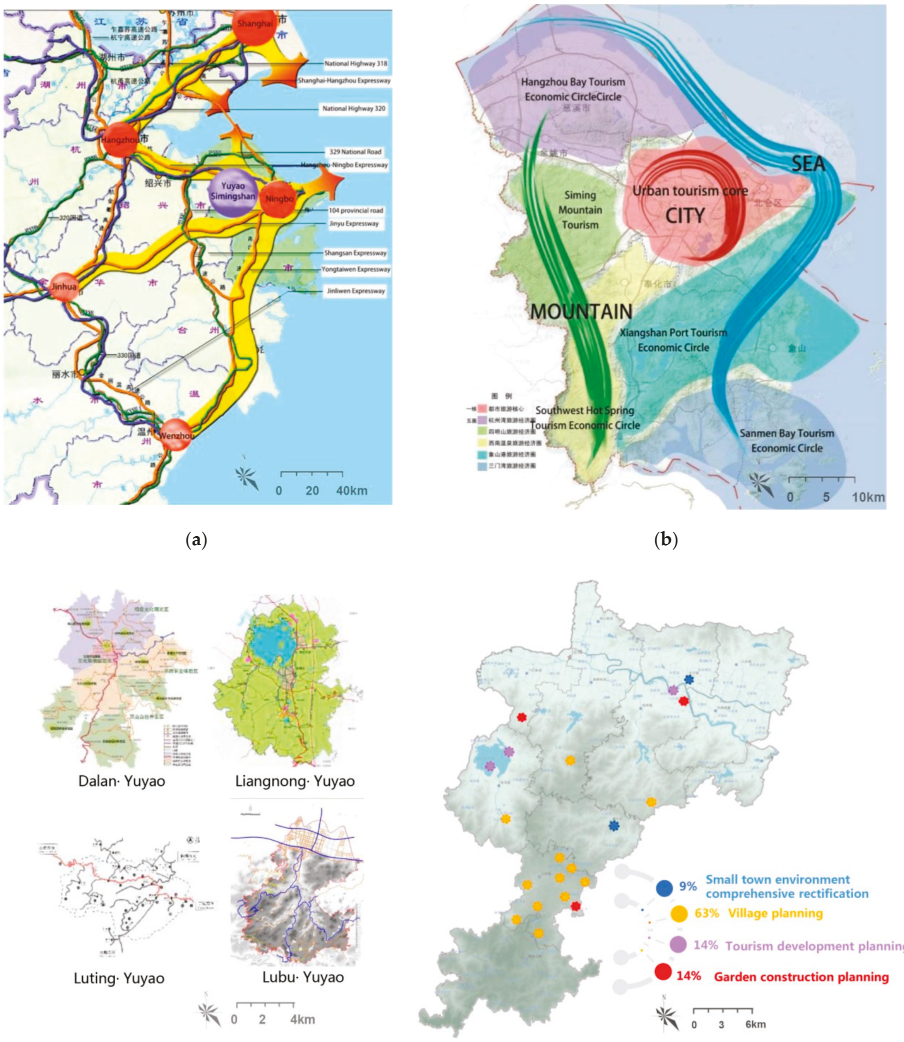
Chinese researchers Wang Zhuyun and Chang Jiangju classified China's rural construction research system as economic and industrial research, village construction and planning research, and traditional culture and local culture research. The imminence of China's rural construction was summarized in four aspects: Imbalanced regional development, imperfect rural infrastructure, the serious problem of rural community hollowing, and insufficient rural development momentum [5].

In a research work by Chinese researchers Yao Long and Liu Yuting, China's rural development model was summarized from a different level: From the perspective of development momentum factors, China's rural development model can be classified as exogenous and endogenous. In terms of space system, China's rural development model is mainly a cluster development model. In terms of regional features, China's rural areas like Wenzhou of Zhejiang, South of Jiangsu, the Pearl River Area of Guangdong, and some other places share a more common rural village-style development model. However, China's rural development model has not sufficiently integrated with rural planning. Researchers Yao Long and Liu Yuting have suggested that further study follow the spatial and regional lead [6].

2. Case Study Overview

2.1. Overview of the Cases

Since 2008, the research team has led and participated in a large number of urban and rural planning, planning and construction projects, and long-term local planning management work, most of which happened in the Siming Mountainous area of eastern Zhejiang. Through planning and construction practices, the research team obtained comprehensive environmental improvement action plans, master plans, tourism development plans, village plans, small towns plans, and regional collaborative development planning, etc., covering more than ten villages and six townships (as shown in Figure 1).



(**a**) (**b**)

(**c**) (**d**)

Figure 1. Research cases maps. (**a**) The relationship between Yuyao Siming Mountainous Area in the Yangtze River Delta, (**b**) The relationship between Yuyao Siming Mountainous Area with Yuyao city and East China Seashore, (**c**) Map of key towns: Dalan/Liangnong/Luting/Lubu, (**d**) Village & town sample cases distribution map (Yuyao, Siming Mountainous Area).

In this research, six typical cases from Dalan, Luting, Liangnong, and Lubu were selected from among a large number of cases for analysis. They cover the key locations of the overall development in the region with exemplary characteristics such as ecological advantages, livable rural residential community compatibility, regional rural tourism development booming, rural and small-town infrastructure sharing, etc. The construction cases are mainly involved in village planning cases, garden construction planning cases, tourism planning cases, small town environment comprehensive remediation cases, etc. Most of the landscape construction and infrastructure implementation has already been completed. Assessing their post-development performance will provide a holistic representation of the "Construction of Beautiful Rural Villages" Policy and the impact of its strategic vision.

2.2. The Coordinated Development of Villages and Towns from the Perspective of All-Area Integrated Development

The concept of ecological priority indicates that development should be aimed at protecting the environment and resources and conducting a circular economy development mode. The concept of all-area integrated development refers to promoting regionally balanced development through resource-sharing and coordination of symbiosis. In a 2017 work report, the Chinese government stressed on the following: "To give full play to the role of the city in leading rural areas and the role of rural areas in promoting urban development" [4]. In July 2016, the Zhejiang Provincial Government proposed that "ecological priority should be integrated throughout the region and the development of the Qiantang River should be comprehensively promoted." [7]

The urban-rural system structure of "City → Central town → General town → Central village → Natural village" that has lasted for a long time in China is a top-down chain-like, single-cycle development pattern of villages and towns. The resources acquired by cities from rural areas are more than the city's supply of products/services to rural areas (as shown in Figures 2 and 3). The resources of each village and town are divergent based on independent development, and the benefits are independent due to dispersed unrelated villages and towns (as shown in Figure 4) [8].

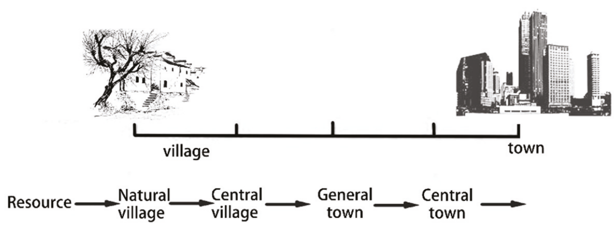


Figure 2. Chain-like, single-cycle development model of villages and towns.

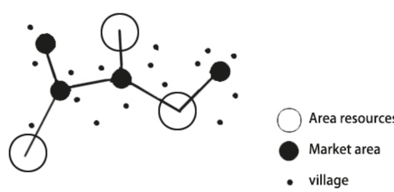


Figure 3. Independently dispersed village and town development benefits pattern.

The coordinated development of villages and towns from the perspective of "Ecological Priority and All-Area Integrated Development" represents a new form in China with a network-like pattern. The area townships, central administrative villages, and natural villages participate in the entire cycle as a node in this network system (Figure 5). Through resource-sharing and coordination of symbiosis, mutually beneficial symbiotic development of villages and towns is achieved. The comprehensive benefits are far greater than the former scattered single-chain type, which intensified resource consumption [8].

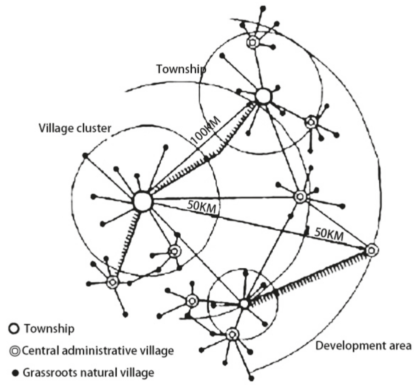


Figure 4. Reciprocal symbiosis and synergy of village and town development pattern.

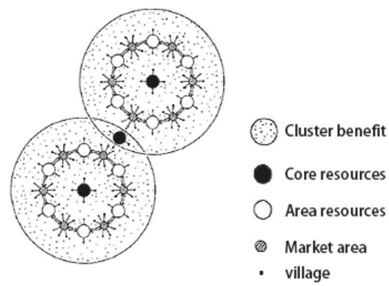


Figure 5. Multi-level, village-town synergy development model.

2.3. Coordinated Development of Villages and Towns in the Siming Mountainous Area of Yuyao, Zhejiang

The development area of the villages and towns in Siming Mountainous Area is not the typical small towns and villages scattered type. These administrative villages cover natural villages and townships with beautiful rural landscape features. It is closely intertwined with many developmental aspects of rural ecology, industry, and livability. The mountain, river, field, forest, and lake systems embodying the characteristics of beautiful rural areas are integrated into one. On this basis, the conceptual boundary of villages and towns is blurred, and the village-city synergy module is the most basic development control unit. This rural revitalization model of villages and towns can fully echo the new establishment of the national all-area land use planning, which includes the belt system of village modules and continuous village modules. In our opinion, this all-area integrated collaborative development model can give full play to achieve resources and infrastructure-sharing for peripheral towns, promoting regional linkage between various towns (as shown in Figure 6).

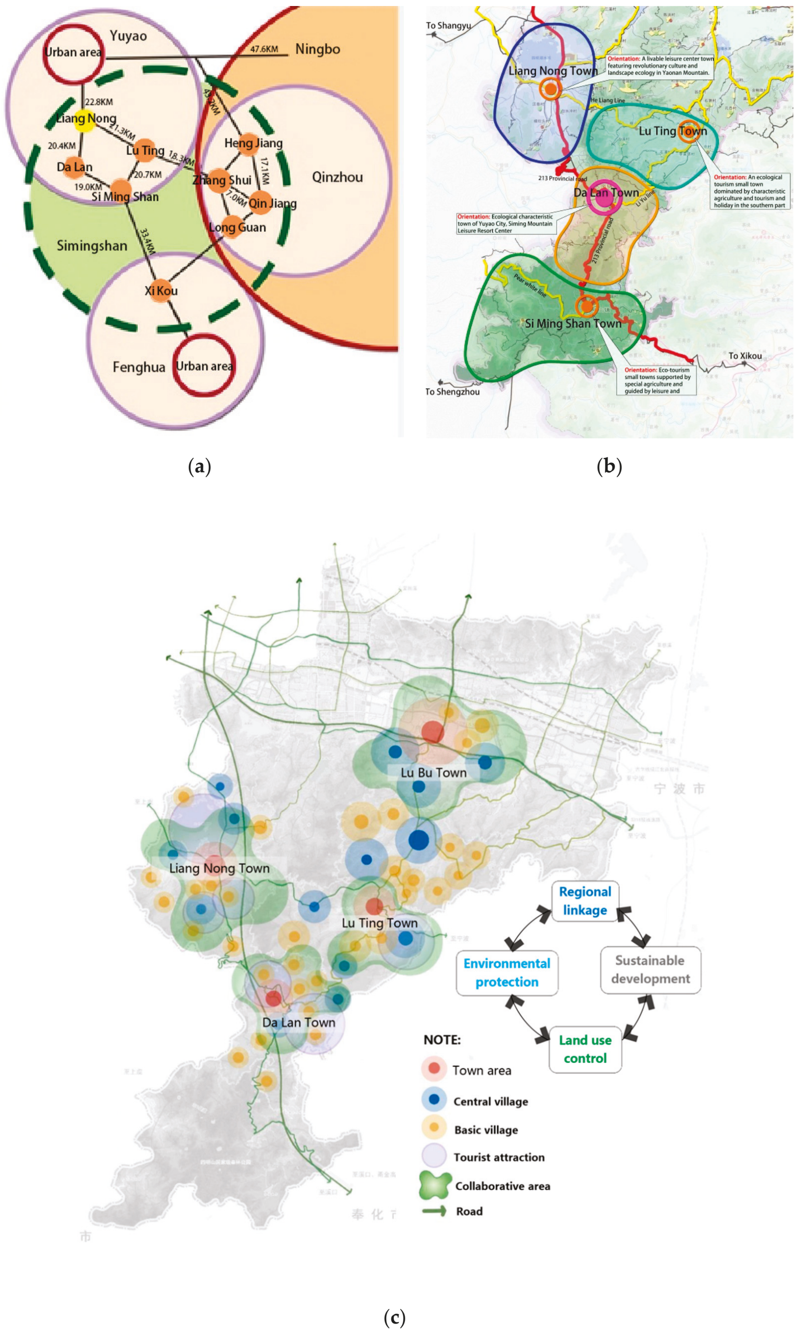


Figure 6. Coordinated development model of villages and towns in Siming Mountainous Area, Zhejiang. (**a**) Geographic relationship between Yuyao, Ningbo, Fenghua, and Siming Mountainous Area, (**b**) The Regional Relations of Liang Nong, Lu Ting, Dalan, (**c**) Schematic diagram of coordinated development of the four towns: Dalan, Luting, Liangong and Lujing.

3. Methodology

3.1. Introduction of Research Methods

3.1.1. Analytic Hierarchy Process (AHP)

Analytic hierarchy process (AHP) is a qualitative and quantitative combination, systematic and hierarchical analysis method proposed by American operations researcher Thomas L Saaty and Professor Sadie of the University of Pittsburgh in the early 1970s [9]. It is often used to evaluate the assignment weight of index weights in the system. It can greatly reduce the disadvantages of subjective assumptions (as shown in Figure 7).

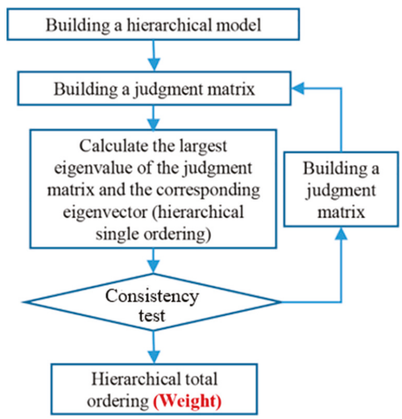


Figure 7. Analytic Hierarchy Process steps.

3.1.2. Fuzzy Comprehensive Evaluation Method (FCE)

Fuzzy comprehensive evaluation method is a semi-quantitative and semi-qualitative analysis of multi-factor events that are not suitable for quantification [10]. This comprehensive evaluation method is suitable for solving various non-deterministic problems.

The research team adopted both the AHP and FCE methods to conduct initial regional evaluation and verify the new comprehensive evaluation system based on "Ecological Priority and All-Area Integrated Development" (as shown in Figure 8).

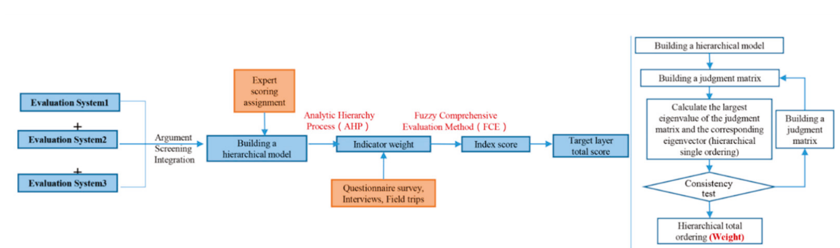


Figure 8. Steps of comprehensive evaluation.

3.2. Research Ideas and Methods

The main research objectives include two parts (Figure 9): (1) Discussion of a new comprehensive evaluation system, and (2) verification of the new system using case studies. By comparing the existing evaluation indicators of different levels and different modules, the new comprehensive rural post-planning evaluation system is formed, based on “Ecological Priority and All-Area Integrated Development”.

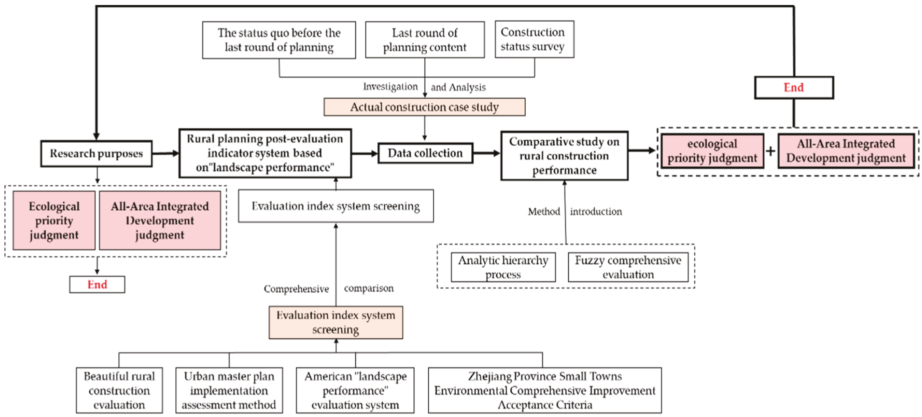


Figure 9. Research process and framework.

For the case study, the author selected different planning and construction projects around Siming Mountainous Area and summarized the pre-planning status, latest planning contents, and planning and construction status. The rural planning post-construction evaluation system based on “Ecological Priority and All-Area Integrated Development” is constructed, combined with analytic hierarchy process (AHP) [9] and fuzzy comprehensive evaluation (FCE) method [10] to conduct the cases study. Six cases were selected to conduct empirical research on rural construction performance and to demonstrate how to further promote ecological priority and all-area integrated development, and coordinate development in regional rural communities and small towns.

3.3. Development of the New Comprehensive Evaluation System

3.3.1. Overview of Existing Evaluation Systems

The Chinese government has issued guidelines for the development, planning and construction of villages, towns and small towns for a decade now. The three selected representative evaluation guidelines systems are: The 2009 “Measures for the Implementation of the Urban Master Plan Implementation (for Trial Implementation)” [11], the 2015 “Guidelines for the Construction of Beautiful Villages” [2], and the 2016 “Three-Year Action Plan for Comprehensive Environmental Improvement of Small Towns in Zhejiang Province” [7].

The introduction of these evaluation criteria has helped village and towns administrators offer strategic guidance for future development. However, each evaluation system is for a single type of planning and construction project. In the context of the new stage of land and space planning, it is imperative to evaluate the construction results of various stages covering different types of construction projects timely and effectively.

Internationally, there is the UK Annual Monitoring Report (AMR) issued by the Greater London Authority in 2004 [12], the “CASBEE-City” Evaluation System issued by the Comprehensive Environmental Assessment Committee of Japan [13], and the Landscape Performance Series released by the Landscape Architecture Foundation in the U.S. [14]. This study selected the Landscape Performance Series evaluation system as a key reference to compose the new comprehensive performance evaluation framework for systematic focus on ecological, economic, and social benefit assessment [15] (Table 1).

Table 1. Comparison of different evaluation systems.

Name	Year of Announcement	Issued by	Evaluation Object Range	Main Evaluation Content	Main Evaluation Method Used by Indicators	Advantages	Disadvantages
Urban master plan implementation assessment method	2009	Housing and urban-rural development of the People's Republic of China	City, built- town area	Implementation of planning objectives and implementation of mandatory content such as land use, transportation, industry, and environmental protection	1. Before and after planning data comparison of various indicators. 2. Site field inspection verification	1. It is a statutory planning assessment and is authoritative. 2. There are many mandatory contents, and the evaluation coverage is wide, including social and economic aspects	1. Weak cooperation between villages development.
Zhejiang Province Small Towns Environmental Comprehensive Improvement Assessment Score	2016	Zhejiang Small Town Environmental Comprehensive Improvement Action Leading Group Office	Small towns in Zhejiang Province	External image remediation as the core, including environmental sanitation, urban order, township and town appearance nodes, etc.	Field research, on-site inspection	The evaluation content is rich and fits the town construction, and it is highly targeted to the villages and towns in this research area	Indicators are too targeted to quantify, weak versatility
Beautiful rural construction evaluation index	2018	State General Administration of the People's Republic of China for Quality Supervision and Inspection and Quarantine and the National Standards Committee	Beautiful country building	Village construction, ecological environment, economic development, public service content, and software aspects such as facility management, maintenance, funding, staffing, etc.	1.Evaluation of the report 2. field investigation 3. access to on-site information	1. Part of the indicators can be quantified and accurate 2. The performance evaluation of rural construction is highly targeted and conforms to the actual situation of rural China	The evaluation of social development performance such as population is weak
US "landscape performance" evaluation index	2010	Landscape Architecture Foundation	Completed urban park green space	Ecological performance evaluation, including land, water, habitat, carbon, energy and air quality, materials and waste, economy [16]	1. Information Verification 2. Field investigation	1. In line with the requirements of the era of sustainable development 2. Has a quantifiable calculation toolbox [17,18]	1. The calculation toolbox need adaptation for practical use in China 2. The content of the evaluation indicators is too microscopic for the performance of village construction [17,18]

3.3.2. Building of New Comprehensive Evaluation Systems

The research team developed the new comprehensive evaluation system by first reviewing the four existing evaluation systems: "Landscape performance" of the Landscape Architecture Foundation (LAF) in the United States [14], "The Evaluation Method of Urban Master Plan (2009), China" [11]. "Beautiful Rural Construction Evaluation (2018), China" [2], and "Three-Year Action Plan for Comprehensive Environmental Improvement of Small Towns in Zhejiang Province, China" [3].

The "Urban Master Plan Implementation Assessment Method" [11] adopts a combination of qualitative and quantitative methods, in a bid to carry out the evaluation by comparing the data of various indicators and field inspection and verification. Due to differences in the scale of the assessment objects, the research team excluded specific indicators that are not applicable to the rural construction scenarios of its original assessment system, such as urbanization rate, intercity railways, waterways, etc.

"Interim Measures for the Assessment and Acceptance of Environmental Comprehensive Improvement Actions in Small Towns in Zhejiang Province" [7] mainly aims at the evaluation of small-town construction in Zhejiang Province. The plan is committed to improving the appearance of the town and functions based on the township's characteristics. The evaluation methods are mainly on-site inspections, and the external appearance remediation is a key factor. Other factors include environmental sanitation, townscape, and township nodes construction. The assessment index is highly targeted to villages and towns in the Siming Mountainous area, especially small towns.

"Beautiful Rural Construction Evaluation (2018), China" [2] was the newest evaluation ordinance. It covers the assessment for both physical construction and plan implementation (such as maintenance, funding, and related staffing).

"Landscape Performance" of LAF [9] mainly aims to evaluate the performance of the operational status of completed projects. According to LAF, the system covers performance categories such as land, water, habitats, carbon, energy and air quality, materials and garbage, economy, society, etc. This system has been implemented into 100 exemplary built projects to quantify environmental, economic and social benefits. It is the collaboration work of designers and/or academic research teams to collect evidence of landscape performance. It is also by far the most comprehensive metrics that has been used to assess projects on different scales—from site improvement to urban planning.

Based on the review and analysis of these four evaluation systems mentioned above, the new comprehensive evaluation system includes first-level indicators (economic performance, social performance, and ecological performance [19]) from the "landscape performance" evaluation system as the key performance framework because of its simplicity and clarity to holistically summarize landscape performance. Selected second-level and third-level indicators from the three existing China evaluation systems were included to cover the characteristics of the regional environment. Table 2 shows the new comprehensive evaluation system under the guidance of "Ecological Priority and All-area Integrated Development" (Table 2).

Table 2. Post-construction evaluation system for Coordinated Development of Rural Communities and Small Towns Based on "Ecological Priority and All-Area Integrated Development".

First Level	Second Level	Third Level	Remark	Source
Economic performance	Industrial economy	Economic strength	Gross regional product and per capita output value	Government statistics
		Industrial structure	Tertiary industry value and proportion	
		Visitor volume		Statistical report
		Resident employment type	General type of employment	Questionnaire
		Parking revenue	Tourism is more suitable	
	Social development	Urbanization rate	For small towns evaluation	Government statistics
		Aging rate		
		Rural hollowing percentage		
		Population growth rate		

Table 2. *Cont.*

First Level	Second Level	Third Level	Remark	Source
	Space usage	Residential space distribution	Planning implementation level	Satellite image observation and analysis available
		Land structure	The proportion of each type of land	Data comparison before and after planning
		Spatial structure		
	Real estate value	Residential sales price		
		Rent		
	Job	Number of jobs created		
	Tourism consumption	Site rental fee		
		Ticket income		
		Sales revenue at the scenic spot		
Social performance	Public facility	Education	Whether the construction of public facilities is in accordance with the plan, construction level and effectiveness	Government statistics, work report and interview
		Medical		
		Culture		
		Sport		
		Pension		
	Municipal infrastructure	Traffic	Whether the construction of public facilities is in accordance with the plan, construction level and effectiveness	
		Water supply		
		Drainage		
		Electric power		
		Telecommunications		
	Related policy	Public participation	Awareness of government-related policies	
		Satisfaction	Residents' satisfaction with government-related policies	
	Safe society	Flood		
		Fire		
		Earthquake		
	Culture	Ancient tree protection		
		Historical and cultural heritage protection	Whether the construction caused a breach of the ring; whether there is protection and repair work; whether it is integrated with tourism development	Site research and interviews
		Cultural activity	What specific cultural practices and cultural activities are carried out	
Ecological performance	Ecosystem	Urban air particulate reduction		
		Water source protection	Whether to protect according to the planning expectations, and the protection status quo	Government statistics and interviews
		Agricultural and forestry protection		
		Water quality	Main rivers and lakes	Data comparison
		Rainwater and sewage construction	Related construction situation	Main landscape node site survey
		Rainwater management		
		Enterprise pollution transformation	Industrial and aquaculture pollution treatment situation	Site research and interviews
		Environmentally friendly materials use	Whether it is implemented according to design	Main landscape node site survey
	Landscape environment	Green space system	Planning and construction	Government work report and interview
		Green coverage		
		Per capita greening rate	Implementation rate	Government statistics
		Main landscape node construction style	Construction status of the consistency with the planning	Photo comparison and interviews to understand the construction situation
		Street environment	Health status, interface appearance, vehicle order	
		Community environment	Sanitary facilities situation	
		Landscape satisfaction	Landscape view	Research

Notes: (blue) Village and town planning implementation assessment other content factors; (yellow) The Beautiful Rural Construction evaluation index factors; (green) Screening of American LP evaluation index factors; (orange) Zhejiang Province Small Towns Environmental Comprehensive Improvement Action Township Assessment Score factors.

The new indicator system adopts the US "landscape performance" evaluation system as the first-level indicator framework, of which the theoretical framework is also based on the three elements of sustainable development (environment, economy, and society). The determination for the secondary indicators and tertiary indicators is based on the verification of practices of village and town construction guided by "Ecological Priority and All-Area Integrated Development". This new system, through a comparative index study, is an implementation of the traditional government-led evaluation model.

The overall evaluation system is set for the comprehensive performance evaluation on the mesoscale, or intermediate scale level. As far as the village and town construction level is concerned, the traditional "landscape performance" indicators are too micro. The overall urban planning implementation evaluation indicators are relatively macroscopic, while the small-town acceptance criteria are relatively specific. In our opinion, the newly composed evaluation criteria for village and town construction should be a combined use of micro and macro indicators. It is a comprehensive study based on qualitative and quantitative research.

In the following case studies, the full Construction Performance Evaluation processing routine was applied to assess Shilin Village (Case 1), and Dalan Town (Case 5). The other four case study results were also summarized.

4. Case Study Results

4.1. Case Study 1: Landscape Implementation for Shilin Village

The landscape implementation goal is to solve the problems of insufficient space in the scenic area of the persimmon village, the tourist reception capacity, the lower level of reception and the protection of the ancient villages [20].

Through on-site investigation, field study, and questionnaire surveys, the AHP, and FCE methods were used to compare and analyze the construction before and after planning (as shown in Table 3.)

Table 3. Shilin Village Construction Performance Evaluation Case Study.

Post-Construction Evaluation Indicator System for Coordinated Development of Rural Communities & Small-Towns Based on "Ecological Priority and All-Area Integrated Development"					Landscape Construction Planning (Shilin Village–2014)			Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation								
									Classification							
First Level	**Second Level**	**Third Level**	**Remark**	**Source**	**Pre-Planning Status**	**Planning Objectives**	**Verifying Status**	**Weights**	**Best (2)**	**Better (1)**	**General (0)**	**Bad (−1)**	**Worse (−2)**	**Score**		
Economic performance	Industrial Economy	Visitors volume		Government statistics	Total number of tourists in 2015 was 500,000, visitors per day were 0.15 million/day.	The planned average daily tourist volume is 0.23 million	●After the planning, the number of tourists has increased	0.053	6	2	1	0	0	14	15.0	12.88
		Parking revenue	Mainly for tourists parking		○	●	●Increased parking lot revenue after planning	0.053	7	2	0	0	0	16		
	Real estate value	Residential sales price			○	○	●	0.053	5	3	1	0	0	13	12.0	
		House rental fee			●Accommodation was two-star level	●	●After the planning, the price of accommodation is raised.	0.053	3	5	1	0	0	11		
	Job	Number of jobs created			● The service industry level was low	●Increasing tourism services; Improving the services quality	●Tourism service projects have increased and the number of jobs has increased	0.053	4	5	0	0	0	13	13.0	
	Tourism consumption	Site rental fee			○	●	●Increased rental revenue after planning	0.053	3	5	1	0	0	11	12.0	
		Ticket revenue			●Ticket revenue is relatively stable, high income in summer and autumn season	○	●Increased whole year ticket sales after planning	0.053	6	1	2	0	0	13		
		Internal consumption within scenic areas			●23 Farmhouses, 1980 dining places, 91 beds homestay of general consumption level	Plan to increase 560 beds, improvement of dining grade	●The number of homestays has increased, and the level of dining has not improved much.	0.053	4	4	1	0	0	12		
Social performance	Cultural style	Ancient tree protection		Site research and interviews	○	16 ancient trees protection planning	Key ancient tree brand protection	0.053	4	5	0	0	0	13	12.0	12.00
		Historical and cultural heritage protection	Protection and repair work situation; tourism development integration situation		Historical and cultural buildings were generally protected; the overall construction quality was poor	To repair and protect historical and cultural buildings, to improve the surrounding environment	Repairing and improvement effect is obvious, the surrounding environment has improved	0.053	5	2	2	0	0	12		
		Cultural activity	Types of specific cultural practices and activities		Existing "Shen Clan" Sacrifice Culture, the Persimmon Festival	Diversifying cultural and folk activities	Implementation of the red cultural activities	0.053	5	1	3	0	0	11		

Table 3. *Cont.*

Post-Construction Evaluation Indicator System for Coordinated Development of Rural Communities & Small-Towns Based on "Ecological Priority and All-Area Integrated Development"					Landscape Construction Planning (Shilin Village–2014)			Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation								
									Classification							
First Level	**Second Level**	**Third Level**	**Remark**	**Source**	**Pre-Planning Status**	**Planning Objectives**	**Verifying Status**	**Weights**	**Best (2)**	**Better (1)**	**General (0)**	**Bad (−1)**	**Worse (−2)**	**Score**		
Ecological performance	Ecosystem	Water quality	Main rivers and lakes	Data comparison	●Most of the water resources were type II water	Dredging the river to improve the quality of the water environment	●Water quality has improved	0.053	5	3	1	0	0	13	12.0	12.13
		Rainwater and sewage construction	Related construction situation	Main landscape node site survey	Frequent flood disasters	Dredging the river channel to improve flood discharge capacity; greening on both sides of the mountain river channel to enhance water storage capacity; widening the river section to consolidate and strengthen flood control capacity	The implementation of rainwater management construction is better, no stormwater disaster occurs during the year.	0.053	4	4	1	0	0	12		
		Environmentally friendly materials usage	Whether it is implemented by design	Main landscape node site survey	Constructed with mostly low environmentally friendly materials	To use native stone for building walls, advocating native plants usage	Partially remodeled buildings use native stone, and more native plants are used.	0.053	5	2	1	1	0	11		
	Landscape environment	Green coverage			Village green coverage was high	Greening along the road line to enrich the plant landscape	The planning area is good in richness and variety.	0.053	4	2	2	1	0	9	12.2	
		Main landscape node construction style	Construction status, consistency with planning	Photo comparison and interviews to verify the construction situation	Node landscape was poor	Transforming and upgrading important landscape nodes, featuring the cultural context	The implementation is basically consistent with the plan, and the effect is better.	0.053	2	6	1	0	0	10		
		Street environment	Cleanness status, Street scape, parking order		Monotonous view, rough street furniture, parking chaos	Improving the street environment to create a clean and tidy street, to build a new garage for village vehicles	The street environment is upgraded to a higher level, the street facilities have been upgraded, the new garage has a high utilization, village parking more orderly.	0.053	7	2	0	0	0	16		
		Community environment	Sanitary facilities situation, and landscape view		Traditional building structures were aging, the public facilities were not perfect	Demolition and repair of certain buildings	The overall community environment has been improved	0.053	5	4	0	0	0	14		
		Landscape satisfaction		Research	○	High satisfaction	●Higher satisfaction	0.053	4	4	1	0	0	12		
								1						12.421		

Notes: ● Data to be collected, ○ Missing data; [blue] Village and town planning implementation assessment other content factors; [yellow] The Beautiful Rural Construction evaluation index factors; [green] Screening of American LP evaluation index factors; [orange] Zhejiang Province Small Towns Environmental Comprehensive Improvement Action Township Assessment Score factors.

In the evaluation process, the equal weight assignment evaluation method was adopted for each indicator input. The performance scores of the comprehensive improvement plan along the village were all greater than 0: economic performance score was 12.88, social performance score was 12.00, and ecological performance score was 12.13.

