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Design Decision Support for Healthcare Architecture: A VR-Integrated Approach for Measuring User Perception

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Abstract: Changing the physical environment of healthcare facilities can positively impact patient outcomes. Virtual reality (VR) offers the potential to understand how healthcare environment design impacts users' perception, particularly among those with brain injuries like stroke, an area with limited research. In this study, our objective was to forge a new pathway in healthcare environment research by developing a comprehensive, six-module 'user-centered' design decision support approach, utilizing VR technology. This innovative method integrated patient engagement, architectural design principles, BIM prototyping, and a sophisticated VR user interface to produce realistic and immersive healthcare scenarios. Forty-four stroke survivors participated, experiencing 32 VR scenarios of in-patient bedrooms, followed by interactive in-VR questions and semi-structured interviews. The results of the approach proved to be comparatively efficient and feasible, provided a high level of immersion and presence for the participants, and effectively elicited extremely rich quantifiable response data, which revealed distinct environmental preferences. Our novel approach to understanding end-user responses to stroke rehabilitation architecture demonstrates potential to inform user-centered evidence-based design decisions in healthcare, to improve user experiences and health outcomes in other healthcare populations and environments.

Keywords: evidence-based design; stroke rehabilitation; healthcare architecture; VR; BIM; game engine

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1. Introduction and Background

The influence of physical environmental factors in healthcare facilities—such as floor plan layout, room configurations, and lighting—have a significant impact on patients outcomes, safety, and satisfaction [1]. These factors underscore the necessity of designing healthcare spaces that positively impact patient care and recovery, a particularly pertinent consideration in rehabilitation settings. Virtual reality (VR) allows researchers to study the impact of various environmental factors, such as lighting, room size, outdoor views, and noise, in a controlled setting, but this technology has rarely been used in vulnerable patient groups [2,3] or people with neurological impairments such as stroke. Our study leverages VR to assess and quantify the impact of these environmental features on patients.

1.1. Evidence-Based Design in Healthcare Architecture

Recognizing the crucial role of environmental factors, the field of healthcare built environment design has evolved toward an evidence-based design (EBD) approach [4]. This evolution marks a shift from intuition-based to research-driven design strategies, necessitating tools and methodologies that can effectively incorporate empirical data into design decisions. EBD refers to creating environments based on the judicious use of best evidence from research, an informed client's view, and interpretation by a skilled designer [5]. The growing emphasis on EBD over the past decade highlights the need for methodologies that can reliably gauge the impact of environmental factors on patient well-being while also providing practical design solutions in healthcare settings [6,7].

1.2. Integrating User Perspectives in Design

While EBD emphasizes traditional research and data, a holistic approach also requires integrating the lived experiences of end-users. In healthcare design, this means valuing patients' perspectives as much as empirical data [8].

Incorporating the user perspective is a crucial component of user-centered design [9]. It is essential to seek feedback from people with lived experiences to understand their needs, preferences, and experiences. This information could be used to optimize the design and operation of healthcare facilities, with the intention of achieving better outcomes.

1.3. The Traditional Approach to Engaging End-Users Is Limited

User contributions to design evaluation largely depend on the institutional context of the planning and design project and vary across regions and health systems. Traditional approaches, such as post-occupancy surveys, interviews, and observations, often limit user input during the design process [10,11]. There is an increasing demand for simulation modelling in the early design stage to test design hypotheses and configurations, aiming to provide evidence of improved design practice [12,13]. This demand encompasses various types of computational simulations, such as the integration of space syntax analysis to optimize spatial connectivity [14,15], as well as experiential simulation models like virtual rapid prototyping and VR, which allow for the evaluation and testing of design options [16,17]. Simulation modelling has been described as the minimum to test design iterations for specific healthcare systems [6,18].

Architectural drawings and mock-ups are commonly used for evaluation, representation and communication [19]. However, these methods are limited because they do not always provide a sense of immersion and presence in the environment. Further, existing methods do not allow for the human perception of dynamic variables in a physical environment, involving movement, sound, and social interaction.

Physical mock-ups have been a mainstay in interactive representation studies [3,19]. While effective in facilitating stakeholder and patient comprehension of design proposals, their utility is hampered by an inability to experiment with dynamic variables [3,13]. Moreover, the deployment of physical mock-ups, typically in the later stages of design, comes with significant financial and temporal costs, and restricts the range of design alterations that can be feasibly explored [3].

1.4. VR as a New Approach for Realistic Virtual Mock-Up with Dynamic Variables

Virtual reality (VR) technology has experienced significant advancements in the past 30 years. It is essentially a collection of computer hardware and software designed to immerse users in artificially created 3D simulated environments [20]. Compared to traditional presentation approaches—such as 2D plans/sections and image mock-ups—VR can give users a sensory perception of some spatial variables, for instance, the actual volume of spaces, sightlines, and lighting [21]. Furthermore, VR as a simulation technique can engage dynamic variables, including movement, sound, and social interaction.

VR has become a valuable visualization and demonstration tool in architectural design, aiding the stakeholder comprehension of projects [21]. However, its application specifically in healthcare environmental design, particularly in the context of stroke rehabilitation, is not widely explored. Recent research has begun to utilize VR in healthcare facility design, yet studies engaging patients, especially vulnerable groups like stroke survivors, to gain their perspectives on built environment design are limited [3,22,23]. This raises questions about VR's feasibility as a tool for such purposes. Stroke survivors often confront cognitive and physical changes, communication impairments, and fatigue—factors that challenge the efficacy of conventional evaluation methods such as 2D mock-ups and post-interaction surveys [24]. These traditional tools may not fully meet the specific needs of these individuals. Consequently, there is an urgent need for innovative methods that can effectively capture the unique perceptions and requirements of stroke survivors in rehabilitation facility design. Advancements in VR gaming user interfaces present a promising solution to the challenge of measuring user perceptions in VR environments, especially among those with memory impairments like stroke survivors. By embedding survey questions within interactive VR scenarios, we can facilitate real-time feedback during immersion, bypassing the traditional reliance on post-experience memory recall. This is crucial for capturing authentic user responses, and the forthcoming sections of this paper will detail specific techniques to effectively utilize these VR interfaces. Such integration allows for the immediate and accurate capture of participants' perceptions, enhancing the validity of data gathered from cognitively vulnerable populations and streamlining the overall process of user experience evaluation in VR.