4.2. Case Study 2: Small Town Remediation Planning Project—Luting Township Market Town

The remediation project was to build the "coordination of tourism development and township construction" based on the existing scenic belt, creating a new brand for rural tourism. The key construction part is village appearance implementation on both sides of the road along the Heliang Road development axis [21].

In the evaluation process, the equal weight assignment evaluation method was adopted for each indicator input. The performance scores of the comprehensive improvement plan of Luting Township were all greater than 0: Economic performance score was 3.50; social performance score was 8.73, ecological performance score was 7.91, and comprehensive score was 6.96.

4.3. Case Study 3: Village Planning Project—Hengkantou Village

The plan of Hengkantou Village achieved four goals: (1) To restore the original spatial structure of the damaged villages. (2) Improvement of tourism reception infrastructure. (3) To prevail in development competition on the basis of featured tourism. (4) To set a leading example in the realization of "new industrialization and urbanization linkage" [22].

In the evaluation process, the equal weight assignment evaluation method was adopted for each indicator input. The performance scores of Hengkantou beautiful rural rectification plan were all greater than 0: economic performance score was 11.07, social performance score was 13.778, ecological performance score was 13.78 and composite score was 12.59.

4.4. Case Study 4: Tourism Planning Project—Along the Ring of Siming Lake

The plan was to build a robot theme park along the Siming Lake, with implementation of a leisure and holiday resort service system around the lake. The whole functional group was to integrate with the overall service system of leisure tourism in Liangnong Township and merge with the overall development plan of Siming Mountainous area [23].

In the evaluation process, the equal weight assignment evaluation method was adopted for each indicator input. The performance scores of the tourism planning projects along the Siming Lake were all greater than 0: economic performance score was 7.46, social performance score was 9.50, ecological performance score was 10.80, and the final combined score was 9.46.

4.5. Case Study 5: Concept Planning of Tourism Development in Dalan Town (2015)

Over the past decade, Dalan Town had undergone rapid all-area tourism development. As the various tourism supporting infrastructure is continuously improved, accommodation and catering for tourism entertainment and leisure activities, and public toilet services have all been implemented [24].

In the evaluation of the tourism development plan of Dalan Town, each indicator sub-item adopts the equal-weight assignment evaluation method, and the performance scores (transportation infrastructure and vacation facilities) were greater than 0: economic performance score was 18.67, social performance was 13.00, ecological performance score was 19.00, and the overall performance score was 16.89 (as shown in Table 4.)

Table 4. Construction performance evaluation case study featuring parking facilities sharing and tourism and leisure facilities in Dalan Town.

Post-Construction Evaluation Indicator System for Coordinated Development of Rural Communities and Small Towns Based on "Ecological Priority and All-Area Integrated Development" (Transportation Infrastructure and Leisure Facilities)					Concept Planning of Tourism Development in Dalan Town (2015)		Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation								
								Classification							
First Level	Second Level	Third Level	Source	Remark	Analysis of the Status Quo before Planning and Construction	Verifying after Planning and Construction	Weights	Best (2)	Better (1)	General (0)	Bad (−1)	Worse (−2)	Score		
Economic performance	Industry	Visitors volume	Statistical report		Catered more than 6.7 million visitors in 2014	Visitors increased	0.10	3	4	2	0	0	10	7.67	18.67
		Resident employment type	Questionnaire	General type of employment	●	The number of employed people in tertiary employment has increased year by year	0.10	3	3	3	0	0	9		
		Parking revenue		Mostly for tourists parking	○	Revenue largely increased in the peak season	0.10	0	5	3	1	0	4		
	Real estate value	House rental fee			●	Rental fee significantly Increased	0.10	1	2	4	2	0	2	2.00	
	Jobs	Number of jobs created			○	Tourism packages such as boutique hotels and hotels have greatly boosted employment in the tourism industry	0.10	2	3	4	0	0	7	7.00	
	Tourism consumption	Site rental fee			●	●	0.10	0	3	5	1	0	2	2.00	
Social performance	Municipal infrastructure	Traffic		Facilities Construction accordance with the plan, and construction effectiveness	One existing gas station; main road frame consist of two road lines, linking various tourist attractions and administrative villages	One tourist distribution center, three bicycle stations, 12 scenic spots VR showcase pavilions are added; over 10 bike riding trails, car driving lines, and walking trails are planted.	0.10	5	3	1	0	0	13	13.00	13.00
Ecological performance	Ecosystem	Environmental friendly materials usage	Main landscape node site survey	Whether it is implemented according to design	Villages roads were mainly old stone pavements	Using local materials such as stones and permeable grass plants for landscape implementation	0.10	2	4	3	0	0	8	8.00	19.00
	Landscape environment	Main landscape node construction style	Photo comparison and interviews to verify the construction situation	Construction status, consistency with planning	The landscape features along the main line were good	Key scenery and vista landscape nodes are further more improved	0.10	4	3	2	0	0	11	11.00	
		Landscape satisfaction	Research		General	Better	0.10	3	5	1	0	0	11		
							1						16.89		

Notes: ● Data to be collected, ○ Missing data; [blue] Village and town planning implementation assessment other content factors; [yellow] The Beautiful Rural Construction evaluation index factors; [green] Screening of American LP evaluation index factors; [orange] Zhejiang Province Small Towns Environmental Comprehensive Improvement Action Township Assessment Score factors. Source: "Dalan Town Tourism Development Concept Plan" prepared by Shanghai Xilian Urban Planning Architectural Design Co., Ltd.; "Dalan Town Master Plan (2011–2030) Partial Revision" (2016) prepared by Zhejiang Jianyuan Architectural Planning and Design Institute.

4.6. Case Study 6: Lubu Town's Overall Tourism Development Plan (2017)

Lubu Town of Yuyao City is a traditional industrial town with a focus on industrial development. In recent years, the Lubu Town Government has changed the original industrial-centric development policy to promote economic transformation to increase the excavation of tourism resources and address the increasing pressure on environmental protection. In this study, parking facilities, and concentration of tourism and leisure service facilities were selected to indicate infrastructure performance [25].

In the evaluation of the overall tourism development plan of Lubu Town, each indicator sub-item adopts the equal-weight assignment evaluation method. The performance scores (transportation infrastructure and vacation facilities) were all greater than 0: economic performance score was 8.00, social performance was 6.00, ecological performance score was 9.50, and the overall performance score was 7.83.

4.7. Comparative Study and Comprehensive Analysis for Key Findings

4.7.1. Findings for Ecological Priority

First, a comprehensive evaluation for the actual construction performance of Case study 1–4 was conducted. Then the newly composed evaluation index system factor based on US "landscape performance" evaluation was assigned, scored and compared. Finally, the comparative evaluation method was used to conduct a comprehensive comparative analysis (as shown in Tables 5 and 6).

Table 5. First-level performance indicator statistics towards ecological priority orientation.

	Luting Town	**Shilin Village**	**Along the Ring of Siming Lake**	**Hengkantou Village**
Economic performance	3.50	12.86	7.46	11.07
Social performance	8.73	12.00	9.50	13.78
Ecological performance	7.91	12.13	10.80	13.78
Comprehensive performance	6.96	12.42	9.45	12.59

Through quantitative comparison of the construction performance for different types of projects, the relatively high and low scores of economic, social, and ecological performances were observed. Comprehensive performance of the project can be obtained separately.

Table 6. Secondary level performance indicator statistics towards ecological priority orientation.

Evaluation Index System After Comprehensive Planning		Study Sample Typical Case Index Selection			
		Project Type			
Level 1	**Level 2**	**Village Planning (Hengkantou Village) In 2013**	**Landscape Planning (Shilin Village) in 2014**	**Tourism Planning (Along the Ring of Siming Lake) in 2016**	**Comprehensive Improvement Project of Small Towns (Luting Town) In 2017**
Economic performance	Industrial economy	12.8	15	8.5	1.5
	Social development	9	/	/	/
	Space usage	10.3	/	10	3
	Real estate value	11	12	7.5	4
	Jobs	12	13	10	6
	Tourism consumption	10	12	6.7	5
Social performance	Public service facilities	13.8	/	8	8.8
	Municipal infrastructure	13.8	/	12	8
	Relevant policy	13	/	7	5
	The social security	10.7	/	11	4
	Cultural landscape	14.3	12	11.3	10
Ecological performance	The ecological environment	10.4	12	11.3	8.4
	Landscape environment	12.8	12.2	9	7

Through horizontal data comparison, the final result shows that the overall performance level is basically consistent with the ranking of ecological performance scores.

It can be seen from Figure 10 that the project's overall performance is consistent with the ranking of ecological and social performance. To a certain extent, it reflects the importance of ecological priority orientation in the construction process of villages and towns in Siming Mountainous area of Zhejiang.

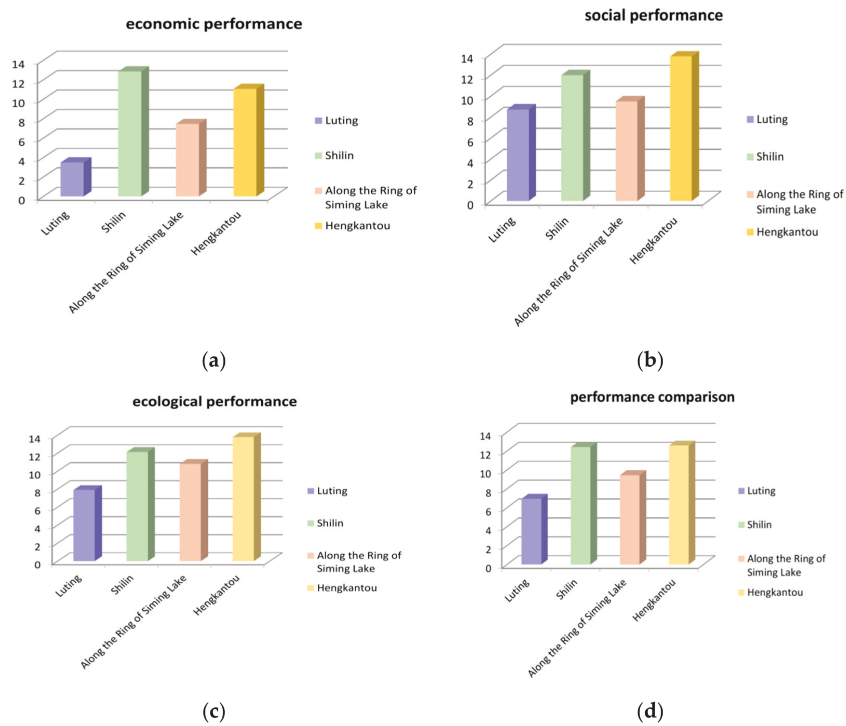


Figure 10. Project performance comparison chart towards ecological priority orientation. (**a**) Comparison of economic performance. Shilin > Hengkantou > Along the Ring of Siming Lake > Luting, (**b**) Comparison of social performance. Hengkantou > Shilin > Along the Ring of Siming Lake > Luting, (**c**) Comparison of ecological performance. Hengkantou > Shilin > Along the Ring of Siming Lake > Luting. (**d**) Comprehensive performance comparison. Hengkantou > Shilin> Along the Ring of Siming Lake > Luting.

Meanwhile, the pre-post analysis shows that the concept of "Ecological Priority and All-Area Integrated Development" is already blended into the planning and construction implementation process. After three to five years of construction, the performance scores were all greater than zero, indicating that the construction achievements are more integrated to a certain extent. Under the concept guidance of the all-area coordinating of villages and towns, each construction project can give it full play to maximize the regional sharing of resources and public facilities.

It is worth noting that this kind of comparison method has limitations, and the amount of data collected in the historical period is relatively insufficient. More research is needed to strengthen future verification.

4.7.2. Findings for All-Area Integrated Development (Analysis of Parking Facilities and Leisure Facilities Indicator)

The last two sample cases are selected from the contents of the town-wide tourism development plans. In this study the demonstration of construction performance is indicated through the aspects of parking facilities and related service facility-sharing. The two towns are all in the Siming Mountainous area. The tourism development boom of Dalan Town happened earlier, resulting in a better overall performance score of transportation infrastructure and leisure events facilities. The Lubu Town, meanwhile, used to be a traditional industrial town, which has gradually transformed in recent years.

The concept of "All-Area Integrated Development" has been leading the practice of village and town construction in the eastern Zhejiang region for a long time. The all-area tourism construction is the most direct practice based on this development concept. A comparative study of the evaluation (the parking facilities and leisure service facilities construction) of the two towns found that the performance scores and other aspects are all positive, highlighting that the towns' development is on the right path. The performance of Dalan Town (in the sharing of parking facilities and the supporting leisure events facilities) is significantly better than that of Lubu Town (as shown in Figure 11). To a certain extent, it also indicated that the effects of All-Area Integrated Development can only be obtained in the long run, since it needs a comparatively whole area integration.

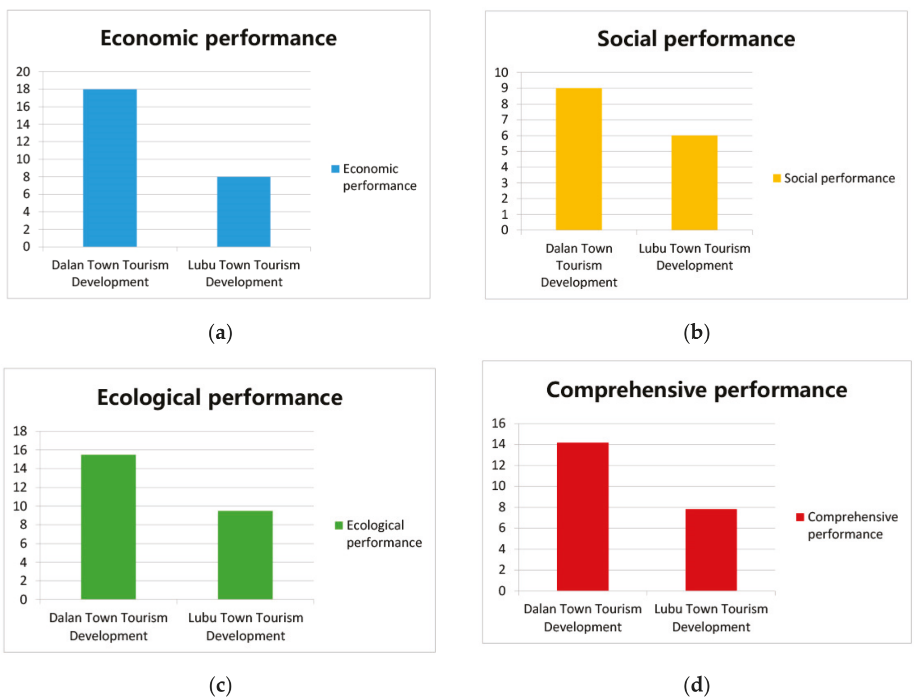


Figure 11. Project performance comparison chart towards All-Area Integrated Development. (**a**) Comparison of economic performance. Dalan>Lubu. (**b**) Comparison of social performance. Dalan > Lubu. (**c**) Comparison of ecological performance. Dalan > Lubu. (**d**) Comprehensive performance comparison. Dalan > Lubu.

This study is intended to demonstrate the use of the new comprehensive evaluation system. For in-depth understanding of the eastern Zhejiang region, more data and further investigation is needed.

5. Conclusions

In this research, the proposed comprehensive post-construction evaluation system based on "Ecological Priority and All-Area Integrated Development" is highlighted as being different from the traditional rural planning and development evaluation systems in China. By introducing the US "landscape performance" concept to existing systems, the new proposed system is more suitable for development evaluation of rural communities and small towns.

This new system is built on comprehensive performance evaluation at the mesoscale level. It is a combined use of micro and macro indicators. Through a combination of qualitative and quantitative methods, the system cites the first-level evaluation framework from the US "landscape performance" model. The overall theoretical framework is based on the three elements of sustainable development—environment, economy, and society.

We adopted this new system for six case studies located in the Siming Mountain area of East Zhejiang, China. The results indicate that the Dalan Town Tourism Development and the Shilin village landscape belt construction of Dalan showed higher performance scores. This result correlates with the unique landscape heritage advantages and livable rural residence community compatibility of the areas in our case studies. The ecological harmonious characteristics of the small-town area greatly benefit sustainable interaction of government, developers, and local community for future development priority of Dalan in the Siming Mountain region. As for the case study of Lubu Tourism Planning and Development Construction, our study found that the town should pay more attention to transforming the existing low-level industry. It should also take smart moves to integrate resources based on the "Coordinated Development" idea.

In this research, "Ecological Priority" refers to both natural ecology and human ecology. "Coordinated Development of Rural Communities and Small Towns" is implied at the spatial resources and rural socio-economic development level, which significantly enhances the highly effective resource-saving development mode. In this process, the development-led intervention based on landscape performance evaluation is conducive to the development of the overall model, which is more scientific and comprehensive, with anticipated performance outcomes. The new evaluation system can be adopted by state government planning departments, tourism agencies, real estate developers, etc. to allow for more informed, environment protection and integrated development decision-making. It can also be a great resource for future application in southeast Asian countries that have similar development patterns and climatic conditions, in a bid to conduct comprehensive evaluation of the vast area of rural communities and small towns.

Although this search uses certain construction evaluation data from 2012 to 2018, it lacks continuous tracking of many key level performance data for non-quantitative evaluation. The swift changes in rural development policies over the past decade have also had a certain impact on the evaluation results.

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Opportunities to Improve Sustainable Environmental Design of Dwellings in Rural Southwest China

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Abstract: This paper addresses the need, established following consultation with stakeholders, for more detailed environmental design guidance to support construction of more sustainable and comfortable rural dwellings in Southwest China. Despite increasing focus on sustainable design in urban developments in China, there are considerable gaps in research and information dissemination for sustainable building in more diverse rural areas. Multiple methods of investigation and analysis have been utilized. Contextual research was undertaken in relation to location, ethnic group, site/location, and building construction options. Visits to typical villages allowed discussions with stakeholders and the gathering of data on existing and new dwelling types and their surroundings. This led to the conclusion that there is insufficient attention paid in understanding residents' knowledge and skills related to design options; further specific accessible guidance is needed. Resulting from this, quantitative analyses using climate data for 46 locations in Southwest China were used to determine the value of design opportunities to create comfortable internal environments. A need for a more detailed level of guidance that can be used by the stakeholders is presented, and 15 exemplar locations were studied in parametric fashion for typical dwelling design configurations. Outcomes indicated the value of location-specific design optimization; something now recommended for all new/redeveloped dwellings. These findings impact across a wide geographical area and could benefit daily living conditions across many rural settlements in China.

Keywords: dwellings; sustainability; comfort; climate sensitive design; rural revitalization; China

1. Introduction

1.1. Background

The introduction is split into three distinct sections: the first deals with the general description of the national context and provides a definition of the research questions and purpose; the second provides a specific and focused review of published research and other documents; the third summarizes the research gap identified and research required.

The context for this research is rooted in the major changes to the buildings and landscape of rural China currently taking place; something which is now happening at a level and scale to rival previous changes to the Chinese urban environment over the last 30 years. The evident worldwide need for efficient use of resources and minimization of carbon emissions means Chinese dwelling design needs to adapt to these requirements and must incorporate better optimization for environmental comfort provision. The location of development in rural areas also means there are substantial consequent impacts on the landscape, particularly because of changes in the use of agricultural land around village dwellings. The specific emphasis of this paper reflects research and also dissemination activities with which the authors are involved through a stakeholder research network [1], and the requirements for informed change that they have identified. The following paragraphs give the background history that is needed to understand the flow of research before the activities of this paper are explained and findings revealed.

China is a country well-known for its fast developing urban economy [2], but the rural areas have not made the same economic progress by comparison; at the same time the physical fabric of rural villages has often deteriorated and has been accompanied by changes to the social structure. However, 2005 onward there was a significant government policy shift, first included in the 11th 5-Year Plan, the major component of which was assigned the title of "Building a New Socialist Countryside." It was widely reported at the time and subsequently [3], it has been the focus of much development as well as research and enquiry [4]. This national policy emphasizes on the rejuvenation and revitalization of rural/countryside areas as a part of spreading the benefits of economic development more widely across the country, and continuance of the approach was recently reaffirmed [5]. The policy has had some significant impacts linked to land use and redevelopment which is expected to be a long-term process [6]. A number of projects have been associated with this issue and were broadly summarized in a Chinese Ministry level report prepared for UN Habitat III Programme [7]. This report not only gave a historic review of changes in rural areas over several decades, it also indicated the contemporary importance of villages and rural areas from a cultural and sustainability perspective. In this context the role of landscape and landscape design is naturally incorporated into consideration of village infrastructure and layout, though the predominant thrust of change needs to consider how to make better rural dwellings. One of the other outcomes of this research is a design guide providing information and exemplars which can be used by individuals as well as practitioners and developers in rural areas.

Taking a regional view, Southwest China is unique in its history and in its cultural and natural environment: there are more than 30 ethnic groups in the region; each group with its own language, architecture, and distinctive dress. Part of the evolution of the national policy included identification of traditional (often ethnically focused) villages with the aim of developing means to protect and revive them and their associated communities [8]. The province with the largest number of designated traditional villages was Yunnan. The authors here concur with development policies which encourage such villages not simply to be preserved, but also to offer routes for economic expansion and for cultural industries development. This could make use of traditional craft and design skills linked to increased tourism; an idea reinforced by discussions about how to achieve rural village sustainability in the Chinese press [9]. This also aligns with the government policies which have increasingly put more emphasis on the sustainability of rural development and on opening new routes for transport and trade as exemplified by the "belt and road" approach. The climate and topography of Southwest China varies with weather conditions ranging from extreme cold to tropical hot-humid and altitudes from sea level to 4000 m.

The rural population in China amounts to approximately 576 million people who live predominantly in a village structured environment (be they "natural" villages or "administrative" villages). Though urbanization is taking place, there will continue to be a very large number of rural residents and more than that, the rural economy is needed to support urban areas with food and other resources. Rural redevelopment is therefore not only concerned with renovation of the fabric of dwellings and other buildings but also for supporting economic revitalization more generally. However, dwelling design and construction can be used as an indicator of change occurring and also of better understanding within communities; and as with urban areas of China, the construction industry can drive other economic benefits.

In Southwest China the range of ethnic groups to be found there means there is an extra dimension to be included in analyses as attitudes of village residents can vary as well as their requirements. Taken together with the aforementioned issues, these factors indicated the need for studies specific to SW China; studies into contemporary village development and also of attitudes and perceptions, not just among village residents but also among those likely to be involved in future revitalization.

The purpose of the research has the following narrative: First, it was necessary to research the circumstances of rural/village life beyond the mere physical attributes of the buildings in order to understand who designed and constructed them, how the construction took place, and what factors were being taken into account in the local decision-making process. Second it was necessary to appreciate the role of "bottom-up" processes/understanding since many rural dwellings are produced not by large-scale developers but by local residents building or renovating dwellings for themselves or their families and neighbors. Third, the intersection of climate and building design needed to be investigated in an organized fashion with qualitative and more importantly quantitative analysis of the outcomes of design/construction choices, and with opportunities appropriate to the location emphasized.

In order to provide geographical context, a map of China showing the provinces of interest in the research is shown in Figure 1.

Figure 1. Map of China showing the southwestern provinces.

1.2. Research Review

In recent years there has been an increase in the numbers of research projects and research outputs concerned with rural revitalization. Some of these projects helped to establish the historic, economic and cultural reasons for the types of development observed, which were initially based more on survival than development, for example as discussed by Zhou and Feng in [10]. Both internally and externally funded research such as the European Union "SUCCESS" project [11] have helped to focus attention and to identify some important themes, and particularly to move the debate about sustainability in China away from solely urban locations. This increased emphasis on rural sustainability has partly focused on how the vernacular aspects of village design and layout, in provinces such as Yunnan, can be understood and developed [12,13].

Several research groups have been investigating the specific circumstances in particular villages which has helped inform the direction of the research described in this paper, especially research on villages that are located in, or close to, Yunnan (the most southwestern of China's provinces). Xiaoyu and Beisi discussed changes in dwelling design and the transformation of the built environment in Xiaqiao Village [14], but this did not produce more generally applicable guidance. Dong and Jin [15] focused on the area now known as Shangri-La, and noted some difficulties in the understanding of cultural needs and problems when modern "urban style" dwellings are introduced. The introduction of new design paradigms and the variation from older style traditional dwellings is a source of contrasts; some research supporting the continuance and enhancement of tradition, other considering the socio-economic forces pushing toward adoption of new styles.

In order to help inform stakeholders of differing benefits and costs, a variety of decision support tools and assessment systems can be used. Environmental assessment tools have been developed in many countries over the past 20–30 years, but none of the most well-known can be applied easily in a rural China setting. Some good attempts have however been made to derive tools and methods based on specific circumstances in particular areas and which are related to SW China, for instance research of Wan and Ng [16,17], but this indicates a wider issue that must be considered—applicability in the regional context. Broader analyses have also been undertaken including for instance the more specific links to landscape [18], which also have greater relevance in rural locations. In this, some of the basic broadly set categories described are based on those in the UK's Building Research Establishment Environmental Assessment Method (BREEAM) [19].

Energy and environmental calculation techniques and assessments have been applied and published by several research groups (such as Evans and colleagues [20]), with many focused on energy consumption (this being a significant issue for resource conservation and pollution control). Most energy calculation methods have historically been associated with urban building types, but not exclusively so. He and colleagues [21] proposed a new theoretical approach for assessing rural building energy use with the aim to impact upon policy-making and assist decision-makers. Shan et al. [22] described surveys of energy use and environmental conditions for rural area examples located across China, though with a limited number of studies in the Southwest, and none in Yunnan.

There has also been research to help identify the building design features which are most closely linked to factors which determine the internal environmental conditions. Gou et al. [23], although working outside the region of SW China, identified which climate responsive strategies could be used to modify internal climate. This theme has been further developed by Pitts [24] in relation to Yunnan in the first stage of a design methodology development. These aspects are taken to a further level of analysis later in this paper where the results of climate design studies for locations across Southwest China are presented and discussed.

There are strong arguments for developing research on the sustainability of villages, such as expounded by Wang and Yang [12]. Some researchers such as Zhao et al. have however expressed concerns related to how social acceptance and public understanding of green buildings need to advance [25] and other research has shown how dwelling occupants might interpret their needs in terms of "green building" design and products post-completion of the main construction phase [26]. Gao [27] also found that there were differences between top-down and bottom-up approaches when dealing with rural village communities with specific ethnic groups; and that in some villages certain family/clan groups took a leading role in supporting development with their co-inhabitants.

The local government in Yunnan province has committed to connect all the villagers with road networks and provide better infrastructure; these features being designed and constructed by professionals. However, villagers' houses have frequently been constructed by themselves or by "amateur" construction teams with minimal checks on design for safety and performance. In the past, the shared beliefs and knowledge of building between builders and householders allowed flexible but coherent changes (for example in Dai traditional timber houses) as part of the ecological system. After new materials such as bricks and concrete began to be used for construction, the shared knowledge of building between builders and householders changed. The lack of knowledge of new materials and of understanding of the associated technology by villagers, not only led to dangerous structures being built in potential earthquake areas, but also added substantial wastes into the ecological system. New houses with non-professional build qualities often needed repair, amendment, and rebuilding in a relatively short period, particularly because of the risks linked to flooding and earthquakes.

To mitigate the problems, guidance documents were distributed to professionals working on redevelopment sites and training workshops were held for villagers; the guidance focused on two aspects. The first concerned the technical issues with the guide entitled *Technical Guidelines for the Renovating Rural Settlements in Yunnan Province*, published by Yunnan Housing and Town and Country Construction Department and Yunnan Urban and Rural Planning and Design Institute [28]. It mainly considered environment and technology requirements for: waste collection, hygiene in public spaces, water supply, transportation, and electricity supply. The aim was to improve infrastructure and public services in order to rectify the problems of "overcrowding, congestion, dirt, and chaotic system" in the rural living environment. It also aimed to solve the pragmatic issues of residents' drinking water safety, waste disposal, sewage discharge, toilet reconstruction, and other problems, and creating more "clean, tidy, and orderly" environment in the rural villages.

The second guide [29] was particularly focused on design styles and needed to take into account 18 different types of vernacular houses of ethnic groups in Yunnan that had evolved over several centuries of Chinese history. Such vernacular houses represented the traditional way of building and included ethnic people's understanding of the relationship between human settlements and natural environment in the province (several texts provide background to understanding traditional design [30,31]). The guide was entitled *Guidebook for Improving and Renovating Vernacular House Styles and Features in Yunnan Province*, published by the Yunnan Housing and Town and Country Construction Department and Yunnan Urban and Rural Planning and Design Institute. It was developed in response to the announcement of the Five-Year Action Plan for Further Improving Urban and Rural Habitat Environment in Yunnan Province (2016–2020). It focused on the themes to build a "colorful Yunnan" and a "beautiful homeland." The actions would be led by the rural and urban planning authorities, and focus on improving the qualities of people's living space avoiding the monotonous design of rural villages.

Outcomes from the programme above are not yet available, however while they did have an important focus on such environmental concerns as clean water supply and adequate waste disposal they have not properly addressed the issue of providing comfort inside either new dwellings or renovated/redeveloped older style dwellings. Gaps in knowledge relating to environmental performance therefore deserve attention.

1.3. Research Gap

Despite much effort to research and enhance design of dwellings in rural areas it seems there are still aspects not yet addressed in a sufficiently direct manner. First, there exists no contemporary and wide ranging evaluation of development taking place in the rural villages of Southwest China that adequately considers the impact of new construction techniques and materials. Further there is no directly associated assessment of the opportunities to produce or understand options for more climate sensitive design of such dwellings in the specific locations of redevelopment.

A report into research published in 2015 [32] indicated that the institutional context was strong in terms of rural agricultural research and that government departments were well-funded. It also indicated that the top-down command and control system was being replaced by more of a bottom-up individual decision-making approach. A key omission it reported however was the poor communication between the individual small-scale participants and the experts working in the subject area.

It seemed clear to the authors that there were many occasions when information on optimal environmental design was not available and which in other circumstances might have been met by additional consultants being engaged to advise on projects; something that was, and is not, generally practical in this area. There is therefore an outstanding need to deliver useful information, to both architects and to building occupants/village groups, at an understandable technical level that relates to the local area. In particular it seems that there is a need to convince owners/occupants in an appropriate way to consider sustainable or green alternatives that is relevant to rural villages more than to urban cities.

The underlying hypothesis of the research described herein is that it is possible to understand rural dwelling design needs and that it is possible to produce suitably useful and focused design guidance. The research undertaken was broken down into two distinct categories: First, "contextual research" (including a survey of village dwellings and a residents' questionnaire); and second, the process of enacting "climate sensitive design." These research themes occurred sequentially and these are therefore reported in sequence in the following sections so as to maintain the logic of the narrative.

2. Contextual Research—Materials and Methods

2.1. Introduction

This section is split into three main segments. In the first, key features of visits to rural villages are described that involved observation and recording of information on dwellings and to meet local residents and other stakeholders took place. The second explains how a series of questions evolved from discussions; questions that could form the basis of prompting residents to review and potentially revise their opinions and attitudes to new building construction. The third section explains how those issues raised by villagers and other stakeholders were converted into a series of questions that were to be tested.

2.2. Village Visits

For the first stage of the research, structured observation was the main tool utilized. A series of visits to villages in SW China were undertaken over a period of eight years; these were developed in a more organized fashion over the period from early 2016. Specific explorations of villages initially located in Yunnan but later across other provinces took place. Over the intensive research period since 2016, over a dozen villages were explored in detail and documented with a number of others also visited in a less complete way. These additional visits are not reported here but form a background of knowledge for the authors and collaborators that support the research. The information from these together with the broader information available in the literature and from research network members, created the understanding upon which the majority of the first stage research was based.

The focus of several studies was the area around the city of Jinghong, the capital of Xishuangbanna Autonomous Prefecture in the south of Yunnan. The population of Xishuangbanna is made up of about one-third ethnic Han; one-third ethnic Dai; and one-third from other ethnic groups providing a special character to the location. The area receives many tourists each year, and to meet the demand for hotels, other attractions have been developed which have tourist villages themselves.

Other studies in Yunnan took place in areas close to the city of Kunming (the Provincial Capital) and also in Guizhou province. Visits to outlying villages close to the major cities of Chongqing and Guiyang also occurred.

The process was planned to be similar in each case:

- The research team was introduced to local residents by intermediaries—local Chinese members of the research network (normally academics who also had professional roles as architects or planners);
- Village residents were engaged in detailed discussions by the research team following a semi-structured process, recording was a combination of notes taken at the time and conversation voice recording electronically; there was also unstructured discussion about residents' experiences and understanding;
- Surveys of dwellings including type and construction were carried out, including detailed photographic records;
- Different types of dwelling were visually identified;
- A review of outcomes between the research team and local academics followed the visits.

The locations of the villages were mainly within the province of Yunnan; however, the research collaboration team include participants from all the southwestern provinces shown in Figure 1. The approximate location of the villages discussed in Section 3 are shown in the more detailed map of Figure 2.

Figure 2. Detailed map of SW China showing the location of main villages visited.

2.3. Questions

As a consequence of the visits and meeting held it appeared to the authors that there were some issues which residents and stakeholders did not address during the process of selections of new dwelling design and construction. The most frequently raised issues were therefore collated and in consultation with stakeholders, a series of pertinent questions for consideration were produced. The series of potential questions were devised for two main groups:

For villager leaders: How long have you lived in the village? What is your role and how long have you been in the post? What is the main ethnic background of the residents/families? What are the major changes that have been experienced by the village? What opportunities were there for the involvement of the village leaders and villagers themselves? What have been the significant influences on how the redevelopment took place? What are the outcomes of the redevelopment? What environmental issues have arisen/been discussed? What will happen in the future?