1.5. Building Information Modelling (BIM) and VR as an Approach in EBD for Healthcare Architecture

Acknowledging the critical role of user input, input in healthcare facility design underscores the necessity for innovative approaches in architecture. Building information modelling (BIM) is a well-established method that utilizes digital tools and software to manage information throughout a project's lifecycle, from early stages to construction [25,26]. Furthermore, BIM's integration with evidence-based design (EBD) in healthcare projects is instrumental in enabling data-driven insights, facilitating collaborative decision-making, and enhancing the visualization and analysis of design options, potentially improving operational efficiencies and patient outcomes [27].

This research introduces a novel design approach to using building information modelling (BIM) by framing it as a collaborative workflow, aligning with the broader perspective of BIM in the field [28]. The integration of game engine and VR technologies further expands BIM's collaborative scope, facilitating dynamic interactions between end-users, information systems, and advanced software tools in the context of healthcare design.

Structured around six modules, this innovative approach prioritizes patient engagement by suggesting immersive VR interfaces and implementing BIM prototyping to simulate healthcare scenarios. These scenarios aim to provide a realistic and immersive environment, enhancing the design and decision-making processes by actively involving patients and staff in the development of healthcare facilities. This workflow not only leverages cutting-edge technologies but also addresses the specific needs and preferences of users, marking a significant leap forward in the domain.

In this experimental study, the selection of VR, BIM, and game engines as approach tools explores their feasibility and safety in examining healthcare built environment variables with vulnerable groups. This emphasizes the study's commitment to advancing the healthcare design process through technology-driven solutions, ultimately contributing to the field's evolution toward more responsive and user-centered environments.

1.6. Aim

The aim of this study is to advance the integration of BIM, VR, and game engines in healthcare architecture by developing and evaluating a 'user-centered' design decision support approach. Specifically, the objectives are two-fold: first, to develop a 'user-centered' design decision support system that leverages BIM, game engine, and VR technologies to explore end-users' perceptions of healthcare environments; and second, to evaluate this approach's efficiency, feasibility, level of immersion and presence, and capability to elicit distinct preference responses from participants, particularly in the context of designing a stroke rehabilitation facility.

2. Materials and Methods

2.1. User-Centered Design Decision Support Approach Modules

To address these two aims, our method involved the development of a six-module 'user-centered' design decision support approach, which integrates stakeholder engagement and architectural design principles with VR technology to create realistic and immersive scenarios representative of actual healthcare settings, intended to elicit genuine responses from participants. This method uses architectural design building information modelling (BIM) prototyping and a game engine user interface to elicit responses from the participants.

The overall workflow of the approach is described in the flowchart graphic (Figure 1), which adopts the American National Standards Institute (ANSI) standard flowchart symbols to represent the process, decision, data, document, database, and terminator [29]. The overall method is based upon White et al.'s study for TfNSW, which investigated informing streetscape design with public perceptions using immersive virtual reality [30], which includes five key steps, including identifying the variables, constructing a digital 3D street model, building an online survey with the embedded environments with revealed preference, recruiting participants, and analyzing the results. Another study this approach was based on is Lin et al.'s study that integrated BIM, game engine, and VR technology for healthcare design in 2018 [27]; in this study, the team developed a database-supported, VR/BIM-based communication and simulation (DVBCS) system integrated with BIM, game engines, and VR technologies for healthcare design in a semi-immersed VR environment. TfNSW used an online survey with 360-degree video embedded, while in this study, the participants were encouraged to use their mobile devices with headphones to participate in the study. Furthermore, in Lin et al.'s study, they adopted the CAVE automatic virtual environment, which is a semi-immersed VR environment where six projectors cast onto a hyperboloid-designed 4992 mm $\times$ 1944 mm wood-made screen. In our study, the method is adapted to suit vulnerable groups and investigate the targeted healthcare environment. Our implementation is quite different; due to the nature of working with vulnerable groups, we adopted head-mounted devices with headphones to fully immerse participants in virtual reality. To reduce the reliance on memory, we embedded the preference questions within VR. The details of this process are discussed in Section 4.

The overall approach includes the following modules:

1. **Pre-define Module**: Workshops with researchers, healthcare providers, clinicians, and design team to identify targeted variables and requirements for the specific healthcare environment.
2. **Mixed Reality Module**: Develop an immersive VR environment including outdoor scenery, indoor physical environments, and spatial audio by using drone footage, ambisonics recordings, and the accurate modelling of the reference healthcare facility.
3. **Flexible BIM Module**: This module centers on creating a 'baseline' model of the typical targeted healthcare environment, while also establishing a flexible, cross-platform building information modelling (BIM) management system. By leveraging procedural modelling, it facilitates efficient design modifications and comprehensive scenario testing.
4. **Quantifying Module**: Design a method to measure and quantify participants' perceptions using standardized response options with a user interface (UI) tailored to specific needs and abilities of the participants.
5. **Game Engine Module**: Combine all assets in a game engine to develop a Windows VR application with four modes (practice mode, immersive scenario mode, interactive mode, and desktop control mode).
6. **Implementation Module**: Elicit responses from target healthcare end-users. Establish a VR testing environment for the recruited participants, introduce them to the system through 'practice mode' and then immerse them in various 'VR scenarios' operated on a VR head-mounted display (HMD), while capturing their preferences and emotional responses through interactive response options, followed by semi-structured interviews.

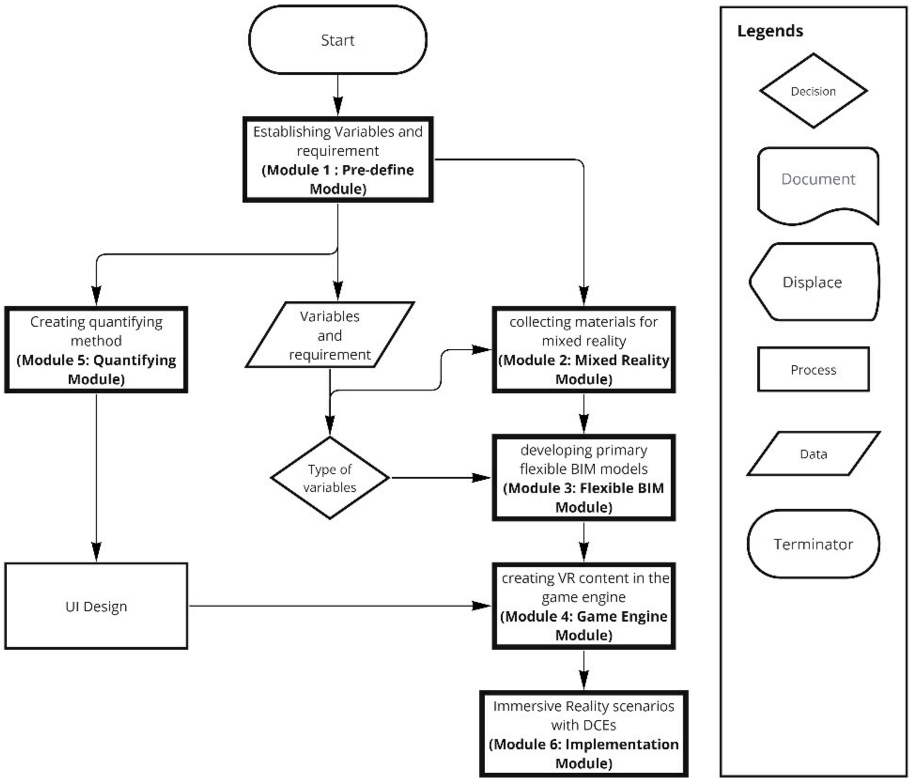

Figure 1. The overall workflow of the approach, using American National Standards Institute (ANSI) guidelines, including the six modules.

2.2. Test Case Context—Stroke Rehabilitation Architecture

To **evaluate** this 'user-centered' design decision support approach for healthcare design for its potential level of efficiency and feasibility, immersion and presence, and preferences for use by end-users, we used a test case study of stroke rehabilitation facility design. The choice of a stroke rehabilitation facility for our study was driven by several critical factors:

- Cognitive Challenges and Broad Applicability: Stroke survivors often face significant cognitive and physical challenges, making them a pertinent group to test the potential level of efficiency, feasibility, immersion, and presence in VR environments. Success in this group suggests a high likelihood of applicability to other populations with unique needs and abilities.
- Under-researched Area: Despite its importance, stroke rehabilitation facility design has not been extensively studied, presenting an opportunity to contribute to an area with substantial evidence gaps.
- Significance and Long-term Stay: Stroke rehabilitation is a critical and often long-term process. Stroke survivors' prolonged stay in such facilities accentuates the importance of their perceptions of the space, making it a significant area to study.
- Global Relevance and Emerging Needs: Stroke is one of the leading causes of disability worldwide. With advancements in acute care leading to higher survival rates post-stroke, there is an increasing need for effective long-term rehabilitation [31]. Our study addresses this emerging need by focusing on the post-acute rehabilitation environment, aiming to fill the current research gaps identified by Ruby Lipson-Smith et al. [32] in rehabilitation architecture design.

In our study, we adapted the six-module 'user-centered' design decision support approach to the specificities of stroke rehabilitation, involving volunteers who had lived experiences as patients in stroke rehabilitation facilities.

2.3. Hardware and 2019 Costs

The devices and hardware in this study were HTC VIVE head-mounted headsets with controllers, Sennheiser 500A headphones, a laptop with NVIDIA GeForce GTX 1080, a DJI Mavic Pro drone AUD, and a ZOOM H2n Handy Recorder. Prices, as of November 2019, are subject to change and serve as a reference point for the cost of equipment at the time of the study, see details in Table 1.

Table 1. Summary of hardware and prices.

Equipment	Model/Specification	Price (AUD)	Date of Price Check
Head-mounted headset	HTC VIVE with controllers	900	19 November
Headphones	Sennheiser HD 500A	165	19 November
Laptop	NVIDIA GeForce GTX 1080	1399	19 November
Drone	DJI Mavic Pro	820	19 November
Handy Recorder	ZOOM H2n	299	19 November

2.4. Personnel

The architectural design, modelling, game engine development, and VR aspects of the test case's approach involved two architects, one of whom also assumed the roles of a BIM engineer and a VR software developer, with a total of 150 h of work by personnel. The total cost, including personnel and hardware in November 2019, was AUD 11,700.

3. Results

In our test case study, we implemented all six of the modules outlined in the method section above to explore the influence of the in-patient room physical environment on stroke survivors' emotional perception and preferences. The following outlines the results of the application of each module.

1. *Pre-define Module.*

In the pre-define module of our study, we streamlined the process to focus on identifying essential architectural and spatial variables for modelling and testing with participants. This involved collaborative workshops with healthcare providers, designers, and software developers. The outcome was a concise list of key variables that were critical for the design criteria, considering the specific needs of stroke survivors using VR (see Module 1, Figure 2).

Our test case study in a VR-integrated user-centered design setting examined stroke survivors' responses to thirty-two different in-patient bedroom environments. These environments varied across four main variables: room size (wide versus narrow), view of outdoor greenery (present versus urban outlook (see Figure 3)), audio–visual social connectivity (present versus absent), and night-time noise levels (noisy versus non-noisy), derived from a literature review [33] and workshop outcomes. These variables were methodically incorporated into 16 daytime and 16 nighttime VR scenarios using a factorial design approach. This focused on sequentially exposing participants to specific physical design variables, thereby enabling a comprehensive investigation of participants' preferences for each variable. For example, Day # 1 Baseline Single serves as the baseline (Figure 3 left), depicting a single-patient room with a minimal greenery outlook, limited horizontal room width, a single patient bed, a window on the façade wall, an ensuite on the corridor wall, an interior window with blinds, a door, and non-meaningful hospital background sounds. In contrast, Day # 3 Green-View Single, as shown in Figure 3 right, is identical to # 1 in all aspects except for with lots of greenery outlook, thus isolating and highlighting the variable of 'greenery'. This controlled approach allows for an in-depth analysis of each individual variable. For detailed descriptions of other scenarios and the specifics of the factorial design, please refer to Appendix A.