For village residents: How long have you lived here? Where you involved in the design/construction of the dwelling? Who makes up the residents in the household? Are you content with the function/operation of the dwelling? What are the plans for the future for the dwelling—do you expect it to change? Are there any environmental issues relating to comfort and experience of using the dwelling?

2.4. Self-Reflective Questions

Following from the discussions with village leaders and residents it was concluded that there would be value in establishing a series of self-reflective, and at times provocative questions which could be used by local villagers to assess their needs. These question responded to the finding of three main types of dwelling often co-located within a village: an old traditional design (basic design with mainly wooden construction—Figure 3), a new modern design (contemporary layout and materials—Figure 4), and a hybrid design (incorporating elements of old and new—Figure 5). Discussions were developed with village stakeholders using these images to stimulate responses.

The practical limitations of working in this context meant that the authors could not meet every resident of every village and they were reliant on the village representatives for providing a fair opinion. As a result there may be bias within the results which could not be excluded in the circumstances, nevertheless even if taken as anecdotal evidence the outcomes do add to the stock of knowledge which is lacking on the topic within this area.

A series of statements developed by the authors with local collaborators was devised and suggested to the residents as being phrases that could be associated with expectation for each dwelling type to exhibit the characteristic. The categories chosen related to: understanding of construction methods and costs; the expectations of the physical fabric of the dwellings; the expected internal environments; operation costs; and of the types of occupant that might be suited to the different styles. Although respondent did not individually have experience of living in each variant of design the exercise would allow the communities collectively to consider important aspects for the future developments of their villages.

The statements were:

1. Built to last for a long time (i.e., the dwelling could be used for many years)—this question was chosen to investigate the perceptions of the expected lifetime of the design.
2. Can be constructed by local people or construction team—this question was chosen to test whether residents expect the construction process to be used within their community.
3. Expensive to build (high construction cost)—this question was chosen to examine perceptions of costs.
4. Creates comfortable (indoor) temperatures—this question was directly related to expectations of indoor climate.
5. Cost a lot to operate each year (to create/maintain comfort)—this question was chosen to examine perceptions of the costs for using heating and/or cooling systems.
6. Has good ventilation—this question was chosen to test if respondents expected high air flow rates which in turn would impact on comfort and operating costs.
7. Uses "green" (or local) materials—this question aimed to examine understanding of the source of building products.
8. Designed by an expert/professional—this question was selected to test if respondent thought particular dwelling types needs professional design input.
9. I would enjoy living here (in that house)—this question was a simple test of respondents dwelling type views.
10. Visitors (tourists) to the village would like to see it—since the village relied on tourists to visit to provide additional local income, views on whether different dwelling types meet the need would be valuable.
11. It is safe to live in if there is an earthquake—this question was chosen to test respondents' expectation about whether the different designs were more or less suited to meet problems created by seismic activity which is common in SW China.

12. This house is suitable for rural life—this question was used to examine if respondents felt the style of dwelling was suited to rural locations.
13. The owner has a good economic position (i.e., relatively rich)—this question was chosen to gain some insight into the perceptions of type with an occupants monetary worth.

Figure 3. Old traditional style of dwelling.

Figure 4. New style of dwelling.

Figure 5. Hybrid style of dwelling (under construction).

3. Contextual Research—Results

3.1. Villages Visits Observations

In this section information is provided on the villages visited and the outcomes of the studies undertaken. Twelve locations are described in order to illustrate the range of data sources though in fact the total number of villages visited during the main period of research since 2016 (which is ongoing) was significantly more. Additional material was obtained through a Chinese website with village level data available [32]. The locations of these villages are shown in the map of Figure 2.

3.2. Villages Overview

3.2.1. Damoyu

This village lies to the west of the city of Kunming at an elevation of 2200 m and situated in an agriculturally orientated area. It is becoming popular for city dwellers to acquire a property in this area to renovate as a weekend/second home investment, yet the previous local population is diminishing because of the allure of employment in the nearby city. The population is approximately 850 with the predominant ethnic group being Yi (90%) with Han (10%). It still has an area of cultivated land within the main village—approximately 0.6 km^2—of which about 20% is flat with water irrigation. Annual rainfall is 920 mm and there is associated reservoir of area 0.05 km^2. It has dwellings built in both traditional construction (mud/straw brick and adobe walls sometimes with rudimentary openings), and also an increasing number of modern glass/concrete designs. The traditional design could be expected to have low embodied energy content and to be better suited to the climate, whereas the large windows in the newer dwelling indicate potential for overheating in summer and cold in winter. The majority of older building required renovation and this is now beginning to take place; some further details can be found in Pitts [24].

3.2.2. Nuohei Village

Situated to the east of Kunming is Nuohei which lies close to the so-called Stone Forest (also known as Shilin—an area with many and often spectacular outcrops of Karst limestone). The population is approximately 1500 living in an overall area of 27 km^2 including substantial cultivated land areas. The main ethnic group is Sani (a branch of the Yi) and there is a cultural center explaining the traditions of the village. A trail leads to a hill top with structures and outlook over the area. The village was founded in 1816 and is at an elevation of 1985 m. Many of the dwellings are constructed using stone however concrete and concrete blocks are also widely used and in a number of cases they are decorated so as to appear to be made from stone and the village is often referred to as the Stone Village). Mud/straw bricks are also in evidence though as with Damoyu they are often in a poor state of repair. The village seems to be benefiting from tourism and also an influx of artists and associated professionals, perhaps because of its proximity to the Stone Forest tourist area.

3.2.3. Manzhang Village

This is a village with an already developing trade as a tourist visitor attraction in the area to the north of the main city of Jinghong in the Dai Autonomous Prefecture of Xishuangbanna in the south of Yunnan. The land area is 2.4 km^2 at an elevation of 660 m with substantial agricultural activity. There are approximately 120 households and a population of 500 almost exclusively from the Dai ethnic group. The housing was traditionally of wood structures and cladding but an increasing number of brick-concrete dwellings were being constructed. The village benefits by being located at a relatively short diversion off the main road leading to significant tourist attractions such as the Wild Elephant Park and areas where the traditional water splashing ceremonies take place. The villagers actively derive benefit from the visiting tourists by selling craft items and food as well as by performing traditional dances and other rituals.

3.2.4. Shayao Village

Also in Xishuangbanna the Shayao Township west of Jinghong was visited. It consists of four settlements covering an area of 21.8 km^2 at an altitude of 895 m. The area has a varied crop agricultural base and is populated by about 1200 inhabitants in over 250 households. The main ethnic groups are Hani (approximately 63%) and Lahu (37%) and the main housing construction varies between the traditional wooden structures and an increasing number of concrete-brick variations. The location was visited with a local guide who was able to facilitate discussions with local residents and this enabled opinions to be sought. There were few significant developments related to the tourist trade although along the main roads additional restaurants and small shops were emerging. Many dwellings retained their traditional characteristics and materials but were often over-layered with new construction and materials to create hybrid variations.

3.2.5. Manjinghan Village

This ethnic village is a relatively prosperous but modern village in the south of Jinghong consisting of eight sub-villages. The population was about 2700 with the vast majority being of Dai ethnicity. The area is suitable for planting a variety of crops and is well connected to the main city. Here the linkages between old and new seemed to be less contrasting and the village has a feel of organization and relative affluence. Buildings were almost universally of a modern style and most residents had employment links within the family to the nearby city. Traditional celebrations took place and there were some attempts to direct visitors to take advantage of local facilities including restaurants.

3.2.6. Jinga Mang Village

Jinga Mang has a number of component parts and lies at an altitude of 572 m. With a population of approximately 600 in about 130 households. Dwellings were a mixture of traditional wooden structures and modern brick and concrete. Within this area was a small settlement known as Meng Mong with an area of 2.25 km^2 which was identified as having a good collection of traditional Dai wood structure and wood clad dwellings, each of which was visited by a member of the research team. Detailed drawings were made to establish the basic parameters associated with the Dai ethnic group represented. There was little evidence of attempting to market the village for tourism and the traditional designs predominated.

3.2.7. Qinsou Village

Qinsou village is located in the region of Dali, a city with well-known tourist attractions in western Yunnan although this village is sufficiently remote that it draws little current tourist benefit and is relatively poor. The village has eight settlements within it and has an area of 29.1 km^2; it lies at an altitude of approximately 1976 m, and the main industry is agricultural crops. There are about 750 households and a significant population of about 3300 and the dwellings of both traditional and modern designs; however visits across several years showed that the older style traditional buildings which had been in a poor condition were being replaced by concrete structures.

3.2.8. South Wuligiao Village

This village is also located in the Dali area and has stronger potential for tourist related development. There are six ethnic minorities represented, of which the largest is a Muslim group but Han, Bai, Yi, Zhang, and Naxi are also found. A substantial amount of proactive development led by the locals has taken place in order for the villagers to benefit from tourists, including multiple restaurants and food shops as well as approximately 40 hotels. Traditional houses in this area were constructed from stone and skills in its use have passed down through generations, now three variations are visible depending on time-period of construction.

3.2.9. Qinkou Village

Qinkou village is located in Yuanyang County of Yunnan at an altitude of approximately 1575 m. It has a long history going back to 200 BC. The hilly location means the land has less cultivation potential and agriculture is dominated by rice production and the use of terracing for growing crops. The area of the village is 3.1 km^2 with 185 households and approximately 900 residents; the ethnic group is almost exclusively Hani. The village had few amenities until a development programme was introduced leading to the establishment of the Qinkou Hani Folk Cultural and Ecotourism Village in 2000. This had major impacts on the village in terms of construction and development and included establishment of franchise stores, handicraft shops, and hotels/household visitor accommodation. A feature of the dwelling construction is the "mushroom" dwelling, so called because of its shape, although modern variants are not always constructed in the traditional manner.

3.2.10. Dahuang Village

This village is located in Nayong County in the region of the major city of Guiyang; it is also in one of the most visited tourist areas famed for its flower displays. This area illustrated a different problem associated with the redevelopment that is associated with tourist enhancement. In this case villagers were being relocated to a new area and provided in the main with new style concrete and brick dwellings but with little obvious recognition of the local climate. Older inhabitants of the village were housed in more traditional wooden buildings. The authors were able to recognize an unmet need to information as well as resources to optimize dwelling design.

3.2.11. Manbayue

A number of villages, such as Manbayue, situated very close to the border with Myanmar were visited with the help of the local Design Institute in Jinghong. Manbayue is a village that lies at an average altitude of 920 m and split into two halves—one in a valley and one atop a hill covering an area of 1 km^2, and with a population of 190 people. These locations were considered significant because at the time it had been reported that some of them were of such poor quality and in a very bad state of repair that it was expected the villages would be demolished within a relatively short period of time. Such villages are very much "on the edge," quite some distance from the main towns.

3.2.12. Chenggong Urban Village

Chenggong was a rather different type of village and very much in contrast to the border villages; it was in a location that had been swallowed up by the expansion of the main city of Kunming in Yunnan. The wider area was designated more than 10 years ago as the center for a redeveloped university zone—effectively becoming a small city in its own right to house the major campuses of approximately a dozen universities. The original village was a rural affair separate from the city with flower cultivation and vegetable growing the predominant industries. With the redevelopment the village lost most of its land but was well-compensated. Many former residents now own apartments in the area though some of the original village still stands (as of 2019) and many buildings have been adapted to provide services for local university students and visitors. The village leader was keen to explain the benefits that had accrued from the redevelopment and the management processes that had been put in place for longer term community support schemes to operate.

A summary of the main village features and characteristics is provided in Table 1.

Table 1. Summary of village characteristics.

Village Name and Location	Population and Main Ethnicity	Topography	Type of Area and Connectivity	Predominant Original Housing Construction
Damoyu, Kunming, Yunnan	Pop: 850; Yi: 90%; Han 10%	Hilly area; elevation 2200 m.	Rural area; approx. 10 km from city; good road connections	Adobe brick
Nuohei, Kunming, Yunnan	Pop: 1500; majority Yi ethnic group	Hilly area; elevation 1985 m.	Rural area; approx. 90 km from city; adequate road connections	Stone materials
Manzhang, Xishuangbanna Yunnan	Pop: 500; majority Dai ethnic group	Flat area; elevation 660 m.	Rural area; approx. 10 km to nearest town; adequate road connections	Timber/bamboo; main family area raised on stilts/columns
Shayao, Xishuangbanna, Yunnan	Pop: 1200; Hani 63%; Lahu 37%	Hilly area; elevation 895 m.	Rural area; approx. 10 km to nearest town; just adequate road connections	Timber/bamboo; main family area raised on stilts/columns
Manjinghan, Xishuangbanna, Yunnan	Pop: 2700; Mainly Dai ethnic group	Flat area; elevation 580 m.	Semi-rural area; approx. 5 km to nearest town; good road connections	Timber/bamboo; main family area raised on stilts/columns
Jinga Mang, Xishuangbanna, Yunnan	Pop: 600; Mainly Dai ethnic group	Flat area; elevation 572 m.	Rural area; approx. 5 km to nearest town; adequate road connections	Timber/bamboo; main family area raised on stilts/columns
Qinsou, Dali, Yunnan	Pop: 3300; Mainly Bai ethnic group	Flat area; elevation 1976 m.	Rural area; approx. 5 km to nearest town; good road connections	Adobe brick
South Wuliqiao, Dali, Yunnan	Pop: 1500; Varying ethnic groups	Hilly area; elevation 2100 m.	Peri-urban area; approx. 5 km to nearest city; adequate road connections	Stone
Qinkou, Yuanyang, Yunnan	Pop: 900; Mainly Hani ethnic group	Hilly area; elevation 1575 m.	Rural area; approx. 35 km to nearest town; adequate road connections	Rammed earth walls with thatched roofs
Dahuang, Bijie, Guiyang	Pop: 1060; Han, Yi, Miao, Chuanqing, ethnic groups	Flat area; elevation 1470 m.	Rural area; approx. 15 km to nearest city; adequate road connections	Timber structure houses
Manbayue, Xishuangbanna, Yunnan	Pop: 190; Mainly Dai ethnic group	Hilly area; elevation 920 m.	Rural area; approx. 20 km to nearest town; limited road connections	Timber/bamboo; main family area raised on stilts/columns
Chenggong urban village, Kunming, Yunnan	Pop (whole area) 350,000; 7% ethnic groups	Flat area; elevation 1800 m.	Urban village/peri-urban area; main city 25 km; very good road connections	Traditional houses of timber structure with adobe bricks

3.3. Contextual Analysis Results from Village Visits

3.3.1. Dwelling Construction

In terms of building redevelopment, the authors found that although local Planning and Design Institutes should (and in some cases do) have a significant leading role, but in meetings with villagers they explained how residents often found ways to bypass advice in order to build quickly once the finance became available. Examples of contrasting styles that might result are shown in Figures 6 and 7; both are from the same village (Damoyu near the city of Kunming). Figure 6 shows a dwelling after being rebuilt using traditional techniques (mud and straw wall bricks); Figure 7 shows a much larger building with large windows—a dwelling which almost fills its whole plot. In this village as with many others there was also what seemed to be a degree of uncontrolled building on what had previously been agricultural land—Figure 8 illustrates one such example.

In discussions with local residents there does not seem to have been any account taken of environmental design needs or comfort in the design and construction process in the more modern examples. The outcome seems to be more of an attempt to emulate the kinds of dwelling features and conveniences found in urban developments; something to be aspired to; and yet something which appears to be a loss to the value and benefit of the rural site and landscape, with potentially negative impacts on the natural visual landscape. Observations of buildings designed and constructed by professionals (such as architects and engineers) also indicated that there was a lack of suitable material to support their decision-making.

Finding 1 from this research is a general lack of information and support to enable the detailed environmental design and control of construction of village dwellings; something which is particularly acute in relation to self-building by village residents.

Figure 6. Damoyu—renovated mud and straw brick/adobe building.

Figure 7. Damoyu—large scale new style dwelling.

Figure 8. Damoyu—new dwelling amidst agricultural land.

3.3.2. Demolition vs. Renovation

A second main outcome from the village visits was the discovery of an expectation among a significant number of residents/stakeholders that many traditional buildings would be demolished. This was almost a presumed outcome, thought of as automatic part of the rural revitalization exercise taking place in their locality. It was accompanied by an expectation that official recompense would provide sufficient funds to permit a new building to be constructed. This gave rise to more general preferences for demolition rather than renovation, so that some avenues for redevelopment were being excluded and within this no calculation of lifecycle environmental costs was being determined.

This situation had been found to be particularly prevalent in some areas of Xishuangbanna in Southern Yunnan. However, on a subsequent visit to the same area approximately 10 months later, policies seemed to have changed and a renovation/rebuilding manual had been produced in conjunction with the local Planning and Design Institute; this guided assessors as to the options. Four categories of disrepair were identified with remediation support rather than full demolition being considered in all but the worst cases. In addition, the manual offered detailed guidance as to how repairs ought to be undertaken and the linking of the assessment process to associated commissioned professionals meant that more and different outcomes became available. The promotion of this alternative route had both the potential to increase sustainability and also to maintain the traditional appearance of the villages.

A further related outcome concerned the changes to appearance taking place in villages which were being supported for tourist purposes: Figures 3 and 4 show dwellings that exist within 100 m of each other in the tourist village of Manzhang a little to the north of Jinghong in the Dai Autonomous Prefecture of Xishuangbanna. The traditional design evident in Figure 3 is most readily be associated with such an ethnic minority village using mainly wood construction and few modern materials. Yet there seems to be little restriction on the construction of concrete block and tiled roof dwellings in Figure 4 adjacent to the traditional styles. The modern designs enjoyed modern facilities which were attractive to residents although conversations with several families in the older properties did not reveal any particular areas of dissatisfaction.

Finding 2 is the need to offer some practical alternatives to demolition of older/deficient properties where possible and also to recognize that there was some value in the traditional design. In order to achieve this, design and reconstruction guidance documents need to be available. In this way renovation could provide some mitigation of the environmental and material resources costs of complete loss and replacement of a dwelling and also support the overall aims of the redevelopment/revitalization programme.

3.3.3. Hybrid Design Alternative

An interesting development found in several locations was the evolution of a "hybrid" design of dwelling—an option which retained some of the design characteristics of the traditional form but which incorporated a number of modern features. The term hybrid can imply a number of different possibilities. In this case it reflects the emergence of a form of design and construction which respects the cultural typologies, the methods and the materials found in traditional dwellings, but which are embellished by use of some modern materials and construction processes. These hybrids are not representative of a fake authenticity and are clearly evident as a different type. The willingness in some villages to embrace the new techniques also indicates potential for other variations that will be considered in Section 4 below.

In the example shown, the upper floor of Figure 5 incorporates glazed openable windows and provides for more control over the principal living space environments. These dwellings have shaded activity and storage space on the lower level and also the overall volumetric proportions and roof shapes were similar to traditional ethnic styles; in this way some of the traditional design values and appearance were retained.

Finding 3 is that alternatives to the simple "old vs. new" model of dwelling design can be found that have value. Opportunities to develop hybrid designs seem to have the benefits of marrying the old to the new and striking a balance between tradition and modern convenience.

3.3.4. Embedded Village Expertise

An important social feature of each village was the degree to which there was embedded level of expertise among the residents and interest to understand the environmental and green design. This was also linked to the degree of community engagement with the procurement and construction process that took place. Variations were found to exist between villages often located in the same area and to a certain extent it appeared to vary according to the ethnicity of the family background of the residents. This is important because many renovation projects require active participation by residents if the outcomes are to reflect ethnic styles and help support tourism. The value of knowledge and understanding among family and clan structures—particularly in the ethnically strong villages—allowed "bottom-up" influences to percolate through to improve final product quality. This reinforced previous studies into functioning of redevelopment at village level [27].

Conversely, a worrying trend found in some villages was a relatively poor standard of craftsmanship and attention to detail where "top-down" had been the predominant construction influence. Materials and construction methods giving an overall impression of matching to form and type were used but closer inspection indicated a poor level of finish and thus risks for the longevity of the finished dwelling. There were also occasions where even in older styled dwellings, traditional construction techniques and materials had been replaced with modern alternatives. This would seem to indicate a loss of local craft skills, something which ought to be addressed in the near future both to ensure the appearance of the buildings are of the quality that would be valued by tourists and also to avoid situations of danger or collapse.

Finding 4 was the identification of variations in embedded knowledge and skills within villages and sometimes a lack of community involvement in the redevelopment process. The fact that a village had a specific ethnic minority focus seemed to be more important in avoiding the difficulty than the identity of the ethnic group. This would indicate that a village with ethnic traits might have better potential to use intrinsic knowledge and skills capabilities required for successful redevelopment.

3.3.5. Socio-Economic Changes

In terms of socio-economic development many villages were populated during the day by the elderly and children, and among other residents there was a gender bias toward females. Depending on the distance from major towns or cities, a number of residents (predominantly male) were often absent during the day or for the working week (and often much longer) while employed elsewhere. The actual period absent seems to have been linked to the travel time to larger centers of employment. Accompanying this was an observation that the tending of the agricultural land was often taken on by the older generation (Figure 9).

Figure 9. Rural agricultural work becoming domain of older female residents.

It is also the case that as a result of tourist visits many villages have tried to develop their own activities offering food and drink, ethnically themed goods and souvenirs, and dance events or other rituals. This has brought economic benefits, which when combined with other support has allowed redevelopment and enhancement of the built environment in the villages. Those members of the village community engaged in such tourist-orientated activities were also more often likely to be older and female.

Finding 5 is that changes to the social structure of the village could impede development in the future because of gender and age biases, and that skills-based knowledge, understanding, and practice need to be supported and re-embedded within communities. This would give more authenticity to the tourist/visitor experience.

3.4. Contextual Research—Self-Reflective Questions

In order to test the value of using self-reflective questions they were embodied in a short questionnaire distributed to a limited number of residents in one of the villages visited. All villagers to whom the questionnaire was offered took part and all indicated it had value for them in considering options.

The testing of the questionnaire survey gave rise to 34 verified responses; the data are summarized in Table 2.

Table 2. Proportion of respondents identifying the house type matching to each statement (note totals may add up to more than 100% as respondents were allowed to vote for more than one option).

Matching Statement	"Old" Style	"New" Style	"Hybrid" Style
Built to last for a long time (can be used for many years)	21.2%	46.2%	32.7%
Can be constructed by local people or construction team	24.5%	51.0%	24.5%
Expensive to build (high construction cost)	8.3%	61.1%	30.6%
Creates comfortable (indoor) temperatures	23.3%	34.9%	41.9%
Cost a lot to operate each year (to create comfort/maintain)	30.8%	51.3%	17.9%
Has goodventilation	37.0%	17.4%	45.7%
Uses "green" (or local) materials	33.3%	7.4%	59.3%
Designed by an expert/professional	27.5%	40.0%	32.5%
I would enjoy living here (in that house)	8.1%	40.5%	51.4%
Visitors (tourists) to the village would like to see it	24.5%	2.2%	73.3%
It is safe to live in if there is an earthquake	50.0%	9.6%	40.4%
This house is suitable for rural life	50.0%	32.7%	40.4%
The owner has a good economic position (rich)	10.5%	76.3%	13.2%

The results in Table 2 indicate substantial variations in opinion even within a small community and is an indicator of a gap in knowledge and understanding. Finding 6 arising from this survey is that there is substantial value in encouraging local residents, who are increasingly having to make design and construction decisions for themselves in their own locality, to use self-reflective questions to stimulate discussion. The outcomes from such a process can then be used as part of the community decision-making process.

It was also clear from discussions with the test group that there was insufficient information available to understand or make informed choices. Conversations and discussions held with stakeholders about the sorts of information that would be valuable fell into several categories, prominent among which was the need for better guidance on choices to achieve climate sensitive and energy efficient outcomes. This led as consequence to the development of the environmental design assessment process explained in the following section.

4. Climate Sensitive Design—Materials and Methods

4.1. Bioclimatic Design Techniques

The authors considered the needs expressed and summarized at the end of Section 3 and the most effective ways in which these might be derived and communicated to stakeholders. The technique of Bioclimatic analysis and design seemed most appropriate and most closely related to the intrinsic knowledge and expectations of the stakeholder group; this technique was therefore chosen and developed for the local context.

Buildings exist to provide shelter and comfort for occupants. There are many variations in such features as orientation, envelope construction, and use of a building which will affect how comfort can be achieved. In order to meet the needs for guidance, bioclimatic analysis tools have evolved to help make choices in basic building design so as to optimize the performance in relation to climate. Their use is predicated on the notion that better environmental building design will reduce or eliminate the need for energy use in conventional heating and cooling systems to produce internal conditions suited to the occupants.

While historically there was an expectation that building designers/constructors would naturally use local and intangible knowledge to build using methods suited to climate, modern expectations for comfort mean better predictive tools are needed. Current techniques of bioclimatic design, which have great quantitative comparison potential, have developed from studies by a number of researchers and practitioners. Significant among these were the Olgyay brothers [33] and researchers such as Givoni [34] and Szokolay [35].

A knowledge of building technologies and techniques combined with information on climate enables preferential design choices to be made and the improvement in comfort to be assessed in a quantitative way. The analysis also provides a visual indication of the hourly values of climate data that can still provide comfort inside a building if appropriate techniques are used by projecting information onto a psychrometric chart (see Figure 10). There have been previous studies in China [36] using bioclimatic analysis, and of course the general techniques are well-known.

Although the potential for the use of such techniques has to some extent already been identified, there is still an assumption in some quarters, and indeed embedded with official documents, that China can be subdivided into just five climatic regions: severe cold region, cold region, hot-summer cold-winter region, hot-summer warm-winter region, and the temperate region. Although these simplified regions have been used in many studies such as those of Sun [37] the authors here content that more location specific analysis is necessary.

The version of the bioclimatic tool used here is that embodied in the "Climate Consultant" software package [38]. There are a number of variations of software product but this has been chosen because it is well-used and freely available. The climate data is usually provided in the EnergyPlus Weather (epw) file format though it can be initially generated by a number of methods. In this case data were downloaded via the EnergyPlus weather data website [39] which contains information on 46 locations in SW China (from the provinces/regions of Yunnan, Guangxi, Guizhou and Sichuan/Chongqing). In most cases Chinese Standard Weather Data (CSWD) files were used for consistency. These weather data files were developed as a database by the Department of Building Science and Technology at Tsinghua University and the China Meteorological Bureau [40].

The range of environmental design technologies and techniques that can be selected from within the software has 16 variations, including basic comfort conditions (that is those external conditions which are already in the comfort range) and also including conventional heat and cooling. The full list is shown in Table 3, however, for the purposes of the analysis here the options were restricted to those which are completely passive in nature—that is, they do not require energy to function in use. In this study any technique which might require significant intervention by the building occupant has also been classified as active.

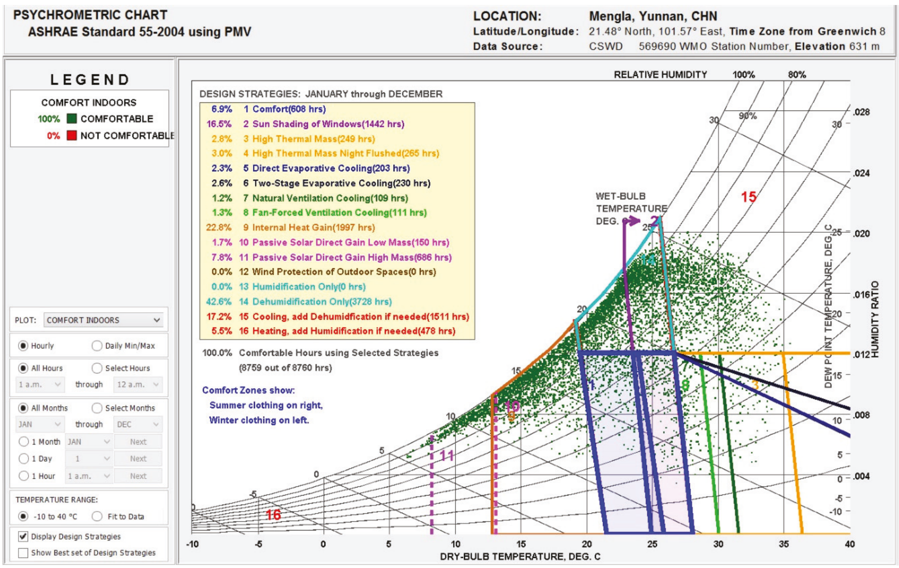

Figure 10. Example of bioclimatic analysis with visualization using the psychrometric chart for Mengla, Yunnan (image constructed using Climate Consultant Software [38]).

Table 3. Identification of environmental design techniques for bioclimatic analysis.

Identifier Number	Technique	Passive or Active
1	Comfort	Passive
2	Sun shading of windows	Passive
3	High thermal mass	Passive
4	High thermal mass night flushed (ventilated)	Passive
5	Direct evaporative cooling	Active
6	Two-stage evaporative cooling	Active
7	Natural ventilation cooling	Passive
8	Fan-forced ventilation cooling	Active
9	Internal heat gain	Passive
10	Passive solar direct gain low mass	Passive
11	Passive solar direct gain high mass	Passive
12	Wind protection of outdoor space	Passive
13	Humidification only	Active
14	Dehumidification only	Active
15	Cooling add dehumidification if needed	Active
16	Heating add humidification if needed	Active

The comfort calculation option chosen was that of the "ASHRAE Standard 55 and Current Handbook of Fundamentals Model" incorporating the predicted mean vote (PMV) modelling process. In addition, changes were made in compiling the data to take into account the potential for adaptive behavior for the occupants of the dwellings as set-up within the software. Data for the 46 locations in Southwest China were used to determine the predicted improvement in comfort as a percentage of hours for the year for those passive options. Outcomes are summarized below in Section 5.

4.2. Detailed Prediction of Internal Conditions

In addition to making an assessment of the potential of passive techniques to be used for each of the 46 locations for which climate data are available, it was also chosen to carry out a more detailed energy analysis in the form of a parametric study for a smaller representative range of locations. The purpose of this was to quantify in more detail the building features that were linked to significant variations in internal conditions and thus to enable design guidance suitable for use by stakeholders, to be determined.

In order to test and demonstrate the potential for the localized technique, 15 locations from the original 46 were selected. This selection consisted of the capital cities of each province and 10 further locations which were representative of a wide range of rural climates and which would not be expected to experience heat island effects. In any choice that is to be made here there is a degree of selectivity but the purpose of the activity is not to provide a complete design guide for all locations, but rather to indicate the value of carrying out such an activity. This then supports advocacy for the process for any village development location that might occur at some point in the future.

The location list used was: in Chongqing—Shapingba, and Youyang; in Guangxi: Hechi, Longzhou, and Nanning; in Guizhou: Bijie, Guiyang, and Sansui; in Sichuan: Chengdu, Huili, and Songpan; in Yunnan: Deqen; Kunming, Mengla, and Yuanjiang.

The analysis tool chosen to perform the analysis was EnergyPlus—this is also well-known and generally freely available so that researchers based in China would have opportunity to develop outcomes further.

A simple building model was defined in conjunction with Chinese collaborators/stakeholders which was based on typical new dwelling design being constructed in villages. The reason for this choice came from the analyses of the villages and the choices being made by their inhabitants. The new modern style of swelling was becoming the predominant choice for new builds yet the survey of residents had suggest a significant degree of dissatisfaction. Other studies reported earlier also indicated a lack of guidance for local village stakeholders more generally and that the development of a systematic evaluation was required. The analysis undertaken aimed to provide guidance which would be of most value to those involved with designing "new" style dwellings rather than renovation of traditional styles, though of course the information would still be of use more generally, if applied sensitively by professional designers.

A relatively simple but representative building model of the new design option was set-up and a number of features varied in a parametric fashion in order to derive simulated outcomes for comparison. For this stage of the research the number of options was limited so as to enable identification of strands for development in the future.

The main characteristics/features of the simple building were:

- Key external dimensions: width: 7.8 m; depth: 8.1 m; 2 floors—floor to floor height 3 m; intermediate floor 0.1 m concrete;
- Double wood door to front elevation 2.4 m high, 1.4 m wide;
- Walls: main component thickness (without insulation or cavity) = 0.24 m;
- Windows: 1.5 m in height; bottom of window 0.9 m above floor; glazing only to front (main) façade and rear façade; variations in window size accommodated by changing the width;
- 2 occupants per floor (1 met activity level); clothing insulation value: 0.7 clo; no other heat gains apart from occupants were incorporated due to the level of complexity.

A series of parametric alternatives were then chosen for other building features:

- Four principal orientations: north, east, south, west;
- Three glazing options (all single glazed): low glazing ratio: front window to wall area ratio (WWR) = 0.2, rear WWR = 0.15; medium glazing ratio: front WWR = 0.35, rear = 0.25; high glazing ratio: front WWR = 0.5, rear WWR = 0.35.

- Three variations in construction with different thermal impacts: Heavyweight: load bearing concrete frame with dense brick infill walls plus 0.015 m internal plasterboard finish; concrete roof structure 0.1 m thick, concrete floor 0.1 m thick; Lightweight: lightweight concrete block walls plus 0.015 m internal plasterboard; concrete roof structure 0.1 m thick, concrete floor 0.1 m thick; Lightweight with Insulation: lightweight concrete block walls with internal insulation of 0.1 m; plus 0.015 m internal plasterboard; concrete roof structure 0.1 m with 0.1 m internal insulation, concrete floor 0.1 m (no insulation).
- Ventilation rates: 0.25/0.5/1.0 air changes per hour.

A sketch illustration of the building basic model is shown in Figure 11; thermal properties for the construction elements were those available from the standard libraries of data for EnergyPlus.