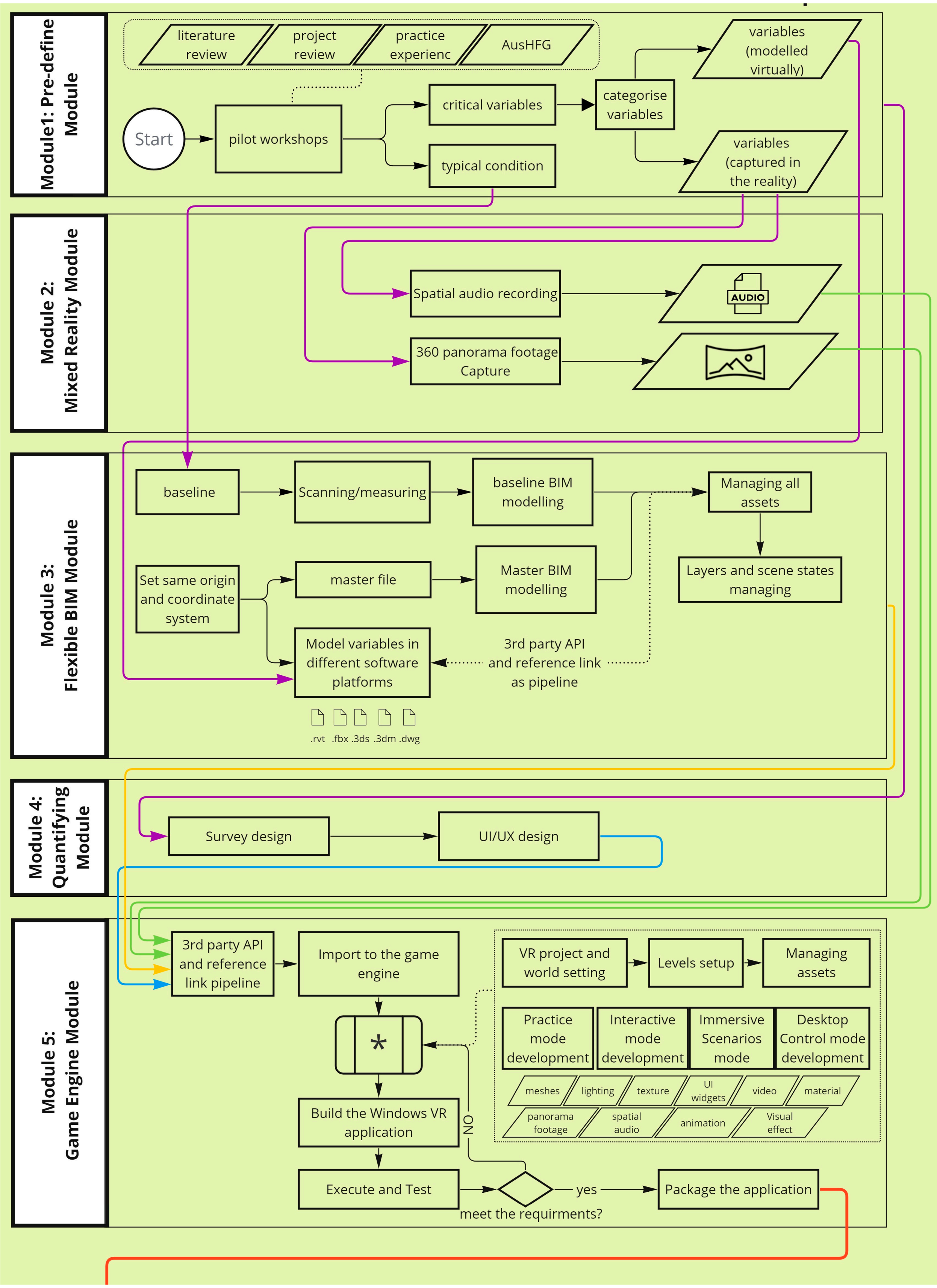

Figure 2. The flow chart (2-1) for the development processes in the study; the development processes consist of six modules. The flow chart shows modules 1–5 for development.

(**left**) (**right**)

Figure 3. Screenshots of Day Scenario 1 and Day Scenario 3 demonstrating controlled variables for investigating greenery in a single-patient room.

2. *Mixed Reality Module—Developing Mixed Reality Using 360-Degree View.*

To create an immersive VR environment accurately reflecting the real-world conditions of a healthcare facility, three main elements were included: outdoor scenery, indoor physical environment, and the 'invisible' variable of sound (see Module 2, Figure 2). To capture the outdoor scenery, drone 360-degree panoramic video footage was utilized as an environmental high dynamic range image (HDRI) backdrop map for virtual reality development. This approach enhanced the level of immersion and provided authentic window views in the daytime scenarios.

The indoor physical environment was accurately represented in the VR environment by including room size and shape, wall finish colors, surface textures, and other physical elements such as medical equipment, fixtures, fitting, and furniture from stroke rehabilitation in-patient rooms in the Bendigo Hospital and the Western Health Hospital.

The 'invisible' variable, sound, which is argued to impact patient well-being and the recovery process [34,35], was incorporated by using a ZOOM H2n Handy Recorder to capture four-channel spatial audio from the background hospital environment for day and night. To create the 'noisy' variable we included multiple external voices, audible keystrokes on a computer keypad, and physiological monitors alarming. The recordings were then encoded into spatial audio tracks in the VR application to produce a full 360-degree soundscape. The head tracking technology within the VR headsets allowed participants to experience the audio while moving their head within the environment, thereby investigating acoustic-related variables (noise/social connectivity).

The incorporation of mixed reality elements into the VR environment resulted in a detailed and authentic depiction of a healthcare facility, elevating the level of immersion and realism within the virtual experience.

3. *Flexible BIM Module.*

The flexible BIM module focused on modelling and texturing the baseline scenarios, the animated assets, and the geometrical variables, such as animated characters representing family members and other patients, using procedural modelling techniques (see Module 3, Figure 2). The baseline model incorporated the 'scan to BIM' method, a process of reconstructing existing buildings into BIM models using accurate geometry from three-dimensional laser scanning and measurement technology [36]. In our test case, we referenced the Australasian Health Facility Guidelines, a standard widely used in Australian healthcare design since 2007, to inform our selection of a real-life in-patient bedroom within a rehabilitation unit. The selected room was carefully measured and scanned in 2018. This approach yielded a detailed and accurate baseline representation of both single-patient bedroom and multi-patients' bedrooms, closely mirroring the actual healthcare environment [see Figure 4]. The aesthetic design of the room is informed by and consistent with several Australian rehabilitation facilities constructed between 2007 and 2017, thereby serving as a representative example of a generic Australian rehabilitation patient room. From this baseline, we developed a master BIM file to serve as an initial baseline BIM scenario, which also included the baseline patient room geometry and the simulation of 'social interaction' and 'crowd movement'. Given the complex nature of the modelling and simulation, we utilized multiple software platforms, each chosen for their specific strengths. A file-referencing/converting pipeline was adopted to ensure flexibility in design changes, with third-party plugins and external referencing systems serving as interfaces for data and asset exchange. To maintain alignment, all platforms and the master file shared the same Cartesian coordinates origin, allowing for efficient collaboration and live changes. The BIM modelling was managed under a flexible procedural structure using 'layers' and 'scene states' to control the baseline BIM model and variables [see Figure 5]. With all geometries being parametric and adhering to procedural modelling, texturing, and shading techniques, this approach increased the efficiency of modelling design changes and enabled iterative scenario testing, preliminary animation, crowd simulation, and digital model optimization.

Figure 4. The high accuracy cloud data and imagery of the typical in-patient room scanned and measured for the initial stage of the VR application development.

4. *Quantifying Module.*

To accurately understand and quantify participants' perceptions and preferences within the VR scenarios, we implemented the quantifying module. This module integrated standardized response options and a custom user interface (UI), grounded in psychological measurement theory and user experience design principles. In this test case, we employed two measurement scales: the Pick-a-Mood Scale (PAMS) and the Visual Analog Scale (VAS) (see Module 4, Figure 2). The questions were displayed on a transparent canvas at eye level in front of the participants in each VR scenario.

Pick-a-Mood Scale (PAMS): For capturing participants' affective responses, we selected the Pick-a-Mood Scale (PAMS), a categorical tool that effectively measures the affective state of individuals. This choice was influenced by the foundational work of Watson and Tellegen, who conceptualized 'affect' through two principal dimensions: arousal and valence [37]. Building upon this foundation, the PAMS was developed to include eight categorical descriptors, offering a more nuanced understanding of mood states, and has been widely utilized for self-reporting affect across various studies [38–40]. The PAMS in our study consists of a grid of buttons, each representing a different mood. The participant selects the button that best represents their current mood or emotional response. The size of the question text was designed to be easily recognizable for participants. While the participant interacted with the buttons, the buttons would turn to bright colors to highlight the choices. Once the PAMS was added to the scenario, a controller model with simple instructions was visible in the VR scenario and automatically enabled a visible ray-casting beam from the controller. Participants could confirm their selection using the controller's trigger, and the button they selected would be highlighted.