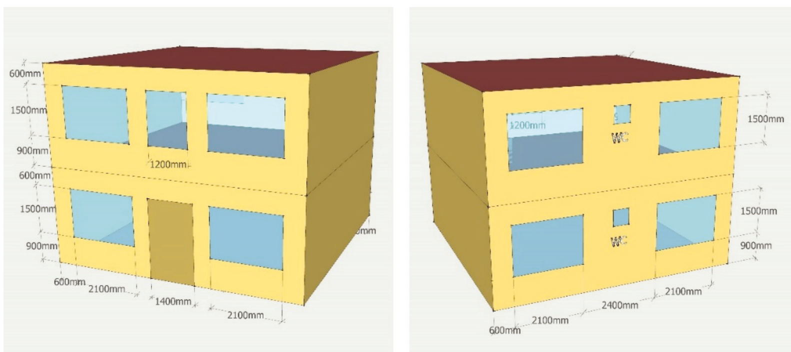

Figure 11. Sketch of dwelling prototype used in environmental simulations: left image shows the front elevation; right shows the rear elevation.

The reasons for choosing the specific variations in parameters are as follows:

- The three alternatives for wall construction represented the two most frequently observed new construction with an addition of a layer of insulation to the form most easily adapted to allow it. Heavyweight construction represented the materials of either dense concrete or stone; lightweight represented the most frequently used form of blockwork construction;
- The three glazing options represented the range of new dwelling window to wall ratios observed in many village visits;
- The four orientations, while not providing exhaustive information did allow investigation as to whether this was likely to introduce significant variation;
- The three ventilation rates represented those associated with air-tight construction; modest air-tightness and also a relatively loose fit, again they were in line with observations (though not formal testing) within the villages;
- Simulations allowed discrimination between upper and lower floor conditions and therefore these alternatives were used as in actual village dwellings there were different uses for different levels—for future research further variations might be chosen.

The analysis procedure consisted of running EnergyPlus with no heating or cooling system in order to determine the free running internal conditions on an hour by hour basis for the year. The free running mode was chosen as for rural dwellings optimization will be led by optimizing passive performance and also to optimize comfort without use of heating and cooling systems. The range of choices in design provided 108 combinations of parameters using the location weather data available for the 15 locations (1620 combinations in total). The programme output was used to compute if the resulting conditions were comfortable using the predicted mean vote (PMV) methodology. As it is known that in these locations a degree of personal adaptation to comfort occurs the comfort limits were set to ±1.0 (that is expected reporting of experienced conditions would be between "slightly warm" and "slightly cool"). The number of hours that comfort was achieved was then compared to the total number of hours to calculate the percentage comfort hours over the year. The outcomes for the 15 chosen locations are summarized in tables presented in Appendix A (one table per location).

It is of course recognized by the authors that many more variations in the parameters could have been chosen or that different output data could have been calculated (such as energy requirements for heating and cooling); however, it was considered that the most valuable data in terms of informing stakeholders would be to present the information in a form that had direct meaning for affecting their comfort experiences.

5. Climate Sensitive Design—Results

5.1. Passive Design Techniques

The Climate Consultant software was used with the available weather data from the 46 locations based in SW China. The summary is shown in Table 4 with the locations separated according to provincial affiliation. A number of key points can be noted:

- The variation in combined potential comfort hours achievable by using all of the techniques combined is considerable: from 19% to 71%;
- The choice of most valuable techniques to be employed for each location varies considerably with the following each showing substantial benefits: use of internal heat gains; natural ventilation cooling; sun-shading of windows; passive solar direct gain (low thermal mass). It is however difficult to make generalized recommendations despite each of the sites being located in the same part of the country;
- There is a substantial need to optimize the heat gains to offset comfort deficit in cooler periods, hence benefits of internal heat gains and passive solar;
- There is a need in warmer areas to make use of ventilation cooling and sun shading of windows;
- It is also clear that even within each province substantial variations occur.

Table 4. Percentage improvement in comfort arising from using each passive design technique independently in "adaptive" mode (%) as calculated from the *Climate Consultant* software.

Techniques / Location	Comfort Conditions	Sun Shading of Windows	High Thermal Mass	High Thermal Mass Withnight Flushed Ventilation	Natural Ventilation Cooling	Internal Heat Gains	Passive Solar Direct Gain (low mass)	Passive Solar Direct Gain (High Mass)	Wind Protection of Outdoor Space	Overall (%) of Comfort Hours (Combined Effect)
CHONGQING										
Shapingba	5	7	0	1	22	22	1	1	0	47
Youyang	6	6	1	1	16	23	1	2	0	42
GUANGXI										
Baise	5	14	1	1	31	25	2	3	0	59
Duan	9	12	2	2	36	25	2	3	0	67
Guilin	7	12	1	1	28	24	3	3	0	56
Guiping	5	12	1	1	37	23	1	2	0	63
Hechi	8	10	1	1	31	24	1	2	0	60
Lingshan	5	14	1	1	38	21	2	3	0	62
Longzhou	6	14	1	1	37	23	1	3	0	63
Nanning	5	13	0	0	37	22	2	2	0	62

Table 4. *Cont.*

Location \ Techniques	Comfort Conditions	Sun Shading of Windows	High Thermal Mass	High Thermal Mass Withnight Flushed Ventilation	Natural Ventilation Cooling	Internal Heat Gains	Passive Solar Direct Gain (low mass)	Passive Solar Direct Gain (High Mass)	Wind Protection of Outdoor Space	Overall (%) of Comfort Hours (Combined Effect)
Qinzhou	5	14	0	0	41	24	2	3	0	67
Wuzhou	6	11	1	1	32	20	2	3	0	55
GUIZHOU										
Bijie	7	5	1	1	10	35	3	3	0	49
Guiyang	8	8	0	0	18	27	2	3	0	50
Sansui	4	7	1	1	15	22	2	1	0	39
Tongzi	7	5	0	0	17	26	1	2	0	46
Weining	8	1	0	0	7	36	7	5	0	47
Xingyi	11	7	1	1	16	33	3	4	0	56
Zunyi	5	5	0	0	16	25	1	1	0	44
SICHUAN										
Barkham	7	2	1	1	6	23	9	3	0	35
Batang	16	6	3	3	12	37	15	8	0	62
Chengdu	6	6	0	0	19	27	2	2	0	49
Garze	3	1	0	0	3	19	17	5	1	33
Hongyuan	1	0	0	0	1	10	18	1	1	24
Huili	16	6	1	1	17	42	10	9	0	67
Jiulong	6	1	0	0	6	28	8	2	0	37
Leshan	6	6	0	0	20	27	1	1	0	49
Litang	0	0	0	0	1	11	12	2	0	19
Luzhou	6	9	0	0	20	25	2	3	0	49
Mianyang	7	8	1	1	22	23	3	2	0	49
Nanchong	6	6	0	0	21	21	1	1	0	44
Songpan	4	1	0	0	4	18	8	2	0	26
Wanyuan	9	7	2	2	14	25	2	2	1	44
Xichang	16	7	3	3	18	39	6	6	0	66
Yibin	7	5	1	1	21	25	1	1	0	49
YUNNAN										
Chuxiong	20	5	2	2	18	43	10	7	0	71
Deqen	1	0	0	0	2	15	13	1	0	24
Kunming	17	4	0	0	14	47	10	10	0	71
Lancang	12	14	4	5	23	24	4	9	0	58
Lijiang	10	2	0	0	8	45	18	10	0	64
Lincang	16	8	2	2	21	38	8	10	0	69
Mengla	7	17	3	3	28	23	2	5	0	58
Mengzi	19	14	3	3	24	35	7	11	0	71
Simao	13	9	2	2	22	34	6	9	0	64
Tengchong	10	3	0	0	12	48	12	10	0	66
Yuanjiang	16	19	4	5	35	21	2	6	0	69

Two findings result which can be incorporated into the discussion and conclusions: finding 7 is that substantial potential to create comfort using passive bioclimatic design techniques exists; finding 8 is that there are so many variations in optimal performance that making choices based on simple regional climatic zones is insufficient to support accurate decision-making and that more localized outcomes ought to be addressed.

5.2. Parametric Environmental Evaluations

The second quantitative analysis technique was set up to investigate a specific sub-set of the overall weather data sites but with a similar aim—to assess comfort hours experienced by residents based on variations in building design/construction parameters. For each location 108 variations in design were assessed using the EnergyPlus software package for each hour of the year. The calculated internal conditions were used to determine if each hour could be considered to lie within the comfort range of predicted mean vote (PMV) −1.0 to +1.0. The calculated percentage of comfort hours is summarized for each location in the set of table presented in Appendix A. A close inspection of those values allows some observations to be made.

The analysis which has taken place has been driven by the need for information and guidance for those involved in designing and constructing dwellings in the villages of the region. In this the authors have the expectation that the information will be of most value to those connected to the "new" and "hybrid" styles rather than the older more traditional options.

Table 5 provides a summary of the data from Appendix A in the format of the maximum, minimum, and average percentage of comfort hours for each location.

Table 5. Variation in comfort hours—average, maximum and minimum values for each location from range of 108 parametric options studied (percentage annual values)—derived from Appendix A.

Location	Comfort Hours (%)			Optimum Comfort Hours Combination of Parameters
	Average	Maximum	Minimum	
CHONGQING				
Shapingba	23.8	28.7	21.1	lww+ins; low WWR; N; 1.0ach; G;
Youyang	26.2	31.3	22.3	lww+ins; low WWR; S; 0.5ach; G;
GUANGXI				
Hechi	21.0	25.2	18.5	lww+ins; low WWR; S; 0.5ach; G;
Longzhou	25.0	31.4	21.0	lww+ins; low WWR; S; 0.25ach; G;
Nanning	26.4	34.2	21.1	lww+ins; low WWR; S; 0.25ach; G;
GUIZHOU				
Bijie	28.1	39.6	21.8	lww+ins; low WWR; S; 0.25ach; G;
Guiyang	30.7	41.4	24.6	lww+ins; low WWR; S; 0.5ach; G;
Sansui	26.2	32.4	22.4	lww+ins; low WWR; N; 1.0ach; G;
SICHUAN				
Chengdu	28.2	35.4	23.1	lww+ins; low WWR; S; 0.5ach; G;
Huili	43.7	65.6	19.9	lww+ins; high WWR; S; 0.25ach; G;
Songpan	8.2	23.6	0.3	lww+ins; high WWR; W; 0.25ach; 1;
YUNNAN				
Deqen	4.5	20.7	0.0	lww+ins; high WWR; W; 0.25ach; 1;
Kunming	42.8	64.6	28.4	lww+ins; med WWR; N; 1.0ach; 1;
Mengla	36.0	51.4	23.7	lww+ins; low WWR; S; 1.0ach; G;
Yuanjiang	27.6	36.3	13.8	lww+ins; low WWR; S/N; 1.0ach; G;

Notes: Key to optimum comfort combinations: hww = heavyweight wall; lww = lightweight wall; +ins = with insulation; low, med, high WWR = low, medium, high window to wall ratios; N, S, E, W = main orientation North, South, East, West; 0.25ach/0.5ach/1.0ach = 0.25/0.5/1.0 air change rate per hour; G = ground floor, 1 = first (upper) floor.

Several outcomes can be identified from the tabulated data taken as a whole, however the authors believe that information of a general nature, can also be absorbed and adapted for use in specific locations by professions from that area.

Although building with significant amounts of insulation is not common in Southwest China for a large number of the climates investigated the highest proportions of comfort hours are often for a design making use of lightweight construction with insulation; indeed all of the optimum comfort combinations are shown in Table 5. That is not to say some other constructions can have value in certain locations and at certain times but overall it is possible to make the identification of the value of insulation finding 9 of this study.

The optimum window to wall ratio varied somewhat but in general the lowest ratio tested seemed to be frequently beneficial; finding 10 might therefore be to suggest lower window areas for providing suitable options to achieve comfort in many locations. The impact of orientation of the main façade varied according to the location as did the optimal air change rate and indicates scope for more detailed analysis. For most of the locations the floor level which yielded the higher comfort hours was the ground (lower) floor. At this stage there is insufficient analysis to identify the reason for this, which might be linked to the protection afforded by the floor above, but this again would be deserving of further investigation.

A consequence of encouragement to change the style and materials used in construction will be an impact on building materials being used; finding 11 is thus the need to assess and accommodate changes to building fabric needs in future years if more climate sensitive design is to flourish.

In addition to the above it also seems appropriate to add a final finding (finding 12) that in order to provide coherence, direction, and confidence for the future, design guidance in these topic areas needs to be produced. Further, in order to prove significant it needs to be advocated by practitioners and officials in order to make a step change to outcomes.

6. Discussion

6.1. Summary

The aim of the authors in carrying out the research reported in this paper was to first investigate important issues impinging on the design and construction of rural village dwellings in China and then to identify opportunities for change. Southwest China is a large and significant area with a number of characteristics which draw the provinces and areas together, these arise from climate and geography, culture, tourist potential and also to some important extent from the remoteness from the East Coast.

The research found a number of key influencing factors that need to be considered in supporting the development of more climate sensitive and robust dwellings in the region of study. This led to several focused areas of further enquiry which has resulted in the identification of recommendations within the findings listed (see Conclusions section below) and the need for more data to support local decision-making.

The paper has provided a significant amount of new data which suggest building climate-sensitive rural dwellings to be used by stakeholders. Since there seems to be more general movement from authorities to pass a greater level of responsibility to the end users then the provision of such advice is timely. Further the network of collaborators that was formed as a background to this research means that there are new avenues for dissemination and creating beneficial impacts.

The main outcome is that it is both possible and important to provide suitable guidance to those designing and constructing dwellings in rural villages in Southwest China. In this the guidance should be targeted particularly at the small scale and individual builder and developer as they are currently least well served by the systems in place. The focus on use of the information is also for use in guiding the design and construction of new dwellings, rather than renovation of older traditional styles. Although modifying the construction of a single dwelling will have limited impact, the sheer scale of change in China and the vast numbers involved mean that better choices for millions of new or renovated buildings can be communicated. The development and use of guidance information would have significant impacts in terms of energy use and material resources consumed.

Methods were applied consistently and with rigor in the various components of the research and the authors believe it makes a significant contribution to the development of knowledge and more importantly provides a foundation for the development of more formalized guidance and advice to stakeholders.

The outcomes while applicable to Southwest China also have potential for exploitation in rural areas of adjacent countries and areas—for instance Myanmar and Vietnam where similar weather exists and where there are also significant cultural and ethnic group influences.

6.2. Limitations

In any piece of multi-dimensional research there will be limitations and the authors have attempted to be clear about the processes they invoked in carrying out the research. Some of the limitations are set by the means of which stakeholders can be accessed by research workers and the types of techniques which are suitable for engaging in discussion with residents of sometimes remote villages. The number of people with whom it was possible to meet clearly represents a small subset of the total population, nevertheless the research team took care to try to ensure that they were indeed representative. The repetition of information in discussions across a wide geographical area and different ethnic backgrounds give credibility to the inferences drawn. The quantitative analyses were numerous and followed previous studies though of course many more iterations of the parametric simulations could be carried out. The research team intend to expand this in the future but suggest the variations in data input and ranges of data outputs suffice to demonstrate both the need for location specific research and that the methods yield useful outcomes that can inform stakeholders.

6.3. Further Work

It is the intention of the authors to work with collaborators and stakeholders to develop information in more detail in order to form a design guide document to be published which will also include examples of good practice. This guidance will be made available to professional and practitioners through research and practice network collaborators and through public dissemination activities. In so doing it should provide a source of information able to meet the gaps in knowledge identified within the research.

The parametric analyses can be extended to cover a greater number of variations in parameters and also in the reporting of outputs.

There is also considerable scope as more verified climate data records become available to extend the number of locations for which parametric analysis can be carried out to give a greater degree of discrimination between the summary of advice provided for different rural areas.

Visits to villages undergoing change are also worthy of development and are part of the ongoing research programme.

7. Conclusions

The purpose of this research was to understand the issues associated with the environmental design of dwellings for rural villages in Southwest China. The most important conclusion is that research into rural dwellings development is very much needed and that there are clearly identifiable requirements for additional guidance for stakeholders (both building residents and also local professional and industry staff).

The pressure for this comes from the changes in the ways in which the redevelopment process is being acted out. Rural villages in China sometimes have little contact with building and construction experts and thus when they need to make decisions about the redesign of their own home or community they are left with often only broad guiding principles or perhaps even misconceptions. In the process at the moment there is insufficient appreciation or differentiation in the support given for the fact that each village is different: there are differences in ethnic make-up; differences in intrinsic technical skills and understanding; differences in climate experienced (even from one side of a hill to another);

differences in resources and building materials available; and differences in wealth and economic outlook. Without more specific guidance documents and exemplars, the development process is likely to operate at sub-optimal levels and dwelling which are not tuned to the locality. Considering the ongoing development as part of the national rural revitalization strategies, such needs will continue and expand.

In terms of providing summary conclusions of the specific activities, in the main body of the text above a number of findings were identified, and these are collated below.

1. There is a general lack of information and support to enable the detailed environmental design and control of construction of village dwellings; something which is particularly acute in relation to self-building by village residents.
2. There is a need to offer some practical alternatives to demolition of older/deficient properties. Design and reconstruction guidance documents need to be available.
3. Alternatives to the simple "old vs. new" model of dwelling design can be found. Such hybrid designs seem to have the benefits of marrying the old to the new and striking a balance between tradition and modern convenience.
4. There are significant variations in embedded knowledge and skills within villages and sometimes a lack of community involvement in the redevelopment process. Villages with strong ethnic traits might have better potential to use intrinsic knowledge and skills.
5. Changes occurring to the social structure of villages could impede development in the future; and skills-based knowledge, understanding and practice needs to be supported and re-embedded within communities.
6. Discussions and survey indicated that there is substantial value in encouraging local residents, who are increasingly having to make design and construction decisions for themselves in their own locality, to use self-reflective questions to stimulate discussion and establish a community view.
7. There exists substantial potential to create comfort using passive bioclimatic design techniques.
8. Since many variations in optimal performance were observed for sites in SW China this means that making choices based on simple regional climatic zones is insufficient to support accurate decision-making and more localized outcomes ought to be addressed.
9. The use of insulation materials in the construction of dwellings would offer opportunities for better environmental performance.
10. The use of lower window to wall area ratios in dwelling design can have benefits in many locations.
11. The change in construction is likely to lead to a need for different availability of products used in building which could have further consequences.
12. Supporting design guidance and advocacy for its use is required from practitioners and official bodies.

Apart from the specific findings above it is also expected that the research and collaboration network that was established alongside the project will grow and enable more research, dissemination and particularly impact.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The following tables show values of percentage of comfort hours predicted using the EnergyPlus software package for the given combinations of building parameters for the 15 chosen sites within Southwest China.

Table A1. Chongqing—Shapingba; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	24.5%	22.9%	25.2%	23.3%	24.9%	22.1%
	North	24.6%	22.9%	25.2%	23.3%	25.0%	22.1%
	East	24.4%	22.7%	25.0%	23.2%	24.6%	21.9%
	West	24.4%	22.6%	25.0%	23.1%	24.6%	21.8%
Medium glazing	South	24.4%	22.7%	25.0%	23.2%	24.7%	22.0%
	North	24.4%	22.7%	25.0%	23.1%	24.8%	22.0%
	East	24.1%	22.4%	24.8%	22.7%	24.3%	21.7%
	West	24.1%	22.4%	24.7%	22.7%	24.3%	21.7%
High glazing	South	24.6%	22.5%	25.0%	23.1%	24.6%	22.1%
	North	24.4%	22.5%	24.9%	23.2%	24.6%	21.9%
	East	24.0%	22.2%	24.6%	22.7%	24.1%	21.7%
	West	24.1%	22.0%	24.6%	22.5%	24.1%	21.5%
Lightweight walls							
Low glazing	South	25.0%	23.0%	25.6%	23.5%	25.0%	22.2%
	North	25.0%	23.0%	25.6%	23.5%	25.0%	22.1%
	East	24.6%	22.8%	25.3%	23.2%	24.7%	21.8%
	West	24.7%	22.7%	25.3%	23.1%	24.8%	21.7%
Medium glazing	South	25.0%	22.9%	25.6%	23.3%	24.9%	22.0%
	North	24.9%	22.9%	25.6%	23.4%	24.9%	22.0%
	East	24.5%	22.5%	25.1%	23.0%	24.5%	21.6%
	West	24.5%	22.4%	25.1%	23.0%	24.5%	21.5%
High glazing	South	24.9%	22.7%	25.5%	23.3%	25.0%	21.8%
	North	24.8%	22.7%	25.4%	23.2%	25.0%	21.8%
	East	24.3%	22.2%	25.1%	22.6%	24.5%	21.3%
	West	24.1%	22.0%	24.8%	22.5%	24.3%	21.1%
Lightweight insulated walls							
Low glazing	South	26.8%	25.6%	28.1%	26.4%	28.6%	26.4%
	North	26.7%	25.4%	28.2%	26.3%	28.7%	26.1%
	East	25.7%	24.6%	27.2%	25.4%	27.5%	25.3%
	West	25.6%	24.4%	27.1%	25.2%	27.4%	25.3%
Medium glazing	South	26.0%	24.8%	27.3%	25.8%	27.5%	25.6%
	North	25.7%	24.6%	27.1%	25.7%	27.4%	25.5%
	East	24.9%	23.4%	26.1%	24.3%	26.2%	24.4%
	West	24.8%	23.0%	26.0%	24.0%	26.2%	24.0%
High glazing	South	25.4%	23.8%	26.6%	24.8%	26.7%	24.8%
	North	25.2%	23.6%	26.4%	24.7%	26.6%	24.7%
	East	24.1%	22.3%	25.5%	23.3%	25.5%	23.2%
	West	23.8%	21.8%	25.3%	23.0%	25.2%	22.8%

Table A2. Chongqing—ouyang; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	28.1%	24.6%	28.3%	25.1%	25.8%	23.8%
	North	28.0%	24.7%	28.2%	25.1%	25.8%	23.8%
	East	27.7%	24.4%	28.2%	24.9%	25.8%	23.6%
	West	27.7%	24.3%	28.1%	24.8%	25.8%	23.6%
Medium glazing	South	28.0%	24.3%	28.4%	25.0%	26.0%	23.7%
	North	27.9%	24.2%	28.3%	25.0%	25.9%	23.7%
	East	27.5%	24.1%	28.1%	24.7%	25.7%	23.6%
	West	27.4%	23.9%	28.0%	24.7%	25.5%	23.5%
High glazing	South	27.8%	24.0%	28.3%	24.8%	26.0%	23.6%
	North	27.7%	24.0%	28.2%	24.7%	25.9%	23.6%
	East	27.3%	23.7%	27.8%	24.5%	25.6%	23.3%
	West	27.1%	23.6%	27.7%	24.2%	25.6%	23.2%
Lightweight walls							
Low glazing	South	27.7%	23.8%	27.9%	24.6%	26.6%	23.3%
	North	27.6%	23.8%	27.9%	24.6%	26.4%	23.2%
	East	27.4%	23.6%	27.6%	24.3%	26.2%	22.9%
	West	27.3%	23.7%	27.5%	24.2%	26.2%	22.8%
Medium glazing	South	27.6%	23.6%	27.9%	24.2%	26.5%	23.1%
	North	27.5%	23.6%	27.7%	24.2%	26.4%	23.0%
	East	27.2%	23.2%	27.4%	23.9%	25.9%	22.7%
	West	27.1%	23.2%	27.4%	23.9%	25.8%	22.7%
High glazing	South	27.4%	23.2%	27.7%	23.9%	26.4%	23.0%
	North	27.3%	23.3%	27.7%	24.0%	26.3%	22.9%
	East	26.9%	22.9%	27.3%	23.6%	25.8%	22.8%
	West	26.8%	22.9%	27.2%	23.5%	25.7%	22.6%
Lightweight insulated walls							
Low glazing	South	30.1%	27.1%	31.3%	28.7%	29.8%	29.7%
	North	29.9%	27.0%	31.2%	28.8%	29.9%	29.5%
	East	29.2%	25.8%	30.8%	27.5%	28.8%	28.7%
	West	29.1%	25.4%	30.8%	27.2%	28.8%	28.5%
Medium glazing	South	29.0%	25.7%	30.8%	27.2%	29.3%	28.5%
	North	28.9%	25.8%	30.6%	27.4%	29.0%	28.4%
	East	27.5%	24.2%	29.8%	25.7%	28.4%	27.2%
	West	27.2%	23.7%	29.5%	25.3%	28.4%	26.8%
High glazing	South	27.9%	24.4%	29.5%	26.0%	29.1%	27.1%
	North	27.7%	24.5%	29.4%	26.2%	28.8%	27.0%
	East	26.1%	22.5%	28.3%	24.2%	27.9%	25.7%
	West	25.7%	22.3%	28.1%	23.7%	27.8%	25.2%

Table A3. Guangxi—Hechi; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	20.3%	19.2%	21.5%	19.9%	21.2%	19.2%
	North	20.3%	19.1%	21.5%	19.8%	21.2%	19.1%
	East	20.0%	19.0%	21.0%	19.4%	20.9%	18.9%
	West	19.9%	18.9%	21.0%	19.4%	20.9%	18.9%

Table A3. *Cont*.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Medium glazing	South	20.4%	19.4%	21.3%	19.9%	21.1%	19.2%
	North	20.2%	19.2%	21.2%	19.7%	21.1%	19.1%
	East	19.9%	18.9%	20.7%	19.5%	20.5%	18.7%
	West	19.9%	19.0%	20.7%	19.4%	20.4%	18.7%
High glazing	South	20.5%	19.4%	21.3%	19.9%	20.9%	19.1%
	North	20.3%	19.4%	21.2%	19.8%	20.8%	19.0%
	East	20.0%	18.9%	20.6%	19.4%	20.0%	18.6%
	West	19.9%	18.9%	20.6%	19.3%	20.0%	18.5%
Lightweight walls							
Low glazing	South	21.1%	20.0%	21.6%	20.5%	22.0%	20.0%
	North	21.0%	19.9%	21.6%	20.4%	21.9%	19.8%
	East	20.7%	19.5%	21.3%	20.1%	21.4%	19.5%
	West	20.7%	19.5%	21.2%	20.1%	21.5%	19.6%
Medium glazing	South	21.2%	19.7%	21.7%	20.4%	21.8%	20.0%
	North	21.0%	19.8%	21.6%	20.4%	21.6%	19.9%
	East	20.3%	19.4%	21.1%	20.1%	21.1%	19.4%
	West	20.4%	19.2%	21.0%	19.8%	21.1%	19.4%
High glazing	South	21.2%	19.5%	21.9%	20.3%	21.6%	19.9%
	North	21.1%	19.6%	21.8%	20.3%	21.5%	19.9%
	East	20.4%	19.0%	21.1%	19.7%	20.9%	19.3%
	West	20.2%	18.8%	21.0%	19.7%	20.8%	19.2%
Lightweight insulated walls							
Low glazing	South	23.7%	24.3%	25.2%	24.7%	24.2%	23.2%
	North	23.5%	23.8%	25.0%	24.4%	24.3%	23.0%
	East	22.6%	22.4%	24.1%	23.1%	23.1%	21.6%
	West	22.4%	22.2%	23.9%	23.0%	23.0%	21.4%
Medium glazing	South	23.6%	23.3%	24.7%	24.1%	23.6%	22.6%
	North	23.1%	23.0%	24.2%	23.8%	23.3%	22.2%
	East	21.7%	21.5%	22.9%	22.1%	22.3%	20.7%
	West	21.7%	21.4%	22.8%	21.7%	22.1%	20.3%
High glazing	South	23.5%	22.3%	24.5%	23.1%	23.3%	22.0%
	North	23.0%	22.4%	23.9%	23.0%	23.0%	21.8%
	East	21.4%	21.0%	22.4%	21.3%	21.5%	20.0%
	West	21.2%	20.8%	22.1%	21.1%	21.2%	19.7%

Table A4. Guangxi—Longzhou; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	25.9%	23.7%	25.8%	23.9%	22.8%	22.4%
	North	25.8%	23.6%	25.7%	23.8%	22.7%	22.4%
	East	25.6%	23.4%	25.5%	23.7%	22.6%	22.2%
	West	25.7%	23.4%	25.5%	23.6%	22.5%	22.2%
Medium glazing	South	26.3%	23.3%	26.3%	23.6%	23.0%	22.3%
	North	26.0%	23.3%	26.0%	23.7%	22.8%	22.3%
	East	25.7%	23.1%	25.8%	23.3%	22.5%	21.9%
	West	25.7%	23.0%	25.8%	23.3%	22.5%	22.0%

Table A4. *Cont.*

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
High glazing	South	26.3%	22.9%	26.5%	23.2%	23.4%	22.2%
	North	26.2%	23.0%	26.2%	23.3%	23.0%	22.2%
	East	25.7%	22.7%	25.8%	23.0%	22.6%	21.9%
	West	25.5%	22.5%	25.7%	22.8%	22.7%	21.7%
Lightweight walls							
Low glazing	South	25.5%	22.6%	26.0%	22.8%	23.8%	22.3%
	North	25.4%	22.5%	25.9%	22.8%	23.7%	22.2%
	East	25.1%	22.2%	25.5%	22.5%	23.2%	22.0%
	West	25.1%	22.2%	25.5%	22.4%	23.2%	21.8%
Medium glazing	South	25.3%	22.2%	25.9%	22.6%	24.2%	22.1%
	North	25.3%	22.4%	25.8%	22.6%	23.8%	22.2%
	East	24.9%	22.0%	25.3%	22.2%	23.2%	21.6%
	West	24.8%	21.8%	25.1%	22.1%	23.2%	21.5%
High glazing	South	25.0%	21.9%	25.5%	22.2%	24.0%	21.8%
	North	25.0%	22.2%	25.5%	22.4%	24.0%	21.9%
	East	24.5%	21.7%	24.9%	22.0%	22.9%	21.3%
	West	24.4%	21.5%	24.8%	21.7%	22.9%	21.0%
Lightweight insulated walls							
Low glazing	South	31.4%	29.9%	30.3%	30.5%	27.0%	27.6%
	North	31.0%	30.2%	29.7%	30.8%	26.4%	27.3%
	East	30.4%	29.7%	29.1%	29.8%	25.4%	26.4%
	West	30.2%	29.3%	29.1%	29.5%	25.5%	26.3%
Medium glazing	South	30.2%	28.2%	29.6%	28.7%	26.6%	26.5%
	North	30.3%	28.9%	29.6%	29.2%	26.4%	26.7%
	East	29.7%	28.2%	28.7%	28.4%	25.3%	25.5%
	West	29.2%	27.8%	28.4%	27.9%	25.2%	25.1%
High glazing	South	29.2%	25.7%	28.8%	26.6%	26.3%	25.3%
	North	29.3%	27.5%	28.8%	27.7%	26.1%	25.7%
	East	28.6%	26.5%	27.9%	27.0%	25.0%	24.5%
	West	28.3%	26.1%	27.7%	26.5%	24.8%	24.1%

Table A5. Guangxi—Nanning; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	26.5%	23.9%	26.5%	24.1%	22.7%	21.6%
	North	26.4%	23.8%	26.4%	23.9%	22.5%	21.5%
	East	26.0%	23.5%	26.0%	23.5%	22.2%	21.2%
	West	26.1%	23.6%	25.9%	23.6%	22.3%	21.3%
Medium glazing	South	26.9%	24.1%	26.9%	24.3%	22.9%	21.8%
	North	26.7%	23.9%	26.7%	24.1%	22.7%	21.5%
	East	26.1%	23.6%	26.2%	23.8%	22.3%	21.2%
	West	26.1%	23.6%	26.2%	23.7%	22.2%	21.2%
High glazing	South	27.3%	24.3%	27.2%	24.3%	23.2%	22.1%
	North	26.9%	24.0%	26.9%	24.1%	23.0%	21.7%
	East	26.2%	23.7%	26.2%	23.7%	22.2%	21.3%
	West	26.2%	23.6%	26.1%	23.7%	22.2%	21.3%

Table A5. *Cont*.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Lightweight walls							
Low glazing	South	26.6%	24.0%	26.6%	24.2%	23.6%	23.0%
	North	26.4%	23.9%	26.3%	24.2%	23.5%	22.8%
	East	25.9%	23.7%	25.9%	24.0%	23.0%	22.3%
	West	25.9%	23.7%	25.9%	23.8%	21.7%	21.1%
Medium glazing	South	27.0%	24.0%	26.9%	24.2%	24.0%	23.0%
	North	26.7%	23.9%	26.5%	24.2%	23.8%	23.0%
	East	26.2%	23.5%	26.1%	23.7%	23.1%	22.2%
	West	26.1%	23.4%	26.1%	23.7%	23.0%	22.2%
High glazing	South	27.2%	23.8%	27.1%	24.2%	24.2%	23.0%
	North	27.0%	23.7%	26.8%	24.1%	23.8%	22.8%
	East	26.3%	23.1%	26.3%	23.5%	23.0%	22.0%
	West	26.2%	23.1%	26.1%	23.4%	23.0%	22.0%
Lightweight insulated walls							
Low glazing	South	34.2%	33.2%	33.4%	33.6%	28.9%	30.5%
	North	33.4%	33.1%	32.6%	33.2%	28.4%	29.9%
	East	32.3%	32.0%	31.6%	32.0%	27.3%	28.3%
	West	32.2%	31.9%	31.5%	31.8%	27.2%	28.3%
Medium glazing	South	34.0%	31.6%	33.5%	32.5%	29.8%	30.5%
	North	33.4%	31.9%	32.8%	32.4%	28.8%	29.6%
	East	32.1%	30.8%	31.7%	31.1%	27.6%	28.2%
	West	31.8%	30.4%	31.4%	30.8%	27.5%	28.0%
High glazing	South	32.7%	30.0%	33.0%	30.9%	29.7%	29.7%
	North	32.6%	30.8%	32.6%	31.3%	29.0%	29.3%
	East	31.3%	29.5%	31.2%	29.9%	27.3%	27.4%
	West	30.9%	29.1%	30.9%	29.6%	27.2%	27.4%

Table A6. Guizhou—Bijie; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	28.8%	25.6%	28.4%	25.7%	24.8%	23.0%
	North	28.7%	25.6%	28.4%	25.8%	24.8%	23.0%
	East	28.1%	25.1%	28.1%	25.4%	24.6%	22.9%
	West	28.0%	25.2%	27.9%	25.3%	24.5%	22.8%
Medium glazing	South	28.8%	25.7%	28.9%	25.8%	25.0%	23.1%
	North	28.8%	25.6%	28.7%	25.7%	25.0%	23.0%
	East	28.0%	25.1%	28.1%	25.3%	24.7%	22.8%
	West	27.8%	25.0%	27.9%	25.3%	24.5%	22.6%
High glazing	South	28.8%	25.9%	29.0%	25.9%	25.2%	23.2%
	North	28.8%	25.8%	29.0%	25.9%	25.2%	23.2%
	East	27.6%	25.0%	27.8%	25.2%	24.8%	22.7%
	West	27.5%	25.0%	27.8%	25.2%	24.5%	22.6%
Lightweight walls							
Low glazing	South	28.4%	25.5%	28.0%	25.5%	24.3%	22.2%
	North	28.3%	25.4%	28.0%	25.4%	24.3%	22.1%
	East	28.0%	25.2%	27.5%	25.2%	23.9%	22.0%
	West	28.0%	25.0%	27.5%	25.1%	23.8%	21.9%

Table A6. *Cont.*

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Medium glazing	South	28.7%	25.5%	28.3%	25.6%	24.4%	22.2%
	North	28.6%	25.5%	28.3%	25.6%	24.4%	22.1%
	East	28.0%	25.0%	27.9%	25.1%	23.8%	21.9%
	West	27.9%	24.7%	27.7%	24.9%	23.7%	21.9%
High glazing	South	28.8%	25.4%	28.4%	25.4%	24.4%	22.5%
	North	28.7%	25.4%	28.3%	25.4%	24.3%	22.4%
	East	28.0%	24.5%	27.8%	24.8%	23.9%	22.0%
	West	28.1%	24.5%	27.9%	24.6%	23.8%	21.8%
Lightweight insulated walls							
Low glazing	South	39.4%	34.4%	38.8%	36.7%	29.2%	33.4%
	North	39.3%	34.1%	38.6%	36.4%	29.0%	33.3%
	East	36.2%	31.7%	36.8%	33.5%	28.8%	30.9%
	West	35.7%	31.4%	36.4%	33.1%	28.7%	30.5%
Medium glazing	South	38.0%	33.6%	38.4%	35.6%	30.3%	32.9%
	North	37.8%	33.0%	38.3%	35.2%	30.1%	32.4%
	East	33.9%	30.5%	35.5%	31.8%	29.2%	29.8%
	West	33.4%	30.2%	35.0%	31.3%	28.9%	29.5%
High glazing	South	36.4%	32.6%	37.2%	34.5%	30.5%	32.1%
	North	36.1%	32.2%	36.9%	34.2%	30.3%	31.7%
	East	32.2%	28.9%	33.7%	30.0%	28.8%	28.5%
	West	31.9%	28.6%	33.3%	29.6%	28.6%	27.9%

Table A7. Guizhou—Guiyang; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	32.2%	27.2%	33.6%	28.1%	32.0%	26.5%
	North	32.1%	27.0%	33.6%	28.1%	32.0%	26.4%
	East	31.6%	26.5%	32.9%	27.6%	31.6%	26.1%
	West	31.4%	26.4%	32.6%	27.4%	31.4%	26.0%
Medium glazing	South	32.1%	27.0%	33.2%	27.9%	31.8%	26.5%
	North	31.9%	26.9%	33.0%	27.7%	31.7%	26.3%
	East	31.0%	26.1%	32.3%	27.2%	31.1%	25.9%
	West	30.6%	26.0%	32.1%	27.0%	30.7%	25.6%
High glazing	South	31.7%	26.9%	33.1%	27.7%	31.5%	26.3%
	North	31.6%	26.8%	33.0%	27.5%	31.5%	26.2%
	East	30.2%	25.7%	31.7%	26.7%	30.5%	25.4%
	West	29.9%	25.4%	31.4%	26.4%	30.0%	25.1%
Lightweight walls							
Low glazing	South	32.5%	27.4%	33.3%	28.0%	30.6%	26.1%
	North	32.3%	27.2%	33.3%	27.9%	30.5%	26.0%
	East	31.6%	26.8%	32.5%	27.4%	30.1%	25.6%
	West	31.5%	26.6%	32.4%	27.3%	29.9%	25.4%
Medium glazing	South	32.0%	27.2%	33.0%	27.8%	30.4%	26.0%
	North	31.9%	27.1%	32.8%	27.5%	30.3%	25.8%
	East	31.2%	26.4%	32.1%	27.1%	29.7%	25.2%
	West	30.9%	26.1%	31.9%	26.8%	29.3%	25.1%

Table A7. *Cont.*

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
High glazing	South	31.9%	27.1%	32.8%	27.7%	30.3%	25.8%
	North	31.7%	26.9%	32.6%	27.6%	30.1%	25.6%
	East	30.4%	26.1%	31.4%	26.7%	29.2%	24.9%
	West	30.2%	25.5%	31.2%	26.4%	28.9%	24.6%
Lightweight insulated walls							
Low glazing	South	40.5%	35.5%	41.4%	36.7%	37.4%	35.6%
	North	40.3%	34.9%	41.2%	36.0%	37.3%	35.4%
	East	37.1%	32.5%	38.5%	33.4%	35.9%	32.3%
	West	36.1%	32.0%	37.6%	32.6%	35.6%	31.3%
Medium glazing	South	38.2%	33.7%	39.4%	35.0%	36.7%	33.8%
	North	37.6%	33.0%	39.0%	34.1%	36.5%	33.0%
	East	34.2%	30.3%	35.9%	31.2%	34.6%	29.6%
	West	33.2%	29.4%	34.7%	30.1%	33.8%	28.2%
High glazing	South	36.2%	31.8%	37.9%	32.9%	35.6%	32.3%
	North	35.4%	31.3%	37.2%	32.4%	35.2%	31.5%
	East	32.0%	28.3%	33.4%	29.1%	32.7%	27.4%
	West	31.2%	27.6%	32.3%	28.2%	32.2%	26.1%

Table A8. Guizhou—Sansui; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	26.6%	23.9%	27.6%	24.4%	26.5%	23.3%
	North	26.6%	23.9%	27.6%	24.4%	26.4%	23.2%
	East	26.1%	23.7%	27.1%	24.0%	26.2%	22.8%
	West	26.1%	23.7%	27.1%	24.0%	26.2%	22.8%
Medium glazing	South	26.5%	23.9%	27.4%	24.3%	26.6%	23.3%
	North	26.4%	23.8%	27.3%	24.2%	26.5%	23.1%
	East	25.9%	23.5%	26.9%	23.8%	26.1%	22.6%
	West	25.9%	23.5%	26.8%	23.8%	26.1%	22.6%
High glazing	South	26.3%	23.8%	27.2%	24.3%	26.4%	23.2%
	North	26.3%	23.7%	27.2%	24.2%	26.3%	23.0%
	East	25.7%	23.2%	26.4%	23.7%	25.7%	22.4%
	West	25.7%	23.2%	26.3%	23.5%	25.7%	22.4%
Lightweight walls							
Low glazing	South	27.4%	24.0%	28.4%	24.7%	26.8%	23.3%
	North	27.5%	24.1%	28.3%	24.8%	26.8%	23.3%
	East	26.8%	23.7%	27.9%	24.2%	26.4%	23.0%
	West	26.9%	23.7%	27.9%	24.1%	26.3%	23.1%
Medium glazing	South	27.4%	24.0%	28.4%	24.5%	26.7%	23.4%
	North	27.2%	23.9%	28.3%	24.5%	26.6%	23.3%
	East	26.7%	23.5%	27.7%	23.8%	26.0%	22.9%
	West	26.6%	23.4%	27.7%	23.7%	26.0%	22.8%
High glazing	South	27.2%	24.0%	28.5%	24.2%	26.4%	23.5%
	North	27.1%	23.9%	28.3%	24.2%	26.3%	23.4%
	East	26.3%	23.1%	27.2%	23.6%	25.8%	22.6%
	West	26.3%	23.0%	27.2%	23.6%	25.7%	22.6%

Table A8. *Cont*.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Lightweight insulated walls							
Low glazing	South	30.3%	27.9%	32.3%	28.9%	32.4%	29.1%
	North	30.3%	27.5%	32.2%	28.6%	32.4%	28.9%
	East	29.4%	26.9%	30.8%	27.8%	31.0%	27.5%
	West	29.2%	26.7%	30.6%	27.7%	30.9%	27.5%
Medium glazing	South	29.2%	26.9%	31.1%	28.3%	31.3%	28.3%
	North	28.9%	26.6%	30.8%	28.0%	31.3%	27.9%
	East	27.9%	25.4%	29.4%	26.5%	29.3%	26.5%
	West	27.7%	25.0%	29.2%	26.2%	29.1%	26.4%
High glazing	South	28.6%	25.5%	30.1%	26.9%	30.4%	27.6%
	North	28.2%	25.5%	29.7%	26.6%	30.2%	27.3%
	East	27.0%	23.7%	28.4%	25.2%	28.2%	25.3%
	West	26.8%	23.3%	28.2%	24.7%	27.9%	24.9%

Table A9. Sichuan—Chengdu; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	28.5%	25.9%	29.1%	26.1%	26.6%	24.0%
	North	28.6%	25.8%	28.9%	26.0%	26.6%	24.0%
	East	28.2%	25.6%	28.6%	25.8%	26.4%	23.8%
	West	28.1%	25.7%	28.8%	25.8%	26.4%	23.8%
Medium glazing	South	28.3%	25.9%	29.0%	26.0%	26.7%	24.0%
	North	28.2%	25.7%	28.9%	25.9%	26.6%	23.9%
	East	27.9%	25.7%	28.4%	25.7%	26.2%	23.6%
	West	27.8%	25.5%	28.4%	25.6%	26.3%	23.6%
High glazing	South	28.5%	26.0%	29.0%	26.1%	26.6%	23.9%
	North	28.3%	25.9%	29.1%	26.0%	26.5%	23.8%
	East	27.8%	25.5%	28.3%	25.5%	26.2%	23.5%
	West	27.8%	25.5%	28.3%	25.5%	26.2%	23.5%
Lightweight walls							
Low glazing	South	28.8%	25.8%	29.0%	25.9%	27.3%	24.1%
	North	28.7%	25.7%	28.9%	25.8%	27.2%	24.0%
	East	28.2%	25.3%	28.6%	25.7%	26.8%	23.6%
	West	28.3%	25.3%	28.6%	25.5%	26.8%	23.6%
Medium glazing	South	28.7%	25.7%	29.0%	25.9%	27.2%	24.0%
	North	28.6%	25.6%	28.9%	25.8%	27.1%	24.0%
	East	28.1%	25.1%	28.4%	25.3%	26.5%	23.4%
	West	28.1%	24.9%	28.4%	25.3%	26.6%	23.4%
High glazing	South	29.2%	25.6%	29.2%	25.9%	27.3%	24.1%
	North	29.0%	25.6%	29.0%	25.8%	27.2%	23.9%
	East	28.2%	24.9%	28.4%	25.3%	26.4%	23.3%
	West	28.1%	24.8%	28.4%	25.1%	26.4%	23.1%
Lightweight insulated walls							
Low glazing	South	34.9%	33.5%	35.4%	34.7%	34.2%	32.1%
	North	34.7%	33.3%	35.3%	34.3%	34.1%	31.9%
	East	33.8%	32.3%	34.4%	33.2%	32.6%	30.7%
	West	33.7%	32.1%	34.4%	33.1%	32.7%	30.6%

Table A9. *Cont.*

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Medium glazing	South	34.5%	32.8%	34.9%	33.6%	33.6%	31.9%
	North	34.2%	32.5%	34.5%	33.3%	33.2%	31.4%
	East	33.1%	31.2%	33.6%	32.0%	31.5%	29.9%
	West	32.8%	30.7%	33.5%	31.6%	31.5%	29.7%
High glazing	South	33.8%	32.2%	34.5%	32.6%	32.8%	31.0%
	North	33.6%	31.8%	34.2%	32.3%	32.4%	30.6%
	East	32.2%	30.0%	32.8%	30.6%	30.5%	28.8%
	West	31.9%	29.7%	32.6%	30.2%	30.4%	28.3%

Table A10. Sichuan—Huili; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	46.9%	40.4%	45.5%	40.5%	35.8%	36.1%
	North	46.7%	40.2%	45.2%	40.3%	35.7%	35.9%
	East	46.7%	39.6%	45.3%	39.7%	36.2%	35.5%
	West	46.3%	39.4%	45.2%	39.5%	36.2%	35.4%
Medium glazing	South	47.7%	40.5%	46.2%	40.6%	37.0%	36.3%
	North	47.1%	40.0%	45.7%	40.1%	36.7%	35.9%
	East	46.8%	39.0%	46.1%	39.3%	37.1%	35.3%
	West	46.6%	39.0%	45.5%	39.1%	36.9%	35.1%
High glazing	South	48.5%	40.4%	47.2%	40.6%	37.7%	36.2%
	North	47.8%	39.9%	46.5%	40.1%	37.3%	35.8%
	East	47.1%	38.9%	46.2%	39.0%	38.0%	35.1%
	West	47.0%	38.4%	46.0%	38.8%	37.7%	35.0%
Lightweight walls							
Low glazing	South	44.9%	37.6%	43.5%	37.5%	34.3%	32.8%
	North	44.5%	37.3%	43.1%	37.2%	34.0%	32.5%
	East	44.4%	36.6%	43.0%	36.6%	34.6%	32.4%
	West	44.4%	36.6%	43.0%	36.4%	34.5%	32.2%
Medium glazing	South	45.9%	37.9%	44.6%	37.6%	35.2%	33.1%
	North	45.2%	37.2%	43.9%	37.1%	34.8%	32.6%
	East	44.8%	36.5%	43.7%	36.3%	35.5%	32.6%
	West	44.6%	36.5%	43.5%	36.3%	35.4%	32.6%
High glazing	South	46.8%	38.1%	45.3%	37.9%	20.2%	29.6%
	North	46.0%	37.3%	44.5%	37.2%	19.9%	29.0%
	East	44.9%	36.5%	44.1%	36.2%	22.4%	29.1%
	West	44.5%	36.3%	43.8%	36.2%	22.4%	28.8%
Lightweight insulated walls							
Low glazing	South	57.7%	61.1%	53.4%	60.5%	40.2%	52.0%
	North	56.0%	58.3%	52.3%	58.1%	39.5%	50.2%
	East	56.9%	52.7%	54.2%	54.1%	42.5%	50.1%
	West	56.9%	52.2%	54.5%	53.5%	42.8%	50.1%
Medium glazing	South	62.2%	63.3%	58.0%	62.9%	43.9%	55.0%
	North	59.2%	57.2%	55.5%	57.7%	42.5%	52.0%
	East	56.8%	48.6%	55.8%	50.7%	45.6%	49.0%
	West	56.8%	47.6%	55.6%	49.6%	46.0%	48.3%
High glazing	South	65.6%	62.2%	61.7%	62.9%	47.2%	57.0%
	North	60.4%	56.7%	57.8%	57.2%	45.2%	51.8%
	East	55.1%	44.9%	55.0%	46.8%	47.1%	45.9%
	West	54.4%	44.5%	54.9%	46.1%	46.9%	45.3%

Table A11. Sichuan—Songpan; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	4.2%	10.1%	3.2%	9.6%	0.7%	6.7%
	North	4.1%	10.1%	3.2%	9.6%	0.7%	6.7%
	East	4.6%	10.5%	3.8%	9.9%	1.2%	7.0%
	West	4.8%	10.6%	3.9%	10.0%	1.3%	7.1%
Medium glazing	South	4.9%	10.5%	3.9%	10.0%	1.3%	7.0%
	North	4.8%	10.5%	3.9%	9.9%	1.2%	7.0%
	East	5.6%	11.1%	4.5%	10.4%	1.7%	7.5%
	West	5.8%	11.1%	4.9%	10.5%	2.0%	7.6%
High glazing	South	5.5%	10.8%	4.6%	10.3%	1.7%	7.5%
	North	5.4%	10.8%	4.5%	10.2%	1.6%	7.4%
	East	6.6%	11.5%	5.4%	10.9%	2.4%	8.1%
	West	6.9%	11.7%	5.7%	11.1%	2.7%	8.1%
Lightweight walls							
Low glazing	South	5.1%	10.6%	4.3%	10.0%	1.9%	7.5%
	North	5.0%	10.5%	4.2%	10.0%	1.8%	7.4%
	East	5.6%	10.9%	4.7%	10.4%	2.3%	7.8%
	West	5.8%	10.9%	4.9%	10.5%	2.5%	7.9%
Medium glazing	South	5.8%	10.9%	4.8%	10.5%	2.4%	7.9%
	North	5.7%	10.8%	4.7%	10.4%	2.3%	7.8%
	East	6.6%	11.2%	5.6%	10.7%	3.0%	8.2%
	West	7.0%	11.2%	5.9%	10.7%	3.2%	8.4%
High glazing	South	6.4%	11.4%	5.6%	10.9%	3.0%	8.2%
	North	6.3%	11.2%	5.4%	10.7%	2.8%	8.2%
	East	7.7%	11.6%	6.6%	11.2%	3.5%	8.5%
	West	8.0%	11.6%	7.0%	11.2%	3.9%	8.5%
Lightweight insulated walls							
Low glazing	South	6.0%	15.1%	3.8%	12.4%	0.4%	5.1%
	North	5.5%	14.9%	3.5%	12.1%	0.3%	4.7%
	East	9.2%	19.1%	6.0%	16.1%	1.5%	7.9%
	West	9.5%	19.8%	6.4%	16.7%	1.9%	8.5%
Medium glazing	South	7.8%	17.1%	5.3%	14.4%	1.2%	6.9%
	North	7.1%	16.4%	4.8%	13.7%	1.0%	6.3%
	East	11.9%	21.5%	8.5%	18.8%	3.0%	10.9%
	West	12.7%	22.1%	9.0%	19.7%	3.4%	11.6%
High glazing	South	10.0%	18.9%	7.3%	16.5%	2.8%	9.1%
	North	9.4%	18.0%	6.7%	15.7%	2.4%	8.4%
	East	15.0%	23.1%	11.3%	21.0%	4.8%	14.0%
	West	15.8%	23.6%	12.0%	21.5%	5.4%	14.5%

Table A12. Yunnan—Deqen; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	0.5%	6.4%	0.3%	5.9%	0.0%	3.2%
	North	0.4%	6.3%	0.3%	5.8%	0.0%	3.2%
	East	0.9%	7.1%	0.5%	6.5%	0.0%	3.8%
	West	1.0%	7.2%	0.6%	6.7%	0.0%	3.9%

Table A12. *Cont.*

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Medium glazing	South	0.5%	6.7%	0.3%	6.1%	0.0%	3.4%
	North	0.6%	6.6%	0.3%	6.1%	0.0%	3.4%
	East	1.2%	7.5%	0.7%	7.1%	0.0%	4.2%
	West	1.5%	7.8%	1.0%	7.4%	0.1%	4.5%
High glazing	South	1.0%	7.5%	0.5%	7.0%	0.0%	4.0%
	North	1.0%	7.3%	0.5%	6.9%	0.0%	3.9%
	East	1.8%	8.4%	1.3%	7.9%	0.2%	4.9%
	West	2.3%	8.7%	1.6%	8.2%	0.4%	5.3%
Lightweight walls							
Low glazing	South	1.3%	8.1%	0.9%	7.6%	0.1%	4.9%
	North	1.3%	8.0%	0.9%	7.6%	0.1%	4.9%
	East	1.6%	8.6%	1.3%	8.2%	0.2%	5.7%
	West	1.9%	8.7%	1.4%	8.3%	0.3%	5.8%
Medium glazing	South	1.5%	8.8%	1.2%	8.2%	0.1%	5.5%
	North	1.5%	8.6%	1.2%	8.1%	0.1%	5.4%
	East	2.3%	9.4%	1.8%	8.8%	0.5%	6.3%
	West	2.7%	9.5%	2.1%	9.0%	0.7%	6.4%
High glazing	South	2.0%	9.2%	1.6%	8.7%	0.3%	6.2%
	North	2.0%	9.1%	1.6%	8.6%	0.3%	6.0%
	East	3.3%	10.0%	2.6%	9.5%	0.9%	7.0%
	West	3.8%	10.1%	3.1%	9.6%	1.1%	7.3%
Lightweight insulated walls							
Low glazing	South	0.1%	6.3%	0.0%	4.3%	0.0%	0.4%
	North	0.1%	5.9%	0.0%	4.0%	0.0%	0.4%
	East	2.0%	11.8%	0.9%	8.7%	0.0%	2.5%
	West	2.4%	12.5%	1.3%	9.6%	0.1%	3.1%
Medium glazing	South	1.4%	9.9%	0.7%	7.5%	0.0%	2.0%
	North	1.3%	9.1%	0.6%	6.9%	0.0%	1.7%
	East	4.8%	16.2%	2.9%	13.5%	0.4%	5.6%
	West	5.8%	17.4%	3.7%	14.7%	0.8%	6.8%
High glazing	South	3.6%	12.5%	2.1%	10.3%	0.1%	4.3%
	North	3.1%	11.7%	1.8%	9.5%	0.1%	3.7%
	East	8.3%	19.7%	5.6%	17.5%	1.4%	9.3%
	West	9.3%	20.7%	6.6%	18.4%	1.9%	10.6%

Table A13. Yunnan—Kunming; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	48.0%	41.3%	44.9%	40.8%	31.3%	35.5%
	North	47.6%	41.1%	44.6%	40.5%	31.0%	35.2%
	East	48.1%	40.6%	45.4%	40.1%	32.3%	34.9%
	West	48.0%	40.4%	45.5%	40.0%	32.8%	34.9%
Medium glazing	South	48.7%	41.4%	46.0%	40.8%	32.8%	35.6%
	North	48.0%	40.9%	45.4%	40.4%	32.2%	35.1%
	East	48.5%	40.1%	46.1%	39.9%	33.8%	34.9%
	West	48.2%	39.7%	46.1%	39.8%	34.5%	34.6%

Table A13. *Cont.*

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
High glazing	South	49.3%	41.2%	46.5%	40.8%	34.1%	35.6%
	North	48.6%	40.6%	45.9%	40.2%	33.4%	35.1%
	East	48.3%	39.4%	46.4%	39.3%	35.2%	34.8%
	West	48.0%	38.9%	46.1%	38.7%	35.6%	34.4%
Lightweight walls							
Low glazing	South	45.8%	38.0%	43.2%	37.3%	29.8%	31.2%
	North	45.4%	37.5%	42.7%	36.8%	29.4%	31.0%
	East	45.4%	37.0%	43.2%	36.5%	30.8%	31.0%
	West	45.2%	36.7%	43.2%	36.4%	31.1%	30.8%
Medium glazing	South	46.5%	38.2%	44.1%	37.6%	31.1%	31.5%
	North	45.8%	37.3%	43.3%	37.0%	30.5%	30.9%
	East	45.4%	36.4%	43.6%	36.1%	32.0%	30.9%
	West	45.0%	36.3%	43.4%	36.1%	32.2%	30.8%
High glazing	South	47.1%	38.5%	44.7%	37.8%	32.2%	32.0%
	North	46.0%	37.3%	43.8%	36.8%	31.5%	31.1%
	East	45.0%	36.2%	43.6%	35.8%	32.8%	30.8%
	West	44.8%	36.2%	43.3%	35.7%	33.0%	30.7%
Lightweight insulated walls							
Low glazing	South	53.5%	61.8%	48.7%	58.8%	29.5%	47.6%
	North	52.1%	59.0%	47.4%	56.6%	28.4%	46.1%
	East	54.5%	56.6%	50.1%	56.1%	33.0%	49.0%
	West	55.5%	55.6%	51.0%	55.3%	34.7%	49.0%
Medium glazing	South	55.5%	64.6%	50.8%	62.2%	33.1%	51.3%
	North	53.0%	58.5%	48.8%	56.9%	31.3%	47.8%
	East	55.4%	52.1%	51.9%	52.9%	36.9%	48.3%
	West	55.9%	51.1%	52.8%	51.5%	38.9%	47.7%
High glazing	South	58.6%	62.4%	53.2%	61.7%	35.8%	53.6%
	North	54.1%	57.3%	50.1%	56.6%	34.1%	48.7%
	East	54.7%	47.7%	52.3%	48.8%	39.8%	45.8%
	West	54.2%	46.3%	52.5%	47.5%	40.8%	44.8%

Table A14. Yunnan—Mengla; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	37.6%	32.0%	38.5%	33.1%	41.5%	34.5%
	North	37.4%	32.0%	38.2%	33.2%	41.3%	34.5%
	East	36.8%	31.7%	37.4%	32.6%	40.0%	33.4%
	West	36.7%	31.6%	37.3%	32.5%	40.1%	33.4%
Medium glazing	South	37.2%	31.1%	38.2%	32.4%	41.9%	34.1%
	North	37.1%	31.4%	38.0%	32.8%	41.5%	34.2%
	East	36.4%	30.8%	37.0%	32.0%	39.6%	32.9%
	West	36.1%	30.4%	36.8%	31.5%	39.6%	32.7%
High glazing	South	37.0%	30.0%	37.9%	31.5%	41.3%	33.3%
	North	36.7%	30.5%	37.7%	32.0%	40.9%	33.6%
	East	35.9%	29.9%	36.6%	30.9%	38.5%	32.1%
	West	35.6%	29.2%	36.3%	30.5%	38.1%	31.5%

Table A14. *Cont.*

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Lightweight walls							
Low glazing	South	37.0%	30.7%	38.8%	32.5%	44.4%	35.3%
	North	36.8%	30.8%	38.6%	32.7%	44.3%	35.4%
	East	35.8%	30.3%	37.6%	31.9%	42.6%	34.3%
	West	35.8%	30.1%	37.5%	31.5%	42.5%	34.1%
Medium glazing	South	36.8%	29.9%	38.7%	32.0%	44.2%	34.7%
	North	36.6%	30.5%	38.6%	32.1%	43.9%	34.9%
	East	35.3%	29.5%	36.9%	30.8%	41.7%	33.3%
	West	35.1%	29.2%	36.8%	30.5%	41.6%	33.0%
High glazing	South	35.8%	29.2%	38.0%	31.1%	43.4%	33.9%
	North	36.1%	29.5%	38.1%	31.5%	43.2%	34.1%
	East	34.8%	28.5%	36.2%	29.8%	40.5%	32.1%
	West	34.2%	28.2%	35.8%	29.5%	40.2%	31.7%
Lightweight insulated walls							
Low glazing	South	42.6%	34.1%	46.2%	38.3%	51.4%	41.7%
	North	43.7%	36.1%	46.3%	40.0%	50.8%	41.4%
	East	41.5%	34.5%	44.3%	37.4%	45.0%	38.5%
	West	40.9%	33.7%	43.8%	36.7%	44.3%	38.1%
Medium glazing	South	38.1%	27.6%	43.2%	31.9%	47.9%	37.9%
	North	40.2%	32.1%	44.3%	36.2%	46.9%	39.3%
	East	38.0%	30.4%	41.6%	33.4%	41.3%	36.5%
	West	36.9%	28.9%	40.9%	32.1%	40.3%	35.6%
High glazing	South	33.4%	23.7%	39.0%	27.7%	43.9%	33.2%
	North	37.1%	28.0%	41.3%	31.6%	43.9%	36.1%
	East	34.4%	26.4%	38.4%	29.6%	38.8%	32.9%
	West	33.2%	25.3%	37.4%	28.4%	38.0%	31.6%

Table A15. Yunnan—Yuanjiang; percentage annual comfort hours achieved.

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Heavyweight walls							
Low glazing	South	31.2%	26.6%	32.5%	27.9%	30.5%	27.0%
	North	31.3%	26.8%	32.5%	28.0%	30.2%	27.1%
	East	30.9%	26.6%	32.1%	27.6%	29.7%	26.7%
	West	30.8%	26.3%	31.9%	27.6%	29.7%	26.6%
Medium glazing	South	30.4%	25.9%	32.0%	27.2%	30.6%	26.9%
	North	30.9%	26.4%	32.2%	27.6%	30.4%	27.0%
	East	30.6%	26.1%	31.7%	27.2%	29.8%	26.4%
	West	30.2%	25.8%	31.2%	26.9%	29.6%	26.2%
High glazing	South	29.9%	25.3%	31.3%	26.5%	30.7%	26.4%
	North	30.3%	25.8%	31.7%	27.0%	30.5%	26.6%
	East	30.0%	25.3%	31.1%	26.7%	29.7%	26.0%
	West	29.7%	25.0%	30.7%	26.3%	29.5%	25.8%
Lightweight walls							
Low glazing	South	30.1%	25.0%	31.3%	26.0%	30.7%	26.7%
	North	30.4%	25.3%	31.2%	26.2%	30.7%	26.7%
	East	30.0%	25.1%	30.9%	25.9%	29.9%	26.3%
	West	29.8%	25.0%	30.8%	25.7%	29.8%	26.2%

Table A15. *Cont.*

Wall Construction Glazing Ratio and Orientation		Air Change Rate and Floor Level					
		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st Floor	Ground	1st Floor	Ground	1st Floor
Medium glazing	South	29.6%	24.3%	30.8%	25.4%	30.5%	26.0%
	North	30.0%	24.8%	31.0%	25.8%	30.4%	26.4%
	East	29.5%	24.5%	30.5%	25.3%	29.6%	25.8%
	West	29.2%	24.1%	30.2%	25.0%	29.3%	25.3%
High glazing	South	28.4%	23.5%	30.0%	24.7%	30.1%	25.5%
	North	29.4%	24.2%	30.5%	25.3%	30.2%	25.8%
	East	29.0%	23.8%	30.0%	24.8%	29.1%	25.0%
	West	28.4%	23.3%	29.6%	24.5%	29.0%	24.6%
Lightweight insulated walls							
Low glazing	South	27.1%	21.1%	31.7%	25.5%	36.3%	31.4%
	North	28.8%	24.8%	33.1%	28.4%	36.3%	32.9%
	East	28.3%	24.6%	32.1%	27.8%	35.0%	31.7%
	West	27.9%	23.8%	31.7%	27.3%	34.5%	31.1%
Medium glazing	South	22.1%	15.9%	27.3%	19.9%	34.2%	26.7%
	North	26.0%	20.6%	30.4%	24.8%	35.1%	30.6%
	East	25.6%	20.3%	29.5%	24.2%	33.6%	29.2%
	West	24.6%	19.2%	28.7%	22.9%	33.0%	28.1%
High glazing	South	18.6%	13.8%	24.0%	17.3%	31.5%	23.1%
	North	22.5%	17.8%	27.5%	21.5%	33.6%	27.2%
	East	22.6%	17.6%	26.9%	21.1%	31.9%	26.1%
	West	21.7%	16.8%	26.0%	20.1%	31.1%	25.1%

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Article

Indigenous Knowledge Systems and Conservation of Settled Territories in the Bolivian Amazon

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Abstract: Landscapes settled by indigenous communities represent nuanced inter-relationships between culture and environment, where balance is achieved through Indigenous Knowledge Systems (IKS). Through IKS, native peoples worldwide live, farm, and consume resources in a manner that is responsive to natural systems and, as such, their lands present less deforestation and more sustainable production per capita than is exhibited by non-indigenous practices. In Bolivia, the Origin Farmer Indigenous Territory (TIOC) communities of Yaminahua-Machineri and Takana-Cavineño, located in the North Amazon, are facing external threats of non-indigenous anthropogenic land use change, such as road-building and industrial-scale resource extraction. In order to understand the potential environmental and cultural loss to these territories, the present work seeks to determine the present, base-line conservation state within these Bolivian communities, and forecast land use change and its consequences until the year 2030. This was undertaken using a three-stage protocol: (a) the TIOC communities' current forest-based livelihoods, characteristics and management were determined using on-site observation techniques and extensive literature review; (b) the historical land use change (LUC) from natural vegetation to anthropogenic use was estimated using multitemporal satellite imagery; and, finally, (c) geographically explicit non-indigenous anthropogenic land-use change threat was extrapolated until 2030 using the GEOMOD modeler from the TerraSet software. Preliminary results show that both TIOCs case-sites are fairly conserved due to their forest dependence. However, deforestation and degradation could be evidenced, particularly within TIOC areas not officially recognized by the central government, due to pressures from surrounding, new non-indigenous settlements, road infrastructure, connection to markets, and the threat of the oil exploitation. Projected LUC suggest serious threats to the unrecognized TIOC areas if community governance is not reinforced, and if extractivist and non-indigenous development patterns continue to be promoted by state and central government.

Keywords: Origin Farmer Indigenous Territory; Bolivian Amazon; Indigenous versus non-indigenous land-use; land use change

1. Introduction

Worldwide, indigenous territories hold and manage between 50% and 65% of the planet's land, despite governments only officially recognizing their tenure as between just 8%–10% [1]. Although there is no single agreed-upon definition of indigenousness, some features have been provided by the United Nations to illustrate the term: self-realization as indigenous nations, community attachment to their original land, different sets of traditions and beliefs, distinct languages and unique cultures, and a perceivable difference in lifestyle and practices distinct from a dominant, colonial culture [2].