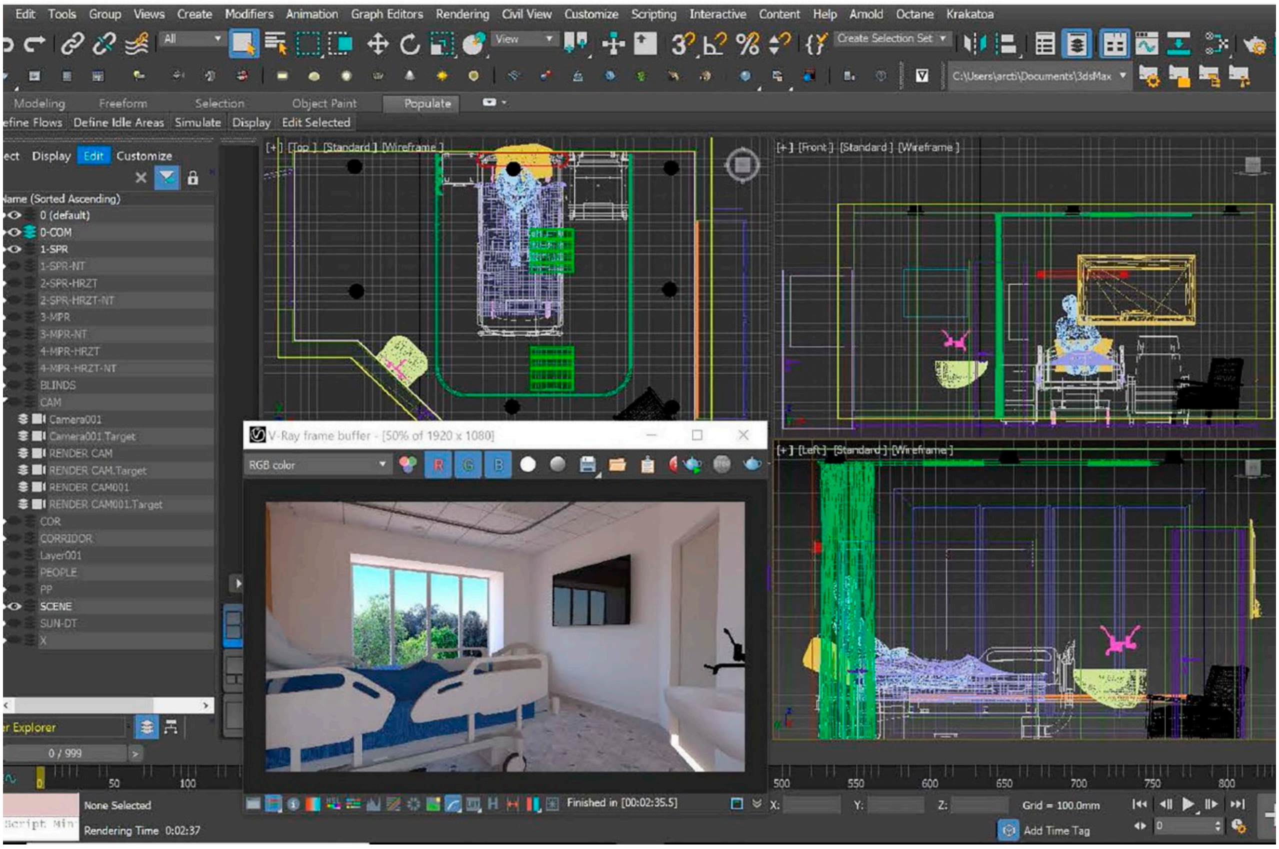

Figure 5. The building information modelling (BIM) model, in progress, is shown in four view perspectives within the modelling software, using 'layers' and 'scene states' to control the baseline BIM model and variables.

Visual Analogue Scale (VAS): The second response scale was a Visual Analogue Scale (VAS) which measured participants' levels of desire to remain in the room. The VAS tool has been widely examined as a valid tool to exhibit strong convergent and discriminant validity when used with stroke inpatients, offering additional evidence for the effectiveness of these concise, readily applied scales [41]. In our study, the participants were presented with a slider on a semi-transparent block and could use the controller to drag the slider to indicate their preference.

To ensure accessibility and accommodate participants with visual or mobility impairments, the user interface (UI) was developed with careful consideration to text/button size and color, transparency, controller sensitivity, and adaptive movement synchronized with the participants' head movements. The PAMS and VAS were integrated into the VR scenarios, displayed sequentially on a transparent canvas at eye level, enhancing the overall user experience and capturing participants' preferences and emotional responses effectively [see Figure 6].

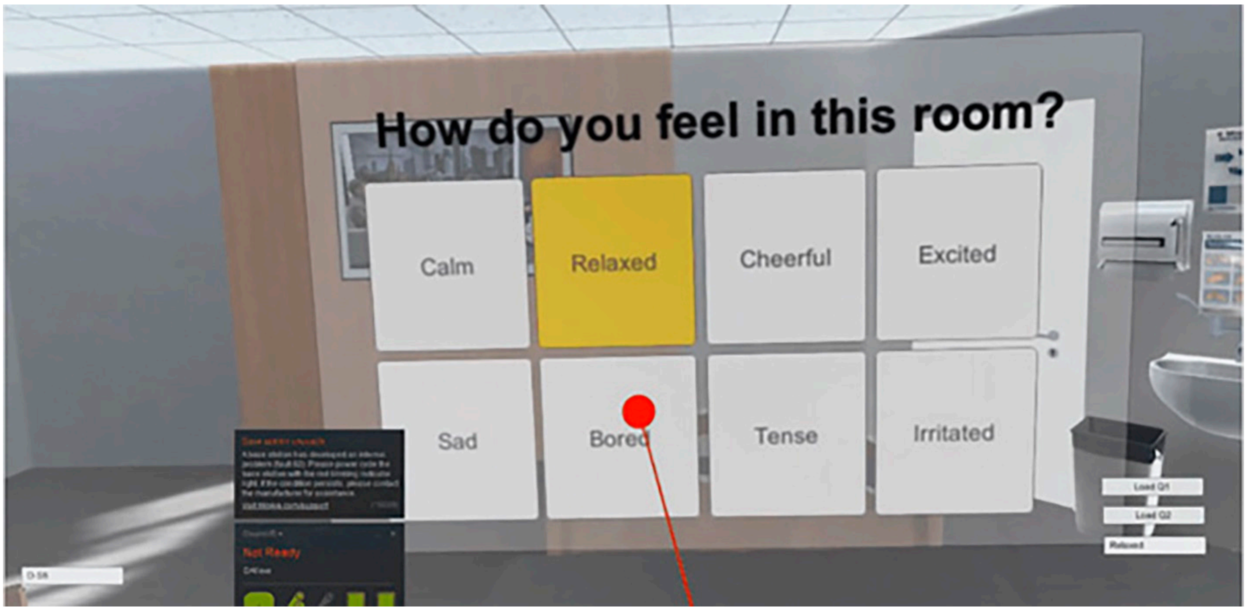

Figure 6. The screenshot displays the Pick-A-Mood Scale (PAMS) Scale that appeared in the VR scenario, where the participant made choices using the controller. The selected button was highlighted in yellow and displayed in the desktop control mode interface. The PAMS was designed as a grid of buttons with a semi-transparent background, and the question text size was made to be easily recognizable.

5. *Game Engine Module.*

After the BIM model creation, all assets from the mixed reality module, the flexible bIM module, and the quantifying module were transferred to the game engine module via the third-party application programming interface (API) and the reference link pipeline, and formed a Microsoft Windows application (see Module 5, Figure 2). This VR application included four developed modes: (i) practice mode, (ii) virtual reality scenarios mode, (iii) interactive mode, and (iv) desktop control mode. The desktop control mode, functioning as a 2D interface on the desktop, was utilized by the researcher to manage and monitor the experiment, record participant choices and the duration of experience, and to switch between the VR scenarios. Data were subsequently synced to a cloud database for comprehensive analysis (see items 1 and 6 in Figure 2). The practice mode, virtual reality scenarios mode, and interactive mode were displayed through the HTC Vive VR head-mounted display (HMD) (see Figure 7) forming the VR interface.

To familiarize participants with VR equipment and controls, a practice mode was established, offering a simple VR scenario unrelated to the target research environment. Then, the immersive scenario mode incorporated four variable research scenarios linked to the game engine via a 'reference link pipeline'. This approach facilitated a flexible workflow, enhancing the development efficiency between modules.