Within their territories, indigenous communities live, farm, and benefit from local resources in ways that are drawn from generations of shared-knowledge, passed down via folkways of art, dance, story-telling, and myth [3]. This intimate, nuanced knowledge of their home environment is called, variously, "traditional", "ecological", "non-formal", "indigenous-technical", and "local-wisdom" [4]. Indigenous Knowledge System (IKS) refers to the specific place-understanding of defined communities within their particular geographical setting (ibid) and has been described as "a dynamic web of interconnected biophysical, economic, political and socio-cultural contexts in which people are involved" (Mokuku and Janse van Rensburg, 1997, p. 32) [5]. The people-place symbiosis of IKS has been proffered as an approach for safeguarding natural and cultural resources and capital, such as local customs and habits, food security, climate-change, and biodiversity [3,4] and, unsurprisingly, there have been calls to study, analyze, and extrapolate from IKS to better inform sustainable practice, policy, and education [6]. Even so, there are inherent dangers in inter-lacing indigenous peoples' knowledge and ways with those of external cultures. Even the best intentions of enriching sustainability discourse (whether extrapolating-out from IKS to a different socio-economic setting, or facilitating indigenous practices from outside-in via education or policy) can be fraught with misunderstandings and misinterpretations [6]. This begins to speak to the limits and challenges of addressing indigenous practices through the internationally accepted lens of sustainable development: although the land-based cultures of indigenous peoples may resonate strongly with the ideals of sustainability, they are perhaps best understood as a different framework altogether. By way of explaining this position, it is instructive to compare the indigenous societies of the Bolivian Amazon, as précised in this paper, with the European-derived culture of the rapidly urbanizing central eastern Bolivian city of Santa Cruz de la Sierra—the region's de facto capital city—and the recent efforts to establish policy-led, large-scale sustainable forestry practices in the region.

In the last half-century, Santa Cruz de la Sierra has grown from an isolated frontier town of around 40,000 inhabitants to the 1.5 million-strong center of Bolivia's agri-industrial production zone [7]. Santa Cruz was originally master-planned in four concentric rings with greenbelts situated along the ring roads surrounding the city center, preserving natural areas and providing amenity [7]. This top-down, if well-intentioned, imposition of extensive anthropogenic patterns across a landscape in a relatively short amount of time is familiar in the "developed world", though it often begets unforeseen socio-environmental inequalities, as the relationship between culture and environmental capacity becomes distant and strained [8]. In Santa Cruz, growth has quickly outpaced the plan, and there has been subsequent uneven provision of greenspace, services, housing, and employment [9]. At the same time, there is still rapid densification across the entire urban transect; Santa Cruz was the most rapidly densifying case in a recent study of ten major Latin American cities [10]. The nationally endorsed infrastructural strategies and construction projects outlined in Section 2.2 below, point to ongoing migration into the central eastern region and the city, and further challenges of inequity and imbalance to come, and the urgent need for "sustainable development".

Ciegis et al. (2009) [11] speak to the limits of the broadly accepted definition of sustainable development derived from the 1987 Bruntland Report "development which meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development, 1987: p. 43) [11,12]. Though this term is widely adopted and understood, it best relates to a developed-world view whose main objective is economic development balanced with responsible growth [11,12]. In this frame, sustainable development is operationalized via concepts such as importation versus exportation of materials, cheap and plentiful fossil-fuels, cultural mobility and disposable income, land-use planning and zoning, and asks for reflection, checks, and balances. It is likely that any attempts to move the city of Santa Cruz de la Sierra in a more sustainable direction will be defined and limited by this frame.

This, however, is not the only armature of sustainable environment-human relations that is relevant to central eastern Bolivia. Beyond considerations of urban development, Bolivia emerged in the mid-2000s as a leader in sustainable tropical forestry, in large part because of increased influence of

Ley 1700, a 1996 forestry law that provided a more pointed and operational reflection on sustainable development as it applies to Bolivian forestry; mandated management plans, inventories, harvest limits, and consideration of indigenous land-rights [13]. Yet, as this paper will show in terms of the extent of extractive practices, this alone may not be enough, as even the best models can still represent a potentially serious and deleterious disruption of ecological capital and closely inter-woven indigenous communities. As pointed-out by Paneque-Gálvez et al. (2018) [14] Amazonian peoples actively manage forests through very different strategies that nimbly adapt on the ground to local ecological conditions and result in a synergistic forest-culture continuum. This indigenous view;

> " ... is originated within the cosmovision of indigenous people, who understand nature as a whole, as life itself. Therefore, nature cannot be instrumentalized on the grounds of further material gains. Consequently, from the indigenous worldview a different model of sustainable development is proposed; one that could be called Integral Development or Ethno-development." Ciegis et al. (2009, p. 31) [11].

It is beyond the scope of this paper to fully articulate or predict the material changes being forecast within the case-site landscapes, and where they might sit within the continuum of outright exploitation, through top-down sustainable development derived from the aforementioned developed-world viewpoint, through to nuanced Ethno-development. Within the context of this volume, this paper touches upon an alternative, indigenous-community view of what a sustainable residential landscape might mean, beyond the developed world's conception of purpose-built homes provided as a commodity largely removed from the landscape and culture that supports and surrounds it.

Given the above, it is not surprising that indigenous settled landscapes present less consumption and deforestation rates, broader forest cover, and a more sustainable production of wood and other goods when compared to areas that are not settled by native peoples [15,16]. This has led some developed-world scholars to explain forest-based indigenous cultures as aligned with forest-stewardship and ecosystem and biodiversity management [17–19]. Studies in Africa [20], simultaneous study cases from India and Chile [21], an extensive longitudinal analysis in Peru [22], and across the tropics [23,24], as well as a study in Bolivia with the Tsimane indigenous community [14], can evidence the overlap between IKS and forest conservation. Consequently, there is recognition, across global sectors and constituencies, that securing indigenous land-rights is a common imperative, and this is increasingly enshrined in international instruments–such as International Labour Organization(ILO) Convention 169 and the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) [25]. Furthermore, supportive state or federal legislation has been enacted in a number of countries, and between 2002 and 2013, 125 million hectares of forest land in lower and middle income countries was recognized as either owned or managed by indigenous peoples [25]. Beyond an ethical imperative of folkway preservation and cultural diversity, the protection and reinforcement of indigenous communities' rights over their ancestral land has been shown to be a powerful instrument against climate change through carbon sequestration [16,26]. For example, world-wide forests to which indigenous peoples and local communities currently have sanctioned/state-recognized tenure, contains over 37.7 billion tons of carbon [25], and at least 24% of all the carbon stored in the tropical soils of the world are beneath community managed land (some 54,546 Mega tons of Carbon or MtC) [27]. Turning our attention to the geographical focus of this paper: the Amazon is the most extended rain forest in the world, and covers approximately 7.4 million square kilometers of South America which represents 5% of the worldwide continental area [28,29]. The Amazon is not only a global carbon sink or source of biodiversity, but also a vital ecosystem that provides oxygen, food, climate regulation, and other important environmental services such as water provision for the continent [30–33]. However, despite its great importance, the Amazon presents increasing deforestation rates escalating from 1.6 million hectares per year in 2015 to 3 million hectares in the year 2018 [34,35].

Since the 1990s, the Bolivian Amazon has shown an increase in its economy due to chestnut production, the improvement of roads to the department of La Paz, and, especially, improved commerce to Brazil [36]. On the one hand, this economical phenomenon has helped to improve income, communication and transportation of goods and services through the region. On the other hand, it has been one of the main causes of land use change from forest to non-forest, with deforestation rates within the Bolivian Amazon basin with fluctuating values of approximately 350,000 hectares in the year 2010, more than 200,000 hectares the year 2014, more than 400,000 hectares the years 2016 and 2017, and almost 300,000 hectares the year 2018 [37–39]. Recently, it has been noted that there is a strong spatial correlation between conservation of old-growth forest and the cultural persistence of traditional ecological knowledge systems among nearby indigenous villagers within the Bolivian Amazon [14]. Given the global importance of the Amazonian basin to global ecological health, and the increasing impetus to ground global initiatives and align national policies in and with indigenous rights, this recent village-by-village based research suggests a need to complement this work, and further the conversation on the current and future relationships between Bolivia's levels of persistent forest-entwined indigenous culture and cosmology, and the state of forest conservation, though reframed to consider federally recognized indigenous initiatives and territories (rather than individual villages). Moreover, investigations of the relationship between IKS and effective forest conservation could be vital in informing the development and management of state-managed land, and the protection of indigenous territories and their IKS. Clearly, there is much to learn: as this article was written, more than 5 million hectares of Amazon forest and dry Chiquitano forest—much of it in Bolivia—burned out of control, representing a catastrophic 230% increase in deforestation over the previous year [40]. The cause: a new federal policy allowing indiscriminate slash and burn practices in order to increase extractive and extensive agriculture and cattle ranching activities [40]. The fire affected individual and collective land (47.3%) as well as state-managed land (52.7%) [40] and was the result of forest-management practices that are a far-cry from the IKS approach. We now turn our attention to the extensive tracts of Bolivian forest lands that—officially or unofficially—lie within the jurisdiction of indigenous peoples and, possibly, their IKS.

From 1996, the land managed under Bolivian indigenous or farmer groups was initially named *Territorio Comunitario de Origen (TCO)*—or Origin Community Territory [41]. The objectives of the TCO were to confer collective jurisdictional rights to indigenous peoples and communities, and with that, to seek the improvement of forests and other natural resource governance [36,42,43]. A decade later, in 2006, the term TCO was changed to TIOC or *Territorio Indígena Originario Campesino* (Origin Farmer Indigenous Territory) [36,43]. Despite the name-change, the chief characteristics remained intact [42–44] (although TIOCs allowed the registration of non-indigenous farmer groups within this category, whereas TCOs did not [41–43]). The TIOCs of the Bolivian Amazon are important to protection and conservation. Although the Bolivian Amazon has historically been an isolated and forgotten landscape with high levels of poverty, this is an ecosystem of great environmental and cultural value [30–32,36]. By 2011, Bolivia held 190 officially recognized TIOCs (i.e., the indigenous peoples and nations that originated in the territory have been officially granted a collective title) with a combined population of more than 530,000 inhabitants [45]. Of this, 55 TIOCs accounting for 168,000 inhabitants are situated within the Bolivian lowlands [45], and this includes territories within the Bolivian Amazon (approximately 142,000 km^2). Specifically, Bolivian Amazon TIOCs includes the total area of the department of Pando, the Iturralde Province of the La Paz Department, and the Vaca Diez and Ballivián Provinces of the Beni Department [30,31].

In Bolivia, land under collective management, such as the formally recognized or titled TIOCs are consolidated collective territories. These areas have undergone, through the state-managed Institute of Agrarian Reform (INRA), a process called *"saneamiento"*, which reviewed, adjusted and recognized the size, ownership, and location of the territory, and then endowed property titles to the community signed by the President [45]). Approximately 1,553 MtC (81%) is contained within these territories' soil, and TIOCs that are yet to be officially recognized contain, approximately, a further 362 MtC (19%) [27]. Unrecognized TIOC is the land area requested by the native indigenous and farmer people, which is generally registered on a map and presented to the INRA for the "*saneamiento*" process. Until the INRA officially recognizes the land area, the TIOC is "unrecognized" [45]. Data shows that land under the jurisdiction of Bolivia's indigenous communities see deforestation rates of around a third of that in land outside of TIOCs [15,16]. These deforestation reductions can be considered as a national environmental benefit, reducing the annual greenhouse gas emissions by more than 8 million tons [9,11]. Nevertheless, despite their high value, TIOCs located in the Bolivian Amazon continue to confront challenges on the control of their territory, and there is an increasing number of threats and external pressure that threaten its physical integrity [46].

Despite the existing literature on deforestation rates in the Bolivian Amazon, there is only limited work addressing the vulnerability that indigenous people managed TIOCs are facing due to new development patterns and land use change, and as mentioned before, this knowledge gap is the focus of our paper. Specifically, we wish to present the actual conservation state and future forecasts for the Yaminahua-Machineri and Tacana-Cavineño TIOCs within the Bolivian Amazon. We understand these TIOCs to be, from an indigenous viewpoint, highly intricate and fragile inhabited landscapes of homes, farms, and communities tightly woven into, and in-balance with, natural systems and processes. In this paper, the extant communities, livelihoods, characteristics, and TIOC forest-management were determined, external land-use change to non-indigenous anthropogenic program was estimated using remote sensing data, and, finally, geographically explicit extrapolation of the deleterious land-use change was conducted until 2030.

Our results show a need for reinforcing TIOCs' governance to help ensure their physical integrity, as the pressures of land-use change due to non-indigenous external pressures can create an "edge effect" that generates a negative impact on their ecosystems and their communities. As such, all of the recent conservation efforts for Bolivian Amazon TIOCs' could be weakened by new patterns of alien development fostered by new national laws. Specific and general recommendations are also discussed based on these findings.

2. Materials and Methods

This study applied a mixed-methods approach including the qualitative research on the perceptions of the indigenous communities' livelihoods and the state of their forests, a multitemporal forest cover analysis of satellite imagery, and a spatially explicit geographical extrapolation of land use change. Previous work by Paneque-Gálvez et al. (2018) and Bottazzi and Dao (2013), both in Bolivia, have applied a similar approach: qualitative tools such as interviews, field visits, participant observation, and land cover analysis, augmenting applied remote sensing procedures for multitemporal Landsat satellite images [14,47]. However, this present work adds to these general mixed-method approaches in two important ways: we report an approximation of our accuracy assessment score regarding the satellite image classification, as suggested by Pontius (2001, 2011, and 2014) [48–50]; and we apply a geographical modeling prediction procedure using the GEOMOD tool, that follows the standard protocol considerations for forest change [51–55] and the correspondent accuracy assessment using the Relative Operating Characteristic (ROC) analysis [48,50,56,57].

In order to determine the TIOC communities' livelihoods and its perceived threats, qualitative research methods were applied such as field visits, non-participant observation, personal communication with different stakeholders, and an extensive literature review. Two field visits in different times of the year were undertaken to both case-study TIOCs. The first expedition took place from April the 6th to the 9th 2018 and included key places in the Bolivian Amazon, such as the town of Guayaramerín (which cross-borders to Guajará-Merín in Brazil), a key-economical center for the north east region of Bolivia. The first expedition showed the particular importance of the chestnut (Brazil nut) economy in the region. Further visits to *Beneficiadoras de Almendras* or *Fábricas* in the town of Riberalta (Beni) demonstrated still further the nut supply-chain in-action. Harvested by indigenous communities of the Amazon forests, the Brazil nuts have to follow an energy and labor intensive process before they are exported to Europe [58,59]. Moreover, in this first expedition, direct communication and non-participant observation techniques were applied while exploring communities belonging to TIOC Takana Cavineño and TIOC Multiétinico II [59].

The second expedition was carried out 19–21 July 2018. In this exploration, a three-hour canoe trip along the Acre River led to the indigenous communities of Puerto Yaminahua and San Miguel de Machineri from the town of Bolpebra [60]. Both communities co-manage the TIOC Yaminahua–Machineri. Field data and image collection, site exploration, and personal communications with different members of the Yaminahua community, including the chief of the community, were undertaken [60], and an exploration to the community of San Miguel de Machineri was conducted after a one-hour canoe ride on the way back to Bolpebra. Although no community members were found in San Miguel de Machineri, it could be evidenced that there are key cultural similarities and differences between the Yaminahua and the Machineri [60]. Among the similarities is that both communities are deeply dependent on their forest, since little evidence of deforestation and forest degradation was evident. Another similarity was the denudation of vernacular architecture. In many areas of the Bolivian Amazon, centralized government plans have replaced native built-fabric for mortar and brick designs, imported from the Bolivian Highlands, and completely alien to these landscapes [60]. Further than their architecture, conversations with the Yaminahuas' people suggested that their community—and that of San Miguel de Machineri—are both struggling to keep their native languages alive, since Spanish and Portuguese are often required to transact the interchange goods and services [60]. One difference was that the Machineri, unlike the Yaminahua, have started to raise cattle and other domesticated species for food security purposes [60]. Both communities now have their own communication tower that allows cell-phone use, and have installed some solar panels in order to charge them along with other devices [60]. All these findings were reinforced by the content analysis of recorded interview videos uploaded on public short documentaries of Yaminahua, Machineri, Takana, and Cavineño people by APCOB (Apoyo para el Campesino Indígena del Oriente Boliviano), CIPOAP (Central Indígena de Pueblos Originarios, Pando, Bolivia), CIMAP (Central Indígena de Mujeres de la Amazonía de Pando, Pando, Bolivia), UNICEF (The United Nations Children's Fund, New York, NY, USA), and UNFPA (United Nations Population Fund, New York, NY, USA) [61–65].

In order to determine deforestation rates in indigenous managed territories and other types of native-community land management, satellite multi-temporal analysis of different land cover was conducted for both TIOCs and their correspondent reference area. A more detail description of the remote sensing procedures can be found in Section 2.4, but with reference to accuracy and reliability, following the recommendations of Li and Eastman (2006), an artificial neural network classifier called SOM (Self-Organizing Map) was used, because it can perform with 1.4–3.3% more accuracy than other standard classifiers such as the Maximum Likelihood that was used by Bottazzi and Dao (2013) [66].

Then, for the extrapolation of non-indigenous anthropogenic Land Use Change (LUC) to the year 2030, the geographical modeler GEOMOD was used, considering estimated deforestation rates from the previous step. GEOMOD was developed by research scientists at the State University of New York, college of Environmental Sciences and Forestry (SUNY–ESF, Syracuse, NY, USA), and is currently available in the GIS software TerrSET developed by Clark Laboratories at Clark University [53,55,67,68]. GEOMOD is a versatile modeler predictor of land use change that has been used for various topics including: the assessment of ecosystem services in the Philippines [69] and China [70]; predicting urban expansion in different countries such as Iran [71,72], Palestine [73], and Puerto Rico [74]; deforestation projections in the Mediterranean [75], India [76–78], Chile [79], Mexico [80], Costa Rica [53], and Papua New Guinea [81]; and for the estimation of carbon baselines for REDD (Reducing Emissions from Deforestation and Forest Degradation) projects [54,56,82] around the world, including Panama [83], Indonesia [51,84], Belize, Brazil, and Bolivia [55].

Data and methods are described in the following sections according to three-pronged research protocol, to report on the current conservation sate of TIOC communities, describe land-use change from non-indigenous anthropogenic program, and provide a future-forecast of further changes to come within a time-frame of 2030. This target year is particularly important because coincide with the world commitment, through the 17 UN Sustainable Development Goals, to achieve a better and more sustainable future for all [85].

2.1. Study Area and Indigenous Communities

At a general scope, the study area is situated within the Bolivian administrative Amazon which is defined by the new Political Constitution of the Plurinational State of Bolivia [86]. Thus, the Bolivian Amazon includes the entire state or Department of Pando, the Iturralde Province of the La Paz state, and the Provinces of Vaca Diez and Ballivián of the Beni Department [86]. At a specific level, this study focused on two *Territorios Indígenas Originarios Campesinos* (TIOC, or Origin Farmer Indigenous Territory) belonging to, respectively, the indigenous groups of the Yaminahua-Machineri in the Department of Pando and to the Takana-Cavineño in the Department of Beni. The TIOCs are separated by more than 320 km within the northern Bolivian Amazon territory (Figure 1).

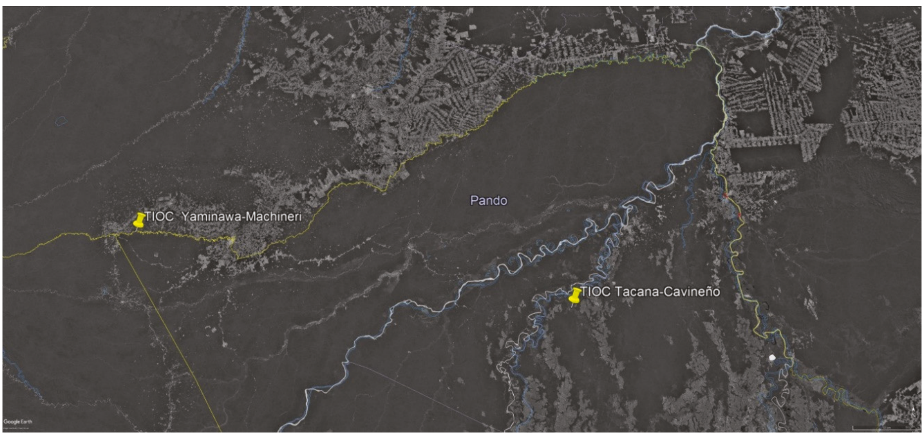


Figure 1. Location of Puerto Yaminahua (Origin Farmer Indigenous Territory (TIOC) Yaminahua–Machineri) (left) in the Department of Pando, and the location of the TIOC Takana-Cavineño (right) in the Department of Beni. Both are in the north part of the Bolivian Amazon delimited by a yellow line [87].

Both TIOCs were chosen because they efficiently and effectively represent a range of current conservation states of, and threats to, native communities in the Bolivian Amazon. The Yaminahua–Machineri TIOC represents territory next to two international borders (Brazil to the north and Peru to the west), where economic activity has had a rapid and significant impact on the landscape; historically, this has been one of the most remote and least navigable places in Bolivia, yet is undergoing waves of external anthropogenic pressure across international borders and, internally, from within the Pando Department. The territory also represents different states of official recognition. On the other hand, the TIOC Takana–Cavineño is typical of a territory that is surrounded by other native community managed areas and thus potentially addresses the effectiveness of agglomerated TIOCs in the protection Amazon forests and culture.

2.1.1. TIOC Yaminahua-Machineri

The TIOC Yaminahua–Machineri, according to the Universal Transverse Mercator (UTM) system, is located in the Zone 19 L between X coordinates: 437,206 m E, Y coordinates 8,790,029 m S, and X coordinates 468,664 m E, and Y coordinates 8,760,287 m S.

After several, decades-long negotiations, the central government officially issued land titles that recognized 24,671.3 hectares under co-management between the Yaminahua and the Machineri under the name of TIOC Yaminahua-Machineri in 2001 [45]. However, from a total of approximately 54,130 hectares that traditionally were also under the TIOC management, the remaining 29,458.7 hectares are still awaiting to be officially recognized (Figure 2) [45,88,89].

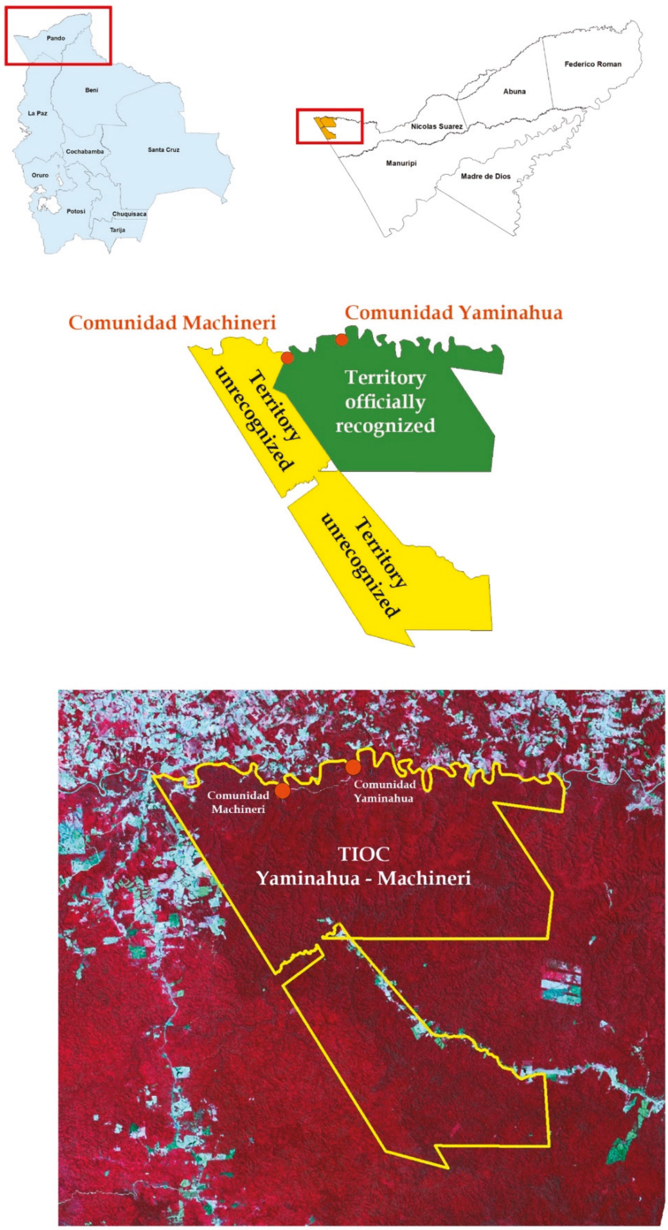


Figure 2. Location of the TIOC Yaminahua-Machineri in the Department of Pando, Province of Nicolás Suarez, and the municipality of Bolpebra. Limits to the north with Brazil and to the west with Peru. The northeastern part of the TIOC has been officially recognized by the central government (24,671.3 ha), but the rest of the territory–to date–has not (29,458.7 hectares) [45,90].

The Yaminahua

Nomads by nature, the Yaminahua had no notion of borders and lived in a vast forested region where Bolivia, Peru, and Brazil now coincide [61]. They have been almost decimated twice; first, between the 1870 and 1914, by the Amazon rubber barons and the *siringureos* (people in charge of rubber extraction) [91–93] and, second, in 1964, due to a new extractivist phase in Brazil that switched the regional economy from rubber extraction to intensive cattle production that destroyed vital forest [93]. Following these set-backs, the remaining Yaminahua moved away from the deforestation and settled in Bolivia around 1976 [93]. They now live in Puerto Yaminahua located in the Bolivian municipality of Bolpebra in the triple border shared by Bolivia (Pando), Peru, and Brazil [94]. They still speak their native language (Yaminahua), along with Spanish and Portuguese [61,88,94], and in 1994, they were officially recognized as a TCO for their agrarian settlement and ownership of the land [93]. Although there might be more Yaminahua people living in Brazil and Peru, its entire Bolivian population consists of just approximately 39 individuals [45,88,91,94]. Their main settlement activities consist of gathering, hunting, fishing, the sale of crafts and Brazil nuts, and eventually the sale of labor to Brazil [88,91]. Access to health services is difficult: the closest medical attention is some 120 km away in Cobija and is only accessible by land during dry season, or via a 20 hour boat trip through the Acre River [93,95].

Given its small numbers, the Yaminahua is one of the most vulnerable indigenous communities in Bolivia. Although some of their traditions, language, and vernacular architecture are being forgotten, their Indigenous Knowledge System of ways to see, connect, and conserve their forests are maintained by the TIOC to this day (Figure 3) [61,94]. However, external threats of non-indigenous activities, such as illegal loggers, hunters, and settlers, still put the integrity of the TIOC at risk [90,93]. In addition, even greater external threats, such as new highways and concessions for oil exploitation overlapping the TIOC territories, are a latent menace.

(**a**) (**b**)

Figure 3. (**a**) Rivers are the highways to most of the indigenous communities in the Amazon, including the Yaminahua. Most of the time, their only way to get access to markets and hospitals are many hours of canoeing along the Acre River. During dry season, they move to the cities by long drives by car on dirt roads. As with other indigenous groups, the Yaminahua have not forgotten about their connection to their forests and rivers. (**b**) Sadly, the Yaminahua community, constituted by only 39 members, is one of the most vulnerable indigenous groups in the country. Their language and culture is threatened, as is their vernacular architecture. The central government's national housing project is pushing alien designs, materials, and spatial organization over traditional approaches and techniques.

The Machineri

Although they share their territory with the Yaminahua, the Machineri is a distinct indigenous community with its own language [62]. Also nomads, they have been present in the tripartite region for 2500 to 5000 years [90]. During the time of Spanish colonization, their skills as river navigators made them intermediaries of different products through the region [90]. By the early 1980s, the Machineri had largely migrated from Brazil to Bolivia [62,90,91,95], and the present Bolivian Machineri community includes around 200 people living in San Miguel de Machineri in the Bolivian municipality of Bolpebra, approximately 8.4 km west of Puerto Yaminahua by canoe [62,91]. The closest town is Assis in Brazil, some four hours to the west by boat [91].

Similar to the Yaminahua, the Machineri want to preserve their native language and culture. Since 2014, and with support from different institutions, they have had bi-lingual teachers at the local school teaching children the original language and culture [96]. Along with the Yaminahua, the Machineri share concerns with illegal loggers and settlers as a constant threat to their forests [62]. However, unlike the Yaminahua, the Machineri's IKS tends to encourage a more diverse range of productive community activities and sustenance: cattle management and fish production alongside Brazil nuts harvest, wood usage under sustainable forest management, gathering, hunting, subsistence agriculture, and trading of labor and products to Brazil [62] (Figure 4). The Machineri were one of the first indigenous communities to implement a solar-powered system, a drinking water system, and a health post [62].

(**a**) (**b**)

Figure 4. (**a**) A Yaminahua mother and her five children waiting in San Miguel de Machineri for land transport to Cobija, the closest big city in Bolivia, some 80 km away. The Machineri community showed evidence of water storage systems and solar panel and communication systems. (**b**) It was again evident that the original landscape of vernacular architecture and natural biodiversity has been replaced by brick and mortar constructions and the presence of big and small cattle for food security.

2.1.2. TIOC Takana-Cavineño

The TIOC Takana-Cavineño, according to the Universal Transverse Mercator (UTM) system, is located in the Zone 19 L between X coordinates: 747,602 m E, Y coordinates 8,760,287 m S, and X coordinates 801,257 m E, and Y coordinates 8,655,206 m S.

The TIOC Takana–Cavineño was officially recognized by the Bolivian central government in 2007, as 801 people from indigenous communities inhabiting owning some 271,049.5 hectares (Figure 5) [45,90].

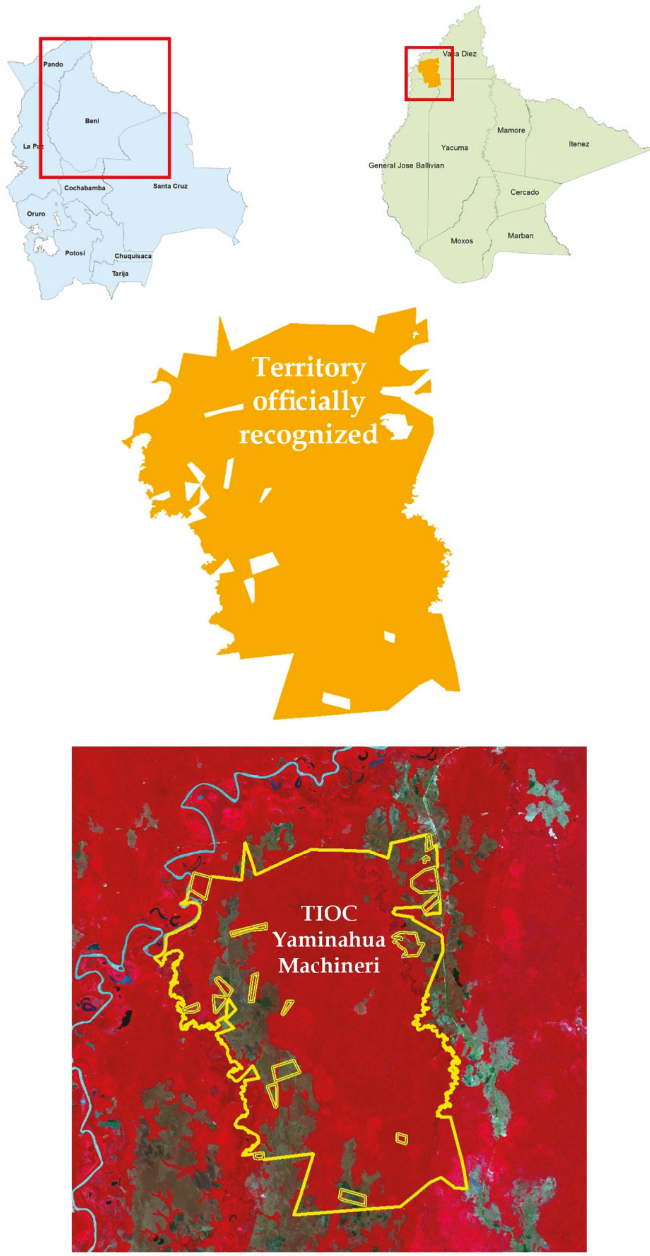


Figure 5. Location of the TIOC Takana-Cavineño in the Department of Beni, Provinces General Ballivián, Vaca Diez, and Yacuma in the municipalities of Santa Rosa, Riberalta, and Exaltación. This TIOC was officially recognized by the Bolivian central government in 2007 as 271,049.5 hectares.

The Takanas

There are approximately 7000 Takana people living in different communities along the states of Pando, La Paz, and Beni on the North Bolivian Amazon Region [63]. As with many other native Amazon communities, the Takanas used to be predominantly nomads practicing hunting, fishing, and gathering in a symbiotic lifestyle with their forests and rivers [63]. They used the forest as a source of clothing, food, building-materials, and weapons [63]. Brazil nuts, Heart Palm, honey, and turtle eggs were part of their diet [90], and they used to construct their own bows and arrows to hunt in a collective strategy [63,90] and designed sophisticated fishing techniques [63].

However, after the influence of various events, such as the Spanish missions on the 18th century, the booms of quinine around 1832 and rubber between 1880 and 1914, and colonizing settlements on their territories during the last century, the Takana started to change some aspects of their culture, adapting new lifestyles and forgetting some traditions [63,90]. Farming, the adoption of the Spanish language, and the use of currency to access clothes, food, and education represented the most significant cultural changes [63,90]. Meanwhile, due to the deterioration of their forests and rivers, many male individuals were forced to travel away from their families in search for jobs [63,90]. This phenomenon is becoming more common in native Amazon communities where the rate of forest destruction and degradations is more evident [63].

Despite these cultural adversities and pressures to their traditional IKS, the Takana are making a great effort to keep their traditions alive [63]. There are still elders and crafts-people with ancient knowledge that share their ways, including house-building, tool-crafts for hunting and fishing, and the Takana language itself, which, is increasingly being practiced and preserved by younger generations [63]. As is often the case, the landscape itself—the settled territory—is the main source of life and the key component to the maintenance of indigenous culture and economy. The Takana are still largely dependent on forest-based activities such as fishing, hunting, wood harvests, and the commercialization of Brazil nuts (Figure 6) [63,97].