Consistency in scenario settings was ensured by a flexible procedural structure: a master level maintained universal settings and assets, while sub-levels were designated for variable-specific assets and settings. The optimization of materials, textures, shaders, and lighting was performed to achieve realistic simulation, further bolstered by the inclusion of mixed reality content, animated characters, and comprehensive lighting systems.

The interactive mode included the VR interactable UI Widgets designed in the quantifying module to quantify participants' preferences.

Following the development and subsequent testing of these four modes, the Windows VR application was built from the game engine, evaluated, and, upon meeting study requirements, 'packaged' for implementation.

Figure 7. The photograph shows the testing of the game engine module with the HTC Vive HMD. The bottom right screenshot shows the content displayed on the desktop monitor.

6. *Implementation Module—Eliciting End-User Responses.*

Building upon the VR application developed in game engine module, the implementation module pivoted to a practical application, focusing on testing the procedure with stroke survivors to elicit their end-user responses.

3.1. Participants

For the implementation module, we recruited adult stroke survivor volunteers (over 18 years of age), who had been admitted to the hospital for their stroke for at least two nights and were less than three years post-stroke. Those with significant cognitive impairment, severe and active mental illness, or severe visual or hearing impairments were excluded. Detailed recruitment procedures can be found elsewhere (ref hidden for review). Forty-four stroke survivors participated in this study: median age (IQR) = 67 years (Q1 57.25 years–Q3 73.75 years), 61.4% male.

No participants withdrew during the study. One participant only viewed half of the scenarios due to relocation overseas during the study. All 44 participants were able to tolerate using the VR headset, and no instances of motion sickness were reported. This finding supports the feasibility of implementing a VR user-led design decision support system for stroke survivors and potentially other vulnerable groups in the future.

3.2. Scenario Sessions

The VR scenarios were administered in two sessions with the majority occurring on the same day of testing (however, participants had the choice to complete the VR scenarios a week later if needed). Each scenario lasts approximately 2–3 min each, with the entire block taking 40–60 min to complete. Rest breaks were provided within and between scenario blocks. A subset of participants (n = 34) completed a semi-structured interview.

The procedure of testing is outlined in Module 6 (shown in Figure 8). The application was developed for one participant at a time, with a researcher controlling it via the desktop control mode. The testing environment was set up with the VR device centrally placed, simulating the seating position of stroke survivors. the participant's information was input into the desktop control mode, and the practice mode was initiated. Participants experienced VR scenarios randomly, with the researcher verifying readiness before enabling the interactive mode. Standardized measurement tools (PAMS and VAS) were added to each scenario to collect emotional responses and preferences. The researcher monitored content and participant choices through the desktop control mode. If participants felt uncomfortable, the testing could be terminated. After all scenarios, participants removed the HMD and headphones and had a semi-structured interview with the researcher.

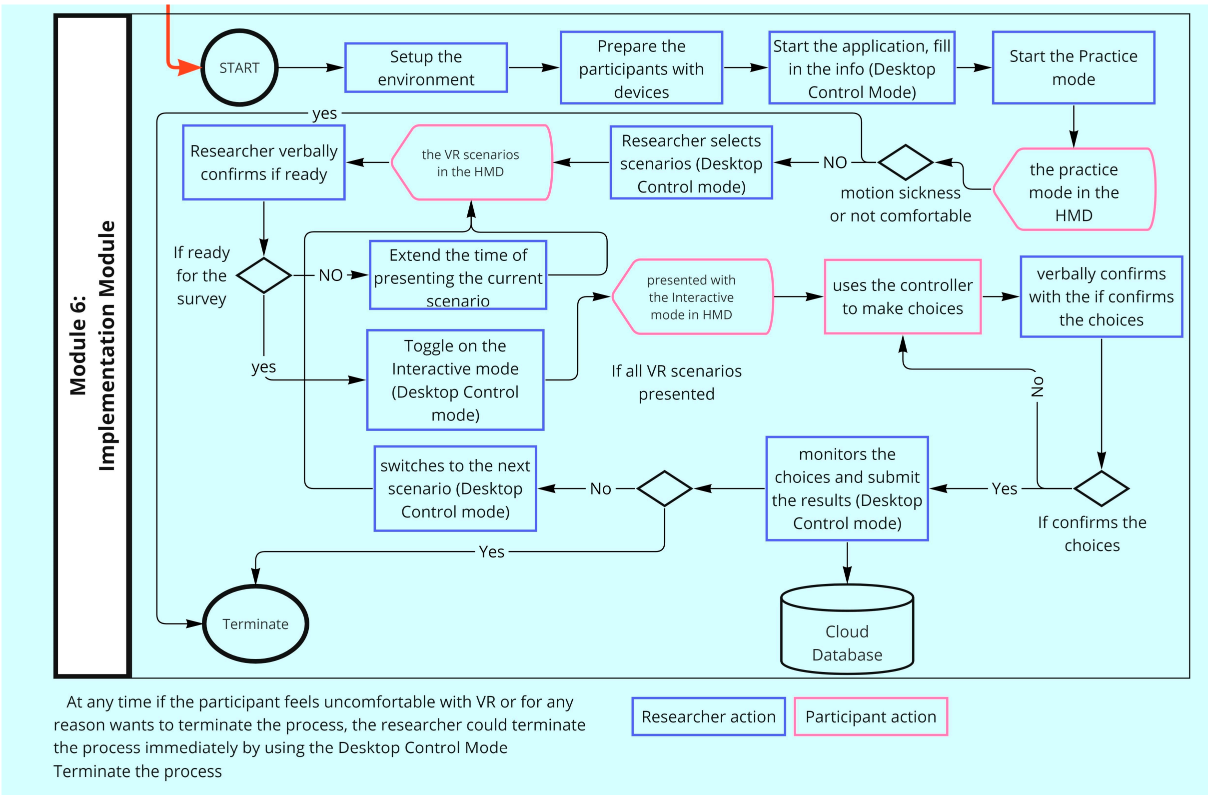

Figure 8. The flow chart (2-2) for the development processes in the study; the development processes consist of six modules. The flow chart shows module 6.