(a) (b)

Figure 6. (**a**) The Takanas and Cavineños' Indigenous Knowledge System (IKS) maintain landscapes with vernacular architecture harmonizing colors, shape, and materials with their environment. (**b**) In a similar way, the IKS represents a vital symbiosis between forests, rivers, and the human community.

The Takanas are now organized in two core organizations: the OITA (Indigenous Takana Organization) and the CIPTA (Indigenous Council of the Takana People) that, together, represent their demands to the central government [90]. In 2002, most of the Takana communities officially received land titles recognizing their territories [90].

The Cavineños

The Cavineños' natural habitat was located in the various ecosystems found around the Beni and Madidi rivers that connect northern La Paz to Beni [64]. Again, the Cavineño is also a differentiated native group that has a particular language that is also under threat of disappearance [90]. Today, there are approximately 2000 Cavineño people distributed in approximately 30 communities, of which the majority (27 communities) live in the state of Beni, and the rest in Pando and La Paz [90]. The communities self-arrange themselves in extended family groups resulting in vital, productive entities that share labor and then distribute the results among all members of the group [64,90]. Although they maintain the figure of a "*Cacique*" as chief of the community, the Cavineños' order still follows an ingrained, ancient respect for the great wisdom of all their elderly [64,90]. A Spanish mission, *Misión Esmeralda*, was the first to contain the Cavineños in 1764 [90]. Then, in 1834, the mission was moved next to the Beni River due to constant invasions from the Cavineños' enemies, the *Ese Ejja jas* and *Toromona* [64]. The new mission was called *Misión Cavinas* and held approximately 1000 natives [90]. During the rubber exploitation boom, the mission became a great farm, focused mainly on agriculture and cattle production in order to provide food for the surrounding rubber-related industry [90]. *Franciscanos* (Spanish priests) used the intensive labor from the Cavineños in exchange for gun-powder, fabrics, and agricultural tools [64,90]. In 1910, the *Franciscanos* managed to acquire the land endowment of approximately 70,000 hectares from the government [90]. In 1941, the Spanish priests left the country, and North American priests from the order of Maryknoll came to Bolivia to replace them [90] and the relationship between the Cavineños and the church rapidly deteriorated. From this point, the natives started to establish and settle new communities away from the mission and sold their labor to other *barracas* or *siringueros* [64].

In 1973, before returning to the United States, the Maryknoll order sold some land to Cavineños individuals, though their rights as landholders were not, at the time, recognized by the church nor the government. Nevertheless, the Cavineños prospered and they continue to base their livelihood on the practices of agriculture, hunting, fishing, and gathering [64,90]. They also maintain practices of traditional medicine along with modern medicine [65,90]. They have particularly developed their agriculture in riparian zones, putting in practice slash and burn techniques to cultivate corn, rice, sweet potato, walusa potato, yucca, banana, peanut, watermelon, and tomatoes [90]. They have also learned skills for rubber extraction (from the time of the Barracas), and the harvest of Brazil nuts (from the time of the missions) (Figure 7) [64,65].

Since the later part of the 20th century, the growing rate of deforestation and the presence of more logging-companies in the region, it has become harder for the Cavineños to have access to wild meat from the forests [64] and, as a consequence, they have intensified fishing and the raising of domesticated cattle, sheep, pigs and poultry [64]. Additionally, similar to the Takana, the degradation of their natural resources have often forced the men to leave their families and communities in order to find jobs and earn money to buy food, clothes, tools, and other goods and services [65]. This placed the integrity of their families and the continuation of the community culture in peril [64,65].

Today, the Cavineños are organized as OICA (Indigenous Cavineña Organization) which is also affiliated to CIRABO (Indigenous Central of the Bolivian Amazon Region) located in the municipality of Riberalta (Beni) [90]. There are still many communities that lack of access to electricity and drinking water, and only some communities have health-posts and schools [90]. They finally received their land titles in 2007, and now Cavineños co-manage TIOCs with the *Esse Ejja*, *Takana*, and a distinct territory of 468,117 hectares [65,90]. Unfortunately, the TIOCs are being invaded by illegal loggers, highway construction companies, and oil companies [64,90]. Despite all these threats to their culture and natural resources, the Cavineños want to recover both, and still conserve IKS beliefs of respect to the forests where the life spirits live [64,65].

(a) (b)

Figure 7. (**a**) A Brazil nut tree standing among the rest of the forest. Brazil nut exports represent part of the 2.3% of the national Bolivian GDP as a forest-friendly sustainable economy [98]. (**b**) However, a road system, which is part of the Corredor Norte's central government development plan, is being connected to the Brazil–Peru inter-oceanic highway. Although it is still a dirt road at the time of writing, it is likely to become a busy, metaled road supplanting the canoe as the chief means of transport and facilitating the driving forces of deforestation.

2.2. National Threats to Bolivian Amazon TIOCs

It is generally known that one of the main drivers for Bolivian deforestation is the presence of roads, especially in tropical areas [99–101]. These disruptions, in the form of spatial data added to other biophysical drivers, can be used as input to a geographic modeler that will then predict the likelihood of disturbance in a given study area. It is also known that oil exploration and extraction is one of the most invasive and destructive activities in tropical forests [102–104]. Apart from other threats on a smaller scale, the Northern Bolivian Amazon faces three major threats, as manifested in a national plan: the North Corridor, the Oil Extraction Block Madre de Dios, and the expansion of the extensive-extractive agricultural and livestock frontier [40,97,105,106].

2.2.1. North Corridor

The *Corredor Norte* or North Corridor, is the construction of a system of highways that will connect the highland city of La Paz to the Amazon in Guayaramerín in Beni, and a branch connection from Guayaramerín to Cobija in Pando [105]. This in turn, will connect to an international highway called *Carretera Interoceánica* or Interoceanic Highway, which connects Brazil to Peru and tangentially touches the town of Cobija in Bolivia (Figure 8) [105]. Its construction started in 2009 [105,107], and the corridor affects both TIOCs case-sites to different degrees.

The influence of the Interoceanic Highway extends to a distance of 100 km either side of the highway itself, including the departments of Pando and La Paz [105]. The corridor initiative seeks to be part of a bigger plan called *Iniciativa para la Integración Regional Sudamericana* (IIRSA) or Initiative for the South American Regional Integration; a pan-continental effort to construct a network of highway infrastructure connecting centers of gas, oil, minerals, wood, and other natural resources in 12 South American countries including Argentina, Chile, Uruguay, Bolivia, Peru, Brazil, Ecuador, Surinam, Guyana, Paraguay, Colombia, and Venezuela [105,108]. The construction of the North Corridor in Bolivia is highly controversial, as it would have irreversible repercussions on the economy, the culture, and the ecosystems of the Bolivian Amazon, such as the degradation and loss of raw materials, the destruction of forests and rivers, pollution, and threats to indigenous communities [105].

Figure 8. The Interoceanic Highway route (shown in purple) connects productive towns in Brazil (Portobello, and Assis), Bolivia (Cobija), and Peru (Iberia and Tambopata). Shown in blue; the North Corridor connecting the city of La Paz to the Northeast Amazon cities of Riberalta and the border city of Guayaramerín with Brazil (Beni). Shown in red; the branch road from El Chorro (Beni) to Cobija (Pando) [105,107,109,110].

2.2.2. The Oil Extraction Block Madre de Dios

Once the country with the second greatest natural gas reservoirs in Latin-American, it has been evident that, over the last years, the oil and gas reservoirs in Bolivia have significantly decreased [111–113]. As a result, since 2015, the central government has approved new legislation expanding oil exploration into Protected Areas and Indigenous Territories particularly in the Bolivian Amazon (Figure 9) [97,106,111,114].

This controversial legislation has, to date, allowed an oil frontier expansion that overlaps 37.6% of all the titled TIOCS in Bolivia, representing about 8 million hectares of indigenous territories in which exploration and exploitation activities is now allowed [114]. State-driven oil company *Yacimientos Petrolíferos Fiscales Bolivianos* (YPFB) along with its international partners, can now, without prior consultation with indigenous communities, undertake seismic activities for further extraction [97].

Both of the TIOCs case-sites of this study are overlapped by this concession to oil exploration. In fact, in the southern parts of the TIOC Yaminahua–Machineri, there has already been an example of conflict with the TIOC Tacana II where oil exploration activities started in 2008 [97]. In this conflict, indigenous communities asked YPFB to respect a distance of 65 m from every Brazil nut tree for seismic detonations, no seismic activities during the harvesting season of Brazil nuts (December–April), and a comprehensive environmental study on Brazil nut trees and others important species [97]. Nonetheless, state-driven YPFB have failed to accomplish all the agreements [97].

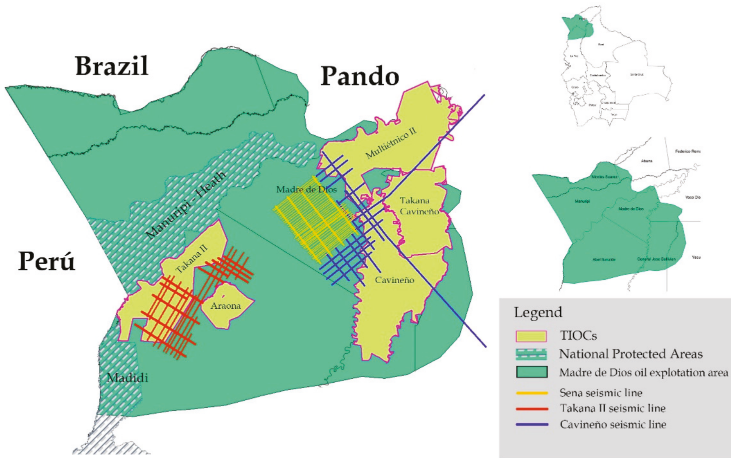


Figure 9. According to Colque and Paniagua (2019), the oil exploration area called Madre de Dios, is part of a central government plan to intensify the oil exploration and exploitation on the west part of the Bolivian northern amazon. Orange, red, and blue colored grids represent overlapping seismic lines on protected areas and TIOCs. Both TIOCs, the Yaminahua–Machineri and the Takana–Cavineño will be affected [97].

2.2.3. The Expansion of Extractive and Unsustainable Agriculture and Cattle Ranching

The need for energy alternatives in the face of the evident decline in fossil fuel reserves has resulted in crop-forests of soy and other monocultures to produce biodiesel and other additives [40,111,113,115], facilitated by Law 1098 (September 2018) [116]. Elsewhere, in order to benefit big agribusiness exports of meat to China, and benefit new settlers in the Bolivian Amazon and Chiquitano dry forest, the Bolivian central government has, since 2013, issued a set of national laws that permit slash and burn practices along with forest deforestation and degradation [40]. These pieces of legislation, inter alia: Law 337 (2013), Law 502 (2014), Law 739 (2015), and Law 952 (2017) for food production and forest restitution [117–120]; Law 741 (2015) that authorizes forest clearance or deforestation of up to 20 hectares for small properties and/or collective properties for agricultural and cattle ranching activities [121]; and the Supreme Decree 3973 (2019) that allows deforestation and fires in the department of Beni for extractive agricultural activities on private and community land [122]. This facilitation of extractive and unsustainable land-practice risk indigenous territories, as evidenced in the aforementioned fires [40].

2.3. Multitemporal Satellite Imagery and Other Spatial Data

Satellite imagery of the case-site territories was downloaded from the United States Geological Survey (USGS) open access repository, using its search tool Earth Explorer [123,124]. Multispectral imagery of 30 m of resolution from missions Landsat 8 OLI/TIRS and Landsat 4-5 TM in GeoTIFF format were used [123,125]. All the imagery were geometrically improved and atmospherically corrected to Level 2 by the USGS before downloading [125].

The most recent images available were used for the two TIOC case study sites, mainly from 2013–2018 for Yaminahua–Machineri, while older imagery was used as comparison references, and 2003 and 1998 for the TIOC Takana–Cavineño. Additionally, Digital Elevation Maps (DEM) from the ASTER Global Digital Elevation Model (ASTGTM) in GeoTIFF format of 1 arc second, were downloaded from the USGS website, then resampled to 30 m of spatial resolution, and finally merged to cover both TIOCs [124,126]. Imagery for the study area corresponded to the DEM scenes ASTGTM_S13W067, and ASTGTM_S12W067 [124,126]. Table 1 shows the satellite scenes used for each year of analysis based on the trajectory, place, day, and hour of the acquisition by the Landsat sensor.

Table 1. Landsat 30-m spatial resolution satellite imagery used for the analysis of each TIOC by year, multispectral sensor, and its trajectory [1].

TIOC	2018 L8 OLI/TIRS	2013 L8 OLI/TIRS	2003 L 4-5 TM	1998 L 4-5 TM
Yaminahua-Machineri	P: 2 R: 68 6/September P: 3 R:67 6/September P: 3 R: 68 6/September	P: 2 R:68 31/July P: 3 R: 67 22/July P: 3 R:68 22/July	P: 2 R: 68 20/July P: 3 R: 67 27/July P: 3 R: 68 27/July	
Takana-Cavineño	P: 1 R: 68 23/August P: 233 R: 69 1/September	P:1 R: 68 19/September P: 233 R: 68 3/September		P: 1 R: 68 15/July P: 233 R: 68 8/July

[1] P = Path; R = Row.

All of the raster satellite scenes, including DEM, were projected to the datum WGS84 of the Universal Transverse Mercator coordinate system (UTM) Zone 19 South, which coincide with both of the study areas. For this, the Raster Projection tool of the ArcGIS software was used [127].

In addition, other complementary spatial information was downloaded in Shapefile format from other specialized open access repositories. The first repository belongs to the *Red Amazónica de Información Socioambiental Georreferenciada* (RAISG) (Amazon Network of Geo-referenced Socio- environmental Information) [128]. The second is the *Centro Digital de Recursos Naturales* (CDRNB) (Natural Resources Digital Center) [129]. Additionally, updated information about country, departmental, and municipal limits was downloaded from the Office for the Coordination of Humanitarian Affairs (OCHA) and GeoBolivia [130]. The road-information was based on the reports provided by the *Administradora de Caminos de Bolivia* (ABC, La Paz, Bolivia) (Bolivian Roads Administrator) from official sites [107]. Finally, some updated spatial information about secondary roads and rivers had to be identified by triangulating information from PDF files, Level 2 raster-based maps, and Google Earth, and integrated as new spatial information the geographical database. Table 2 shows the files, sources, and websites from which the geographical information was downloaded.

Table 2. Source and content of the spatial information used in the present work.

Repository	Content	Source
Amazon Network of Geo-referenced Socio-environmental Information (RAISG)	Vías en Amazonía Territorios Indígenas Concesiones Petroleras	FAN (2015) [131] SNID (2005) [132] y INRA (2015) [89] FAN (2015) en base a YPFB (2012) [133]
Natural Resources Digital Center (CDRNB)	Vías Principales Vías Secundarias Centros Poblados Límite Nacional Límites Departamentales Límites Municipales Ríos Mayores Ríos Menores Cuencas Cuencas nivel 4	ABC (2008) [134] ABC (2008) [135] INE (2001) [136] MDS (2004) [137] y GeoBolivia (2019) [130] MDS (2004) [138] MDS 2004, incluye población INE 2000–2010 [139] SUNIT y SITAP (2009) [140] SUNIT y SITAP (2009) [141] FAO (1993) [142] VCRR (2008) [143]
Office for the Coordination of Humanitarian Affairs (OCHA)	Administrative Boundaries	OCHA, HDX, GeoBolivia [130]
Bolivian Roads Administrator (ABC)	Red Vial Fundamental (PDF)	ABC (2019) [107]

2.4. Land Use Change from Forest to No-Forest in the TIOCs Region

In this section, four steps to obtain deforestation rates for TIOC Yaminahua-Machineri and TIOC Takana–Cavineño, based on the satellite analysis, will be detailed: (1) definition of the study boundaries for both TIOCs; (2) the improvement of satellite imagery; (3) the classification and merging of satellite images; and (4) the estimation of anthropogenic land use change rates. A detailed description of these steps follows.

2.4.1. Definition of the Study Area Boundaries

For both TIOC case-studies, a study area was considered in the analysis within a certain circular radius to obtain a 360-degree view approximation of the potential land use change from all directions. For the Yaminahua–Machineri, the officially and not-officially recognized territories comprised the total polygons of the TIOC, and the contiguous surrounding areas constituted the overall study area. Overall, eight zones were encompassed within a 45.5 km radius from a geographic center at the municipality of Bolpebra. The study area includes, to the north, the Brazilian state of Acre, to the west the Peruvian state of Madre de Dios, to the east, the Bolivian municipalities of Bolpebra, Cobija, and Porvenir, and to the south, the Bolivian municipality of Filadelfia (and the extensive Bolpebra) (Figure 10).

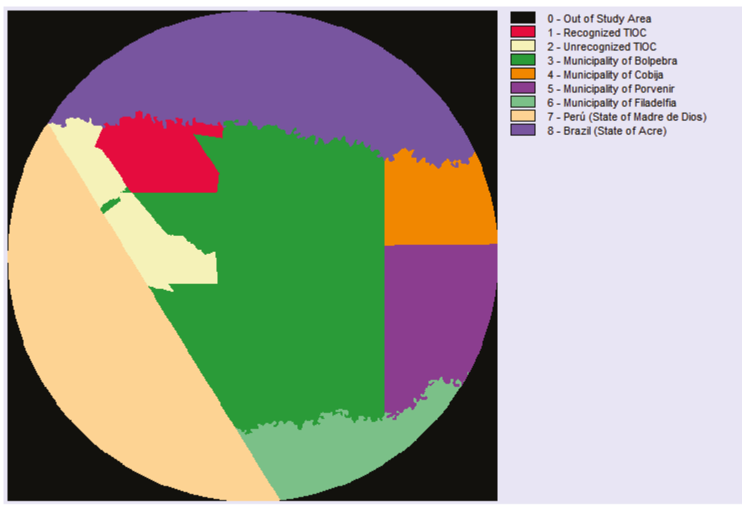


Figure 10. Study region conformed by the Yaminahua–Machineri TIOCs (Labels 1 and 2), and other six reference areas including international areas of Brazil (Acre State, label 8), and Peru (Madre de Dios State, label 7). The Bolivian municipalities of Bolpebra (label 3), Cobija (label 4), Porvenir (label 5), and Filadelfia (label 6) were also taken into consideration to evidence land use change pressures from these municipalities towards the TIOCs.

For this case, the international limit with Brazil (the route of the Acre River) was re-digitized into a new shapefile using official open information from the Bolivian government, Level-2 satellite imagery from the USGS, and Google Earth [87,125,130,137,139]. A similar procedure was followed to digitally redefine the Tahuamanu River at the south of the area, which comes from the Peruvian state of Madre de Dios and crosses east, separating the Bolivian municipalities of Bolpebra and Porvenir to the north and Filadelfia to the south. Overall, the reference area is very rich, representing an officially recognized TIOC next to an unrecognized TIOC, surrounded by two international socio-economic dynamics as well as state-managed land. State-managed land, or *Tierras Fiscales* in Spanish, belongs to a central government domain under departmental or municipality jurisdiction. State-managed land could be either available for endowment in favor of native indigenous or farmers people or could not be available for endowment such as protected areas, timber and non-timber concessions, and public domain areas [45]. The central government agency, National Institute of Agrarian Reform (INRA, La Paz, Bolivia), is in charge of state-managed land endowment through a process called "*saneamiento*", only if the land accomplish a Social Economic Function (*Función Económica Social*—FES). According to the Bolivian Constitution [86], the Social Economic Function is the "sustainable use of the land by native indigenous peoples, community farmers, or carried out on small properties, and constitutes the source of subsistence and welfare and socio-cultural development of its owners..()..

in the development of productive activities, according to its greater capacity for use, for the benefit of society, or interests of its owner" (Article 397, 1st and 2nd paragraphs). However, in the last years, there is evidence that INRA stopped verifying the FES, which encouraged the appropriation of fiscal lands for extensive agro-industrial production and new settlements with great consequences for the forests and the environment increasing deforestation rates [40,144]) of different Bolivian municipalities.

For the case of the Takana–Cavineño, the study area was encompassed by a radius of 47.2 km from the geographical center set to the officially recognized TIOC. The other three officially recognized TIOCs included in the study area were the TIOC Multiétnico II, administered by the indigenous groups Esse-Ejja, Tacana and Cavineño to the north, the TIOC Cavineño to the west and south, and the TIOC Chácobo–Pacahuara to the east. Additionally, unrecognized TIOCs and state-managed land were considered in the reference area (Figure 11).

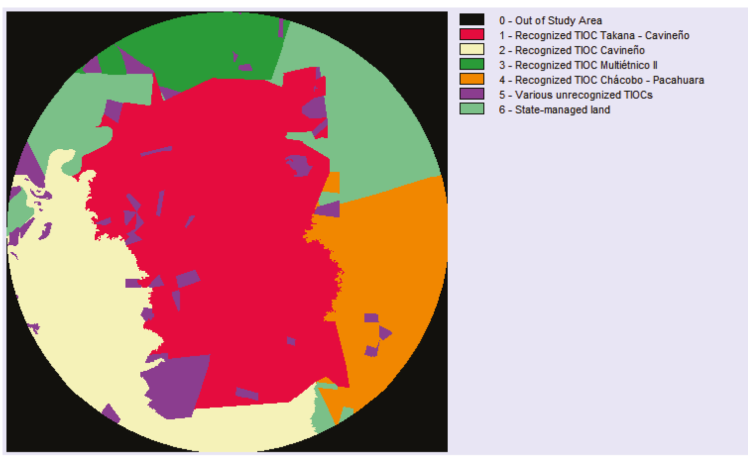


Figure 11. Study region including the Takana-Cavineño TIOC (Labels 1), and other reference areas including other officially recognized TIOCs: Cavineño (Label 2), TIOC Multiétnico II (Label 3), and TIOC Chácobo–Pacahuara (Label 4). Unrecognized TIOCs (Label 5) and state-managed land (Label 6) were also included in the spatial analysis.

For both cases polygons (in shapefile format) of the Indigenous Territories, including the TIOCs, were obtained from the Amazon Geo-referenced Socio-environmental Information Network (RAISG) that uses official Bolivian government information from the Agrarian National Institute (INRA, La Paz, Bolivia) and the National Information System for Development (SNID, La Paz, Bolivia) [89,132,145]. All the polygons were checked and adjusted to obtain clean shapefiles.

Based on the geographical delimitation of the study areas, a spatial reference grid for raster working space analysis was prepared using the software TerrSet as follows (Table 3) [68]:

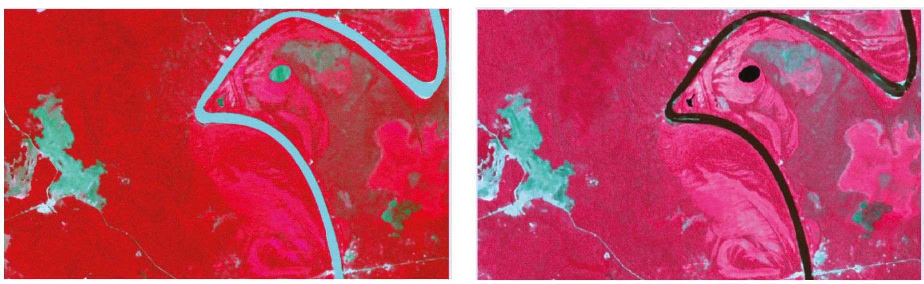
Table 3. Spatial reference grid for raster analysis for both study areas.

Spatial References	TIOC Yaminahua–Machineri	TIOC Takana–Cavineño
	Values	
Number of columns	3150	3033
Number of rows	3150	3033
Reference System	UTM 19-S	UTM 19-S
Units	meters	meters
Minimum X coordinate	727,999.9801647	429,878.7500000
Maximum X coordinate	822,499.9801647	520,868.7500000
Minimum Y coordinate	8,640,903.0455630	8,719,806.0000000
Maximum Y coordinate	8,735,403.0455630	8,810,796.0000000
Y resolution	30	30
X resolution	30	30

2.4.2. Improvement of Satellite Imagery

The satellite scenes (Table 1) were improved using the Principal Component Analysis (PCA) module from the software TerrSet [68]. For the multi-temporal analysis, the PCA provided forward and inverse transformation with t-mode (treats each band as a variable) in order to remove noise from the images [68]. For the forward t-mode, the unstandardized type of a covariance matrix was selected and produced six components for the Landsat 4-5 TM images, and seven components for the Landsat 8 OLI TIRS images. Depending on the results from the Forward T-mode, the first two or three components explained from 95 to 99 percent of the total variance in the original set, which means that the rest of the components could be dropped for noise removal [68].

Eight of the scenes were improved using three components produced by the inverse T-Mode procedure (2018: 01/68, 02/68, 03/67, 03/68; 2013: 03/67, 03/68, 233/68; and 2003: 02/68); six of the scenes were improved using two components (2018: 233/68; 2013: 01/68; 2003: 03/67, 03/68; and 1998: 01/68, 03/68), and one image was processed with no improvement due to its original quality (2013: 02/68). The main criterion for selecting the number of components was the result of different multispectral band combinations in order to distinguish water bodies (Figure 12).



(**a**) (**b**)

Figure 12. Comparison between two false color map compositions, both created by the combination of the bands 5 (NIR–Near Infrared), 4 (Red), and 3 (Green) from imagery of the 2013 Landsat 8 OLI/TIRS mission: (**a**) to the left, image created using the first three components of the PCA analysis and (**b**) to the right, image created using the first two components produced by the PCA. Note that the image on the right (**b**), which is product of the inverse t-mode module using the first two components, shows an enhanced contrast between water bodies (black and dark areas), savannas (darker blue green areas), and anthropogenic land use change (bright blue areas). Images of 2013 for the Takana–Cavineño TIOC downloaded from the United States Geological Survey (USGS) webpage [124].

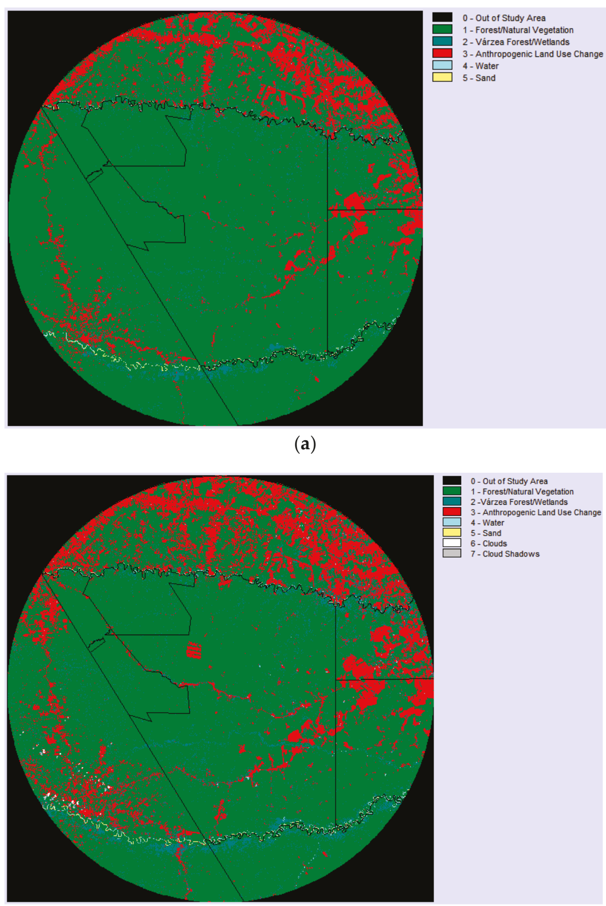
2.4.3. Classification and Merging of Images

The supervised classification took three steps. First, the definition of training sites considering general classes for land cover. For this study, the most important features to define were anthropogenic land use change and natural vegetation. In this way, the classes considered for the TIOC Yaminahua–Machineri were: 1 = Forest, 2 = Várzea Forest/Wetlands, 3 = Anthropogenic Land Use Change, 4 = Water, 5 = Sand, 6 = Clouds (when present), and 7 = Cloud Shadows (when present). The classes for the TIOC Takana–Cavineño were: 1 = Forest, 2 = Savannas/Cerrado forest, 3 = Várzea Forest/Wetlands, 4 = Anthropogenic Land Use Change, and 5 = Water. The polygon digitization tool was used to assign classes over different band combinations using the software TerrSet.

To reduce uncertainty in the identification of each class process, simultaneous comparisons with different band combinations (For example bands 4, 3, and 2 for Landsat 4–5 TM images, and bands 5, 4, and 3 for Landsat 8 OLI/TIRS), the open platform Global Forest Watch, Google Earth, and the Vegetation Map of Bolivia were conducted [38,87,146].

Secondly, the classification process was conducted using the Kohonen's Self-Organizing Map (SOM), an artificial neural network classifier also available in the software TerrSert. There is evidence that the neural network SOM can perform with 1.4%–3.3% more accuracy than other supervised standard classifier [66]. Finally, the misclassified pixels were digitally corrected using digitizing polygons and then conducting raster reclass operations to assign the proper numeric value to these pixels.

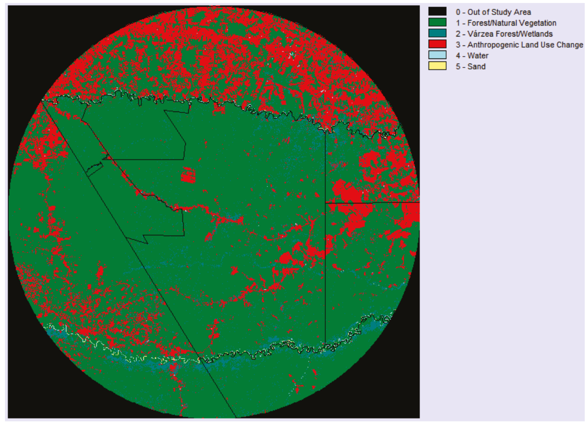
At the end of this process, for the Yaminahua–Machineri study area, each of the three scenes that corresponded to a specific year (2003, 2013, and 2018) were mosaicked into one and then clipped according to the spatial study area delimitations (Figure 13). In the same way, two scenes corresponding to each year (1998, 2013, and 2018) for the Takana–Cavineño area were mosaicked and clipped accordingly (Figure 14). The Mosaic tool was used to merge the images and then the Overlay tool was applied along with a general Mask file to delimitate the study area, as part of the TerrSert software toolbox.



(**a**)

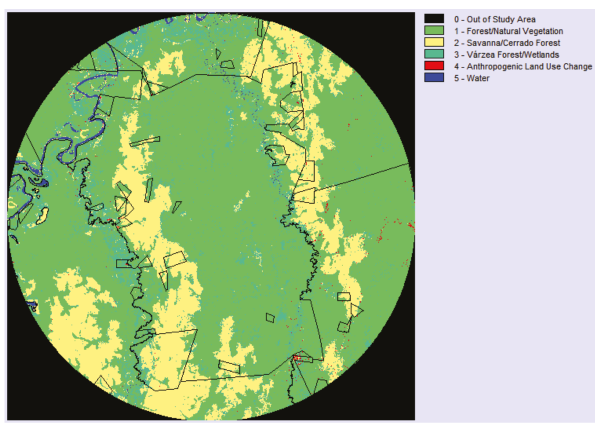
(**b**)

Figure 13. *Cont.*

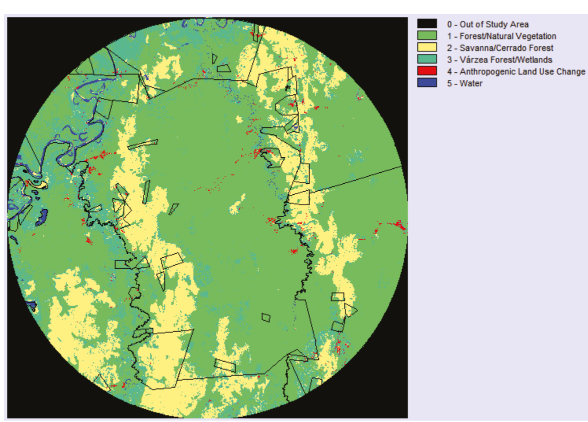


(**c**)

Figure 13. Study area including official and unrecognized Yaminahua–Machineri TIOCs. Classified maps of: (**a**) 2003; (**b**) 2013, and (**c**) 2018.

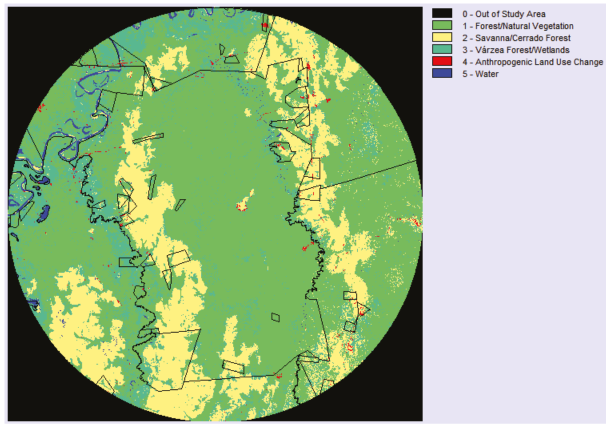


(**a**)



(**b**)

Figure 14. *Cont.*



(**c**)

Figure 14. Study area including Takana–Cavineño TIOC. Classified maps of: (**a**) 1998; (**b**) 2013, and (**c**) 2018.

An accuracy assessment technique was conducted after a similar classification protocol was followed in a study of the protected area Lomas de Arena in Santa Cruz, Bolivia. For this, a section of a finer resolution image (1.24 m) from Google Earth was manually digitized, assigning a specific class cover to each distinguishable area. This image was rasterized (30 m) and considered as the ground truth image or reference map. Then, the ERRMAT (Error Matrix Analysis) tool from the software TerrSet was used to create an error matrix between the categorical map, product of the classification protocol, and the ground truth image [68]. The results showed that the classification accuracy was over 81% [147]. Because similar steps of the supervised classification process were followed in the present work, it can be expected similar or higher levels of accuracy.

2.4.4. Estimation of Anthropogenic Land Use Change Rates

The anthropogenic land use change rate was estimated following two steps: first by determining the surface of forest cover during three periods of times in each specific study zone, and a quantification of the number of hectares corresponding to cover forest and cover loss for each study zone using the surface calculation tool of the software TerrSet; secondly, with this information, the formulas of annual rate of change of forest recommended by Puyravaud were applied [148]:

$$r = (1/(t2 - t1)) \times \ln(A2/A1), \quad (1)$$

$$r = (A2 - A1)/(t2 - t1) \quad (2)$$

Formula (1) uses the information of the forest area at the initial time (A1), forest area at the final time (A2), at an initial time (t1), and in a final time (t2). The rate is expressed in percentage (%), which allows to make standardized comparisons between different areas.

Formula (2) uses similar information as formula (1), except the result is expressed in hectares per year (ha/year).

The deforestation rate considered for the extrapolation of land use change was estimated using the forest cover information from the oldest scene and the most recent one. This approach follows a recommendation from a study that conducted a sensitivity analysis of various deforestation rates as product of different time periods [52].

2.5. Land Use Change Extrapolation to Year 2030

In order to predict the spatial land use change for both TIOCs to year 2030, three steps were taken. First, suitability maps (maps of potential land use change) were generated by the GEOMOD modeler on the TerrSet software during the calibration process. The suitability maps were created based on initial time maps, different stratifications of the study area, and different driver maps with biophysical information organized in categories of 100 as input maps. Tables 4 and 5 describe the driver maps used to obtain the suitability maps for both study areas. The explicit driver maps can be found on Appendix A as Figures A1 and A2.

Table 4. Spatial pattern driver images used in the calibration procedure of the geographic modeler GEOMOD for the Yaminahua–Machineri study area.

Analysis Zone	Number of Categories	Interval Distance	Min Value	Max Value
		m		
Digital Elevation Map	100	2	169	398
Distance to Bi-oceanic highway	100	539	0	53,928
Distance to Corredor Norte roads	100	809	0	80,911
Distance to secondary roads	100	322	0	32,208
Distance to highly populated centers	100	849	0	84,898
Distance to medium-populated centers	100	470	0	47,064
Distance to low-populated centers	100	980	0	98,010
Distance to administrative borders	100	188	0	18,816
Distance to major rivers	100	279	0	27,896
Distance to secondary rivers	100	198	0	19,774

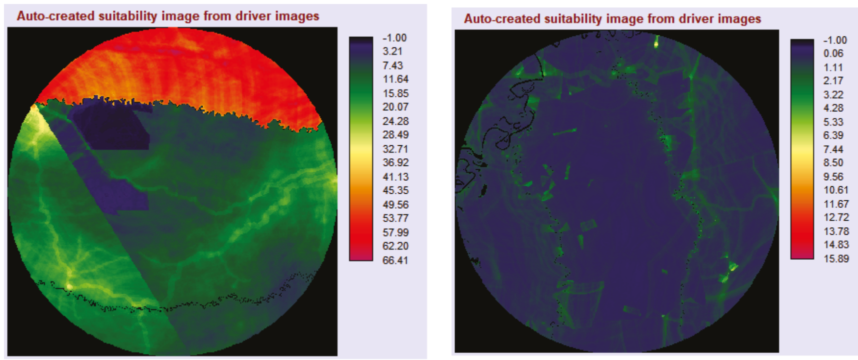
Table 5. Spatial pattern driver images used in the calibration procedure of the geographic modeler GEOMOD for the Takana-Cavineño study area.

Analysis Zone	Number of Categories	Interval Distance	Min Value	Max Value
		m		
Digital Elevation Map	100	2	69	278
Distance to populated towns	100	495	0	49,513
Distance to Corredor Norte roads	100	766	0	76,619
Distance to secondary roads	100	481.5	0	48,146.3
Distance to administrative borders	100	297	0	29,732
Distance to main rivers	100	925	0	92,517
Distance to secondary rivers	100	375	0	37,487

Second, the selection of the suitability map with the best fit of spatial agreement of projected land use change based on an accuracy assessment was made using the Relative Operating Characteristic (ROC) statistic available in the TerrSet software. The ROC statistic assesses the validity of a location prediction model by comparing a suitability image and a reference image [48,50,57,68]. If the ROC output produces an Area Under the Curve (AUC) with a value of 1, this indicates that there is a perfect spatial agreement between the reference map and the suitability map [48,50,57,68]. Hence, a perfect prediction power was obtained. On the other hand, an AUC value of 0.5 is the agreement that would be expected due to pure chance [48,50,57,68].

Figure 15 show the two suitability maps chosen for the geographical extrapolation, and Tables A1 and A2 (Appendix B) describe the ROC results for each stratification combination.

The suitability maps with higher ROC statistics and with the most recent reference images were selected based on the recommendations of a sensitivity analysis study that tested different reference area with different suitability maps zone stratifications [52].



(**a**) (**b**)

Figure 15. Suitability maps generated by the calibration process in the geographical modeler GEOMOD and selected from other maps with lower ROC scores. The higher values on the suitability maps correspond to areas most likely to change class from forest to no-forest: (**a**) to the left, selected Suitability map for the Yaminahua–Machineri TIOCs. It is evident that the Brazil's part of the study area has the highest probabilities of land use change occurrence along with the cities of Iberia in Peru (southwest), and Cobija in Bolivia (northeast) as development poles; and (**b**) to the right, the selected suitability map for the Takana–Machineri TIOC. This map suggests low chances of land use change occurrence across the study area.

3. Results

3.1. Land Use Change from Forest to No-Forest in the TIOCs Region

The results suggest that TIOCs that are officially recognized by the central government present a good conservation state and the lowest deforestation rates (Tables 6 and 7). Additionally, TIOCs surrounded by other officially recognized TIOCs are fairly protected in contrast to those TIOCs that are surrounded by international and national development sites and state-managed land. Unrecognized TIOCs can witness deforestation rates similar to unprotected state-managed land. This implies the effect of the IKS reinforced by government recognition, which is the holistic understanding of forests as a life resource that should be carefully managed.

Regarding the TIOC Yaminahua–Machineri, on the one hand, the lowest deforestation rate registered belonged to the official TIOC area (−0.01%). On the other hand, the highest deforestation rate registered in the scene belonged to the Brazilian state of Acre (−2.46%). Unfortunately, the deforestation rate of the unrecognized TIOC (−0.32%) is comparable to rates on the state-managed land of the municipalities of Bolpebra (−0.31%) and Porvenir (−0.38%). Within the borders of Bolivia, the highest anthropogenic land use change rate was found in the municipality of Cobija (−1.43%), even higher that the rate estimated in the Peruvian state of Madre de Dios (−0.65%).

Table 6. Deforestation rates for the Yaminahua–Machineri TIOC study area.

Analysis Zone	Forested Area 2003	Forested Area 2013	Forested Area 2018	Deforestation Rate (2003–2018)	
	ha			ha/Year	%
1–Official TIOC	25,455	25,382	25,398	−3.8	−0.01
2–Unrecognized TIOC	29,051	28,362	27,682	−91.2	−0.32
3–Municipality of Bolpebra	186,484	180,359	178,115	−557.9	−0.31
4–Municipality of Cobija	24,600	20,429	19,845	−317.0	−1.43
5–Municipality of Porvenir	45,566	43,343	43,066	−166.7	−0.38
6–Municipality of Filadelfia	38,357	38,043	38,034	−21.5	−0.06
7–Peru (State of Madre de Dios)	142,222	132,514	128,937	−885.6	−0.65
8–Brazil (State of Acre)	85,065	69,879	58,829	−1749.3	−2.46

Table 7. Deforestation rates for the Takana-Cavineño TIOC study area.

Analysis Zone	Forested Area 1998	Forested Area 1998	Forested Area 2018	Deforestation Rate (1998–2018)	
	ha			ha/Year	%
1–Official TIOC Takana-Cavineño	221,882	224,309	222,402	26.0	0.01
2–Official TIOC Cavineño	96,804	99,530	98,026	61.1	0.06
3–Official TIOC Multiétnico II	37,863	38,198	38,514	32.6	0.09
4–Official TIOC Chácobo-Pacahuara	75,927	76,104	70,089	−291.9	−0.40
5–Various Unrecognized TIOCs	21,788	22,808	22,577	39.4	0.18
6–Municipality of Riberalta	77,821	79,886	76,598	−61.2	−0.08

The TIOC Takana–Cavineño, an area surrounded by other officially recognized TIOCs, presented consistent forest gain patterns. This means that after the land is used by the indigenous peoples, vegetation is then allowed to take over. All the TIOCs, including the non-official ones, have shown evidence of forest gain, except the recognized TIOC Chácobo–Pacahuara (−0.4%) in which deforestation rates are higher than rates estimated on the state-managed land of the municipality of Riberalta. It is important to mention the positive correlation between the existence of the Corredor Norte roads (although still undeveloped dirt tracks at this time) and the proximity of deforestation patches.

3.2. Land Use Change Extrapolation on the TIOCs Study Region until the Year 2030

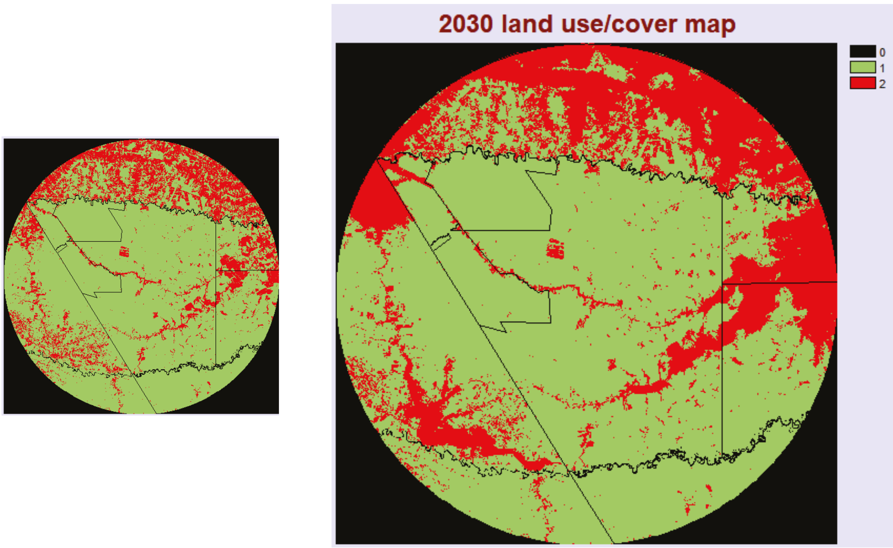
Both TIOC's LUC projections up to 2030 suggest that officially recognized indigenous territorial holdings will tend to be associated with sustained forest cover. As discussed above, the field-visits suggested the close-relationship and co-dependence between native cultures and indigenous knowledge systems and settled landscape-type: forests and rivers being particularly important. In short, it appears that, historically and in the future, indigenous knowledge systems, if reinforced by official land-rights recognition, can greatly contribute to landscape conservation of the Bolivian Amazon. However, leaving all the conservation efforts to IKS may not be enough, alone, to ensure long-term landscape health.

In the case of the Yaminahua–Machineri communities, they have demonstrated that their IKS has been fairly effective in its protection and conservation of forests in a cross-border area with dramatic contrast in land use change patterns. However, for the 2030 scenario, the TIOCs in this study area are—relatively speaking—in greater danger of non-indigenous LUC, because it is located among three massive development centers in Brazil and Peru, and domestically out of Cobija. These centers are intensely pushing inwards towards the Bolpebra municipality, and to the recognized and unrecognized TIOCs (Figure 16). The development of the road system and lack of government recognition and associated support will very likely impact the north of the unrecognized TIOC by 2030. It is evident that the immense pressure from Peru and Brazil will pierce the territory creating a sort of "suction tunnel" that will facilitate trade and forest extraction from within Bolivia, and further weaken the fundamental cultural components of the IKS on land governance.

From the east, the dramatic expansion of the urbanization from the Bolivian city of Cobija will play a fundamental role in the LUC development patterns that will connect Bolivian markets with the Peruvian city of Puerto Maldonado, which is connected at the same time with the bi-oceanic international highway system. Improvement on the actual road system, such as pavement implementation and width extension, could significantly accelerate and worsen deforestation and forest degradation patterns.

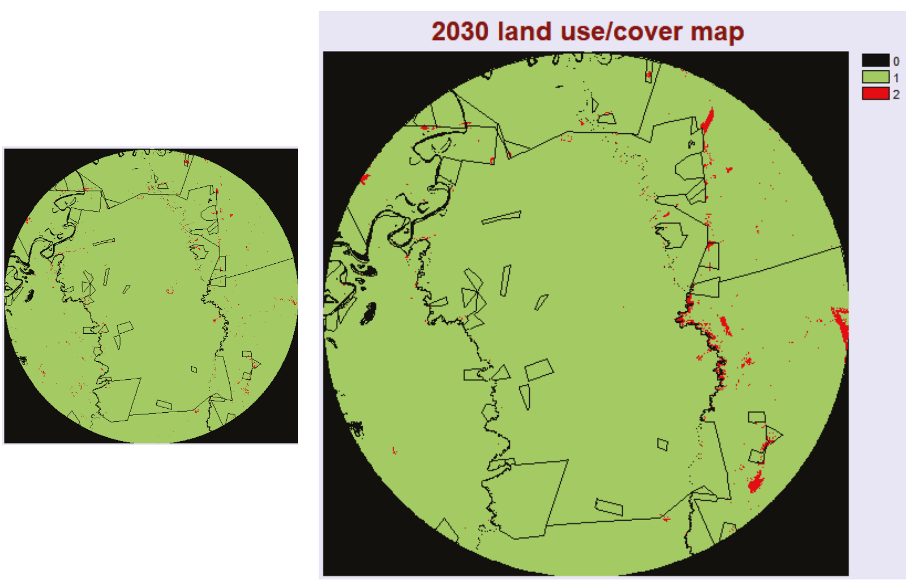
The case of the Takana–Cavineño communities provides evidence that officially recognized TIOCs maintain their territory with little to no deforestation especially if, as is this case, a TIOC is also surrounded by other official recognized territories where indigenous settlement and land management can facilitate patterns of vegetation regrowth or negative deforestation rates.

Moreover, although road infrastructure is considered one of the main driving factors for deforestation, the cluster of recognized TIOCs around the Takana–Cavineño demonstrates that deforestation is fairly controlled despite the presence of the Corridor Norte road system (Figure 17).



(**a**) (**b**)

Figure 16. Study area for the TIOCs Yaminahua–Machineri. Class 0 = Out of Study Area; Class 1 = Forest/ Candidate Area for Land Use Change; and Class 2 = Anthropogenic (projected) Land Use Change: (**a**) to the left, image of forest and no-forest areas of 2018; (**b**) to the right, projected anthropogenic land use change to the year 2030.



(**a**) (**b**)

Figure 17. Study area for the TIOCs Takana-Cavineño. Class 0 = Out of Study Area; Class 1 = Forest/ Candidate Area for Land Use Change; and Class 2 = Anthropogenic (projected) Land Use Change: (**a**) to the left, image of forest and no-forest areas of 2018; (**b**) to the right, projected anthropogenic land use change to the year 2030.

However, based on the historical deforestation rates, the 2030 forecast suggests that non-indigenous LUC may take place, first, in the officially recognized TIOC Chácobo Pacahuara, and then in state-managed land of the municipality of Riberalta. The explanation for this projection could include variables and dynamics specific to this particular TIOC that are quite different to other TIOCs with lower deforestation rates, and this difference requires further investigation.

It is also important to understand that not all TIOCs are surrounded by other recognized TIOCs in the Amazon, as is the case of the Takana–Cavineño, nor are they located in the midst of a tripartite area of aggressive international development centers as is the case of the Yaminahua–Machineri TIOC. Both study cases represent particularly interesting, if somewhat extreme, examples of TIOCs under contrasting conditions, and further work is necessary to understand forecasts for TIOCs in other, perhaps less dramatic, circumstances to understand the fuller picture.

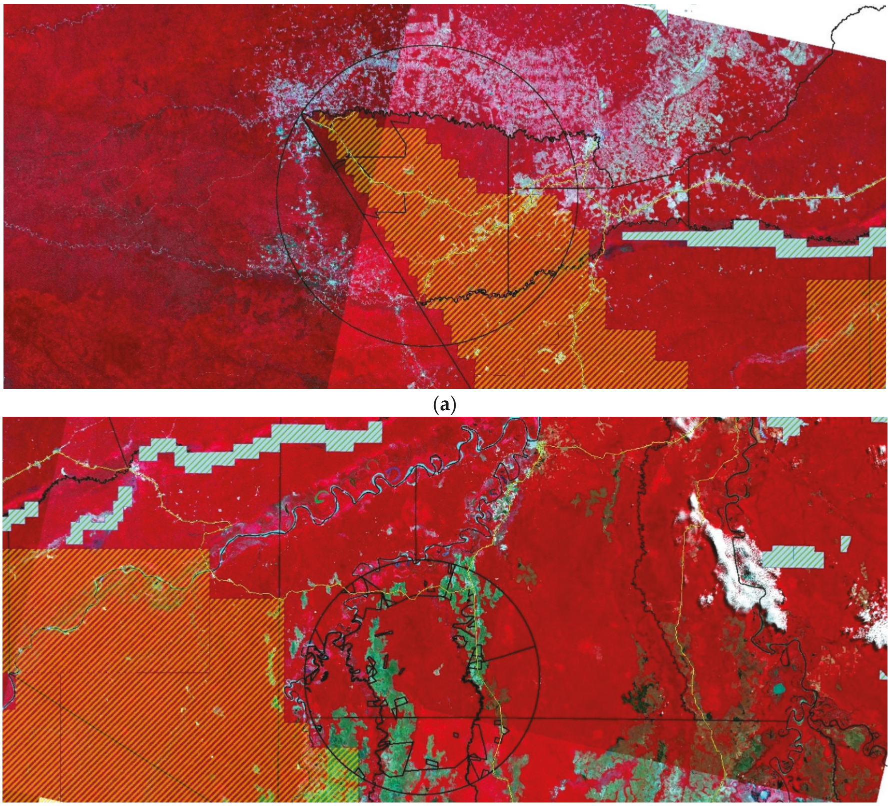
Furthermore, these projections were based on the assumption that things will continue under a business as usual scenario based on current political, administrative, and biophysical conditions. Any change in these variables such as enhancing of road systems, or the appearance of new settlements should be updated and included for new geographical predictions.

4. Discussion

Historically, Bolivia's economy has been predominantly extractivist; it has been blessed, or cursed, to have rich-mineral deposits, gas and oil reservoirs, and other natural resources. History has demonstrated that human development indicators and sustainable development goals have yet to gain much traction. Up to the present day, oil exploitation and the sale of natural gas to Brazil and Argentina are Bolivia's main Gross Domestic Product (GDP) contributors (~32%) [98]. Mining exploitation provides the second biggest GDP contributor (Zinc Ore 17%; Gold 13%; Precious Metal 6.5%; and Raw Tin 4.5%) [98]. Although natural resource exploitation and extrativism are an ingrained part of the country's development agenda, their markets are no longer as strong as they were [115]. Yet, the current need to meet immediate fossil fuel export commitments to Brazil and Argentina [115,149,150] are forcing the legal opening of protected areas and indigenous communities lands [97,106,114].

Figure 18 shows infra-red map compositions (Bands 5, 4, and 3) of both TIOCs study areas, the same that are overlapped with oil expansion blocks layers (orange blocks), mining blocks layers (light blue blocks), and road systems (yellow lines). Such alarming patterns speak to a grave concern: if Bolivian Amazon (and other) TIOCs are going to endure, this will only be because of government support when highways, oil exploration, mining, cattle expansion, and promotion of biofuels such as ethanol [151] are big driving factors for the economy and IKS degradation. Furthermore, pernicious activities, such as illegal mining or fake legal logging in the Bolivian Amazon, as outlined in the study of Brancalion et al. (2018), require careful monitoring to safeguard ecosystems and IKS [152]. Another point of consideration is the exposure of indigenous people to a commodity-based and transactional market economy. Reyes García et al. (2012), in their study of 87 Bolivian Amazon Tsimane villages, found that exposure to traders, loggers, cattle ranchers, highland colonist farmers, and other non-indigenous peoples was linked to unregulated natural resource extraction [153].

Curiously, despite all the central government policies promoting deforestation and disruption of indigenous territories over the last 15 years, such as the Supreme Decree 2549 (2015) for oil exploration expansion, or the constant promotion of expansion to the cattle frontier in Supreme Decree 3973 (2019) that has allowed 9 to 10 million hectares of deforestation; forest friendly economies such as Brazil nut, cashews, and coconuts exportation still makes-up the 2.3% of the national GDP [98,106,154]. Bolivia exports yearly over 24,000 tons of Brazil nuts to the United States, Germany, the United Kingdom, the Netherlands, Italy, and very soon to China [97]. Bolivian Amazon forests and their associated environmental services where protected by IKS and folk-ways, are contributing to the mitigation of climate change [15,26,27], and they represent a great potential to investigate and leverage significant forest-friendly economies. However, this would only be possible if it were to be part of a new paradigm of development for the country, and one that would need to make the leap from exploitation to something akin with the aforementioned cosmovision of indigenous people from Ciegis et al. [11].



(**a**)

(**b**)

Figure 18. Infrared map compositions (Bands 5, 4, and 3) where photosynthetic activity is shown in reds, savannas/cerrados are in opaque green-blue shades, and anthropogenic land use change in light blue patches. Roads are yellow lines, oil concessions are orange blocks, mining camps in light blue blocks. Note that the Yaminahua–Machineri TIOC (**a**) is under direct threat from oil exploitation, and the Takana–Cavineño (TIOC) (**b**) is under partial threat from the same.

Although this is somewhat aspirational, this paper at least points the way to some actionable steps in the right direction, as does previous work and actions drawn from across the world, which suggest that IKS integration into land-use policy and practice is achievable. Our work suggests that Bolivian Amazon TIOCs need full government support to officially recognize all their land. This recommendation is compatible with the work of Blackman et al. (2017), whose findings in the Peruvian Amazon affirm that the recognition of indigenous territories reduced forest clearing by more than 75% and forest disturbances by two-thirds in just two years [22]. Furthermore, a national program to support and reinforce indigenous communities land governance could well be founded and justified simply in the fact that IKS can be a cost-effective approach to ensuring forests' environmental services, and help catalyze local green-economies [24]: for example, and specific to the Bolivian Amazon, there is a need to incentivize and enhance Brazil nut exportation and increase its representation in the national GDP. Examples from elsewhere—for example Huntintong (2000) and McCarter et al. (2014) [155]—have demonstrated the fertile cross-pollination of the highest-technologies and the most authentic folkways to nurture best land-culture relationships, and there could be opportunities for the development of Amazon research facilities and academic centers to promote technology and understanding transfers with IKS. There could also be better integration of forest carbon-based markets such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) to incentivize Bolivian Amazon forest protection and maximize benefits to indigenous community-managed forests. While the main critiques of market-based conservation strategies such as REDD and the Noel Kempff Mercado Climate Action Plan in Bolivia [52] are based on a lack of effective indigenous participation and the commoditization of mother earth (which is why the Bolivian constitution currently does not allow REDD+), the work of Schmitt and Mukungu (2019) in the Democratic Republic of Congo shows that successful project interventions can and should consider free and prior consent, recognition of knowledge and community rights, and the involvement of communities in all steps of the monitoring process [156]. Studies conducted by Schroeder and Gonzáles (2019) based on REDD+ experiences in Colombia and Bolivia, affirm that Traditional Ecological Knowledge (TEK) could be a potential resource to help understand the complexity of the forest systems and enhance ecological and community benefits [157]. In order to avoid short-sighted vision that prioritize economic capital for a few people over collective natural capital (and which can lead to the devastation seen this year), a new national vision, forged by a systems thinking approach, is needed. For instance, the work of Puc-Alcocer et al. (2019) in the Maya area of Mexico, proposed more inclusion of IKS in the making of conservation policies for rainforests points the way [158]. In short, the paper recognizes the need for sea-change shifts away from an extractive economy to a whole-sale leveraging of IKS thinking at the highest-level of government that is already underway in other parts of the world. This is compatible with the idea of Nobre et al. (2016), who proposed:

> " ... a new development paradigm ... () ... in which we research, develop, and scale a high-tech innovation approach that sees the Amazon as a global public good of biological assets that can enable the creation of innovative high-value products, services, and platforms through combining advanced digital, biological and material technologies of the Fourth Industrial Revolution in progress." [159]

Finally, in order to ensure a quality of life, it would be necessary to complement the country's economic metrics of success with Happy Planet, Human Development, and Environmental Impact Indexes, concepts that are already embodied in Amazon indigenous communities who have endured through time, and safeguarded this vision inherited from their ancestors in their IKS or way to see the world.

Reccomendations and Further Research

More research is needed on indigenous-managed TIOCs in the Bolivian Amazon from a holistic perspective, addressing land governance components and the relationship with the biophysical environment. This will add to the knowledge of the benefits of a more symbiotic communion between community and landscape. It was beyond the scope of this paper to offer a précis and forecast of different TIOC situations and circumstances, and how this might correlate with future land-use patterns and change and, in particular, the threat of outside development pressures and the loss of valuable forest cover. We would recommend that estimation of deforestation rates, and geographical modeling projections of the same of TIOCs are conducted at least every five years to incorporate updated drivers, reduce uncertainty in the estimations, and inform stakeholders of damages, risks, and opportunities. Could this date be used to enrich, rather than replace, IKS and folk-wisdom? Could precise spatial resolution satellite maps analysis along with pertinent accuracy assessments help indigenous-managed communities to self-monitor and manage their territories? Further research can reduce uncertainty levels by using finer resolution imagery (<30 m) for the classification and its corresponding accuracy assessment, and increase the number of land cover classes for geographical prediction using neural networks and Markov chain based modelers such as the Land Change Modeler

(LCM) or Markov Modeler, both available on the TerrSet software. Furthermore, whether the selected modeler is GEOMOD or LCM, both assume the continuation of patterns extrapolated from historical data, and will therefore project land use change in a "business as usual" scenario. Future work may address this methodological limitation considering a forecasting approach that accounts for multi-level alternative scenarios, drawn-from regional, ground-truthed, empirical evidence of external events such as the occurrence of deforestation in TIOCs as a function of oil and mining activities, and the sudden expansion of the extractivist agriculture frontier including slash and burn episodes. This will nuance the forecasted range of scenarios for which TIOCs, academia, society, and multilevel government institutions can prepare for, and takes into account matters of resilience (as well as sustainability), and the recovery of these forest systems from major disruptive events, such as the devastating fires we have seen in recent months.

For future TIOC research, we also recommend that the Institutional Analysis and Development Framework (IAD), as proposed by Elinor Ostrom in 2005, is incorporated. The IAD can be used to identify key, nuanced variables that impact the collective governance of common natural resources [160,161]. This will help to better understand the "on-the-ground" factors responsible for subtle differences in forest conservation even between recognized TIOCs, such as the ones of the present study with low deforestation rates, and the also recognized TIOC Chácobo Pacahuara with deforestation rates with even higher deforestation rates than land without any sort of institutional protection.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

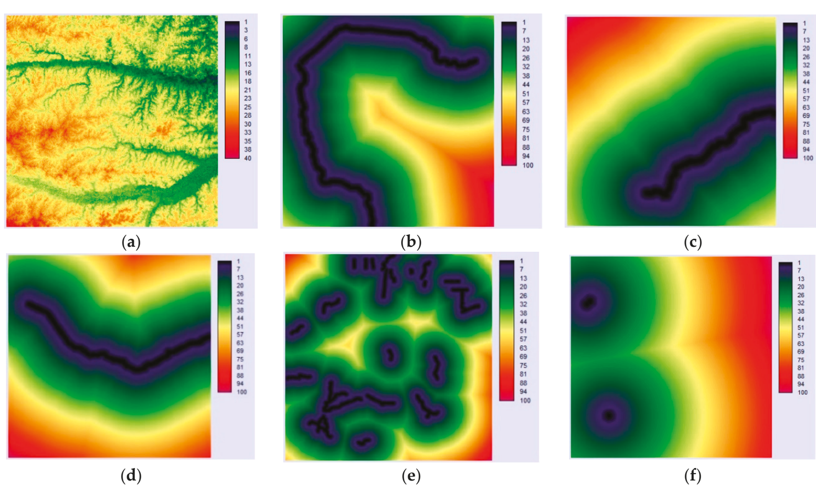

Figure A1. *Cont.*

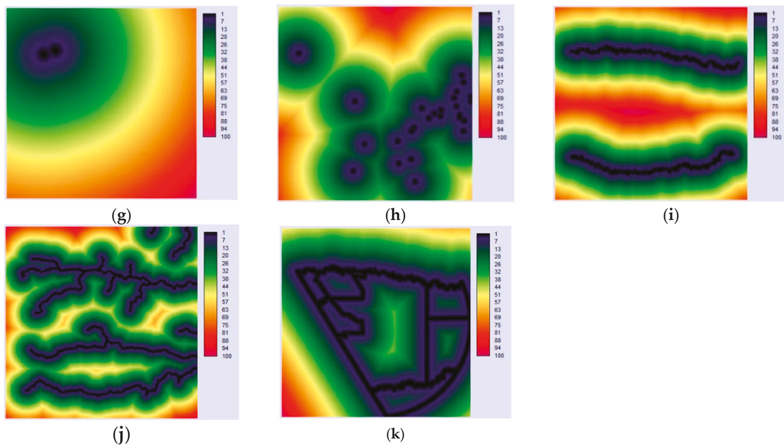

Figure A1. Driver maps used on the calibration process for the GEOMOD projection to year 2030 for the Yaminahua-Machineri TIOC: (**a**) Digital Elevation Map, (**b**) distance to bi-oceanic highway, (**c**) distance to the Corredor Norte highway system, (**d**) distance to fundamental road network, (**e**) distance secondary roads, (**f**) distance to highly populated centers, (**g**) distance to low populated centers, (**h**) Distance to medium populated centers, (**i**) distance to major rivers, (**j**) distance to secondary rivers, and (**k**) distance to administrative limits.

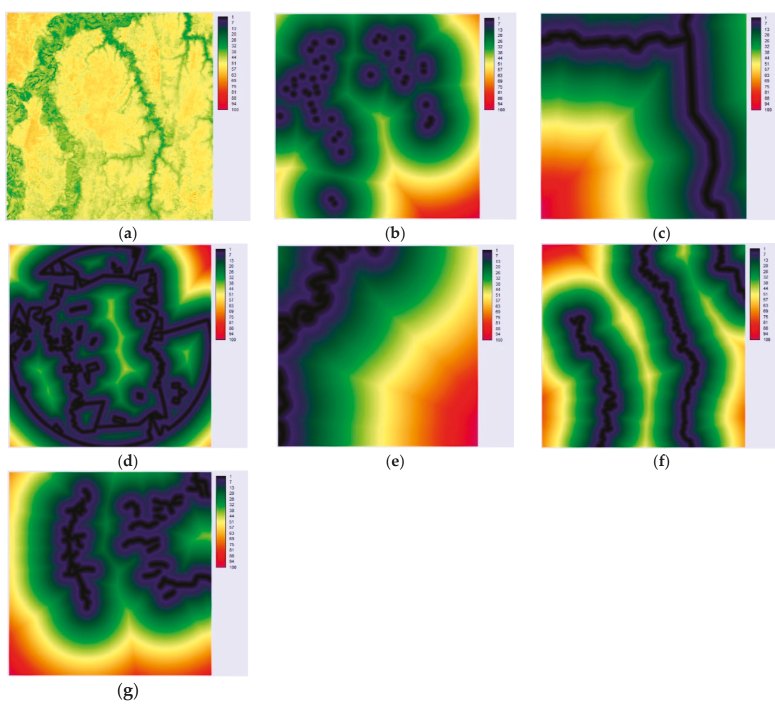

Figure A2. Driver maps used on the calibration process for the GEOMOD projection to year 2030 for the Takana–Cavineño TIOC: (**a**) Digital Elevation Map, (**b**) distance to populated centers, (**c**) distance to the Corredor Norte highway system, (**d**) distance to administrative limits, (**e**) distance to major rivers, (**f**) distance to secondary rivers, and (**g**) distance to secondary road system.

Appendix B

Table A1. ROC (Relative Operating Characteristic) scores based on beginning landuse image for the Suitability Map and strata image combinations for the Yaminahua–Machineri study site.

Beginning Landuse Image for Calibration Process	Strata Image Combinations on Suitability Maps	ROC Value for Reference Image	
		2003	2018
2003	Seven individual zones	0.889397	0.852537
	Three zones separated by countries	0.892819	0.863404
	Joint TIOCs and three countries	0.893725	0.861102
	Separated TIOCs and three countries	0.893964	0.861277
2018	Seven individual zones	0.877221	0.867673
	Three zones separated by countries	0.877388	0.870434
	Joint TIOCs and three countries	0.880581	0.871916
	Separated TIOCs and three countries	0.880804	0.874492

Table A2. ROC scores based on beginning landuse image for the Suitability Map and strata image combinations for the Takana–Cavineño study area.

Beginning Landuse Image for Calibration Process	Strata Image Combinations on Suitability Maps	ROC Value for Reference Image	
		1998	2018
1998	Six zones	0.857328	0.722349
	Four zones	0.828743	0.718536
2018	Six zones	0.794960	0.887050
	Four zones	0.763244	0.874470

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