3.3. Presence Feedback

During the testing and subsequent interviews, participants frequently emphasized the 'realistic' nature of the VR scenarios, which effectively evoked a profound sense of being in a hospital setting. This high level of immersion and realism not only triggered vivid memories but also elicited strong emotional responses from many participants. The inclusion of specific audio stimuli, such as background hospital noises and conversations, as well as the presence of nurse animations, played a significant role in this process, resonating deeply with the participants' recollections of their time in rehabilitation facilities.

Moreover, the details and nuances of the VR environment, such as the views from the windows and the layout of the rooms, were noted by participants as remarkably authentic. The emotional impact was profound; for instance, one participant emotionally reacted as if family members were physically present, highlighting VR's ability to bridge the gap between virtual and real experiences. Others expressed a desire to explore beyond their immediate environment, indicating the scenarios' success in not only capturing attention but also inspiring a sense of curiosity and interaction.

The VR scenarios effectively replicated the acoustic environment of a hospital, with participants specifically commenting on how the sounds, ranging from keyboard strokes to the beeps of hospital equipment, added to the realism. This attention to auditory detail was crucial in creating a holistic and immersive experience. Even the small frustrations, such as not having an equal view of the outdoors, mirrored real-life experiences in a hospital, demonstrating VR's thoroughness in replicating a true-to-life healthcare environment.

These findings underscore the success of the VR scenarios in creating a deeply immersive and emotionally resonant experience, mirroring the complexities and subtleties of a real hospital stay, thus enhancing the understanding of patients' needs and preferences in healthcare facility design.

3.4. Quantitative Analysis of Stroke Survivor Responses to Varied Physical Environments Using VR

Through the test case of using our VR-integrated approach, we were able to generate a quantitative overview of stroke survivors' distinct emotional and preference responses tied to specific environmental variables that could be used to inform design decisions. The PAMS and VAS responses were statistically analyzed; frequency distributions and mixed-effect regression analyses of these scores across VR scenarios revealed how design variables influenced participants' affective states and choice preferences. The data in this paper presented here offer a glimpse into the broader insights that can be derived from our comprehensive VR-integrated study. While detailed statistical analysis and full results are explored in a companion paper, the sample data underscore the potential of our method to contribute to evidence-based design decisions in healthcare environments.

Affective Responses: Using green-view daytime scenarios with non-green-view daytime scenarios as an example, our analysis of PAMS uncovered significant variations in emotional states when comparing environments with a greenery outlook to those without. Specifically, participants in scenarios with greenery were 1.4 times more likely to feel calm and 1.7 times more likely to feel cheerful, indicating a positive influence of natural views on emotional wellbeing. Conversely, the likelihood of feeling bored, sad, tense, and irritated was notably lower in greenery scenarios, with adjusted odds ratios of 0.4, 0.2, 0.8, and 0.3, respectively, suggesting that views of nature can significantly reduce negative emotional states.

Preference Responses: Using green-view daytime scenarios with non-green view daytime scenarios as an example, our analysis of VAS revealed a significant preference for greenery outlooks, indicated by a ß coefficient of 7 with a 95% confidence interval of (4.3, 9.8). This result suggests that, in terms of choice preference during the day, participants displayed a stronger inclination towards environments with greenery.

Our method identified a signal of changed user responses to a physical environment that had a single changed design variable (one level of the variable was changed at a time). The results showed that altered emotional responses can be linked to the physical environment alone. In addition, the use of the PAMS (emotional response) within this experimental study provided increased the ability to attribute a category of responses to specific design variables.

These findings underscore the impact of environmental design, particularly the inclusion of greenery, on the affective states of stroke participants.

4. Discussion

Our study employed a user-centered design decision support approach to test a VR-BIM-game engine method for measuring perceptions of a rehabilitation environment. Through a test case study with stroke survivors, we found this approach to be immersive and feasible. In this discussion, we will explore the method's novelty, development efficiency, immersion and presence, feasibility in exploring emotional responses and preferences, its use with stroke survivors, and address limitations and future research directions.

4.1. Novelty of the Method

The unique combination of BIM, VR, and game engine technologies in our study enabled the creation of realistic and immersive virtual environments for participants.

The approach went beyond the work of White et al. [30], who utilized 360-degree videos and spatial audio as immersive virtual environments investigating public perceptions of streetscape design, and Lin et al.'s work [27], which employed CAVE as a semi-immersive virtual environment discussing healthcare environment design between a design team and medical staff. Recent research has begun to utilize VR in healthcare facility design, yet studies engaging patients, especially vulnerable groups like stroke survivors, to gain their perspectives on built environment design are limited [3,22,23]. Our study introduces and tests an approach engaging fully immersive VR with head-mounted devices (HMD) and headphones with four channel spatial audio, incorporating quantifying questions embedded in VR environments, specifically designed and tested with stroke survivors.

This novel approach allowed us to efficiently represent physical healthcare spaces and collect timely data on patient preferences and responses to the design elements. The integration of these technologies has refined the design process, providing researchers with a powerful tool for conducting user-centered design studies.

4.2. Immersion and Presence

In the context of co-design in healthcare, it is crucial to include people with lived experience in design decisions [42]. Our study demonstrates the power of virtual reality (VR) technology in creating highly realistic and immersive scenarios, evoking memories of participants' time spent in rehabilitation facilities. This aligns with the existing literature that highlights the immersive nature of VR in artificial 3D environments [20]. By effectively simulating spatial variables such as the volume of spaces, sightlines, and lighting, VR enables a better understanding of physical environments [21], making it a valuable tool for co-design processes in healthcare settings.

By integrating survey questions directly within the VR scenarios, our approach overcomes the challenge of relying on memory recall, which is particularly relevant for populations with memory impairments. This integration allows participants to provide feedback and respond to design elements while actively immersed in the VR experiences, aligning with the principles of co-design. Leveraging advancements from VR gaming user interfaces, our approach facilitates a more accurate representation of participants' preferences and emotional responses, enhancing the co-design process in healthcare facility design.

Our study also demonstrates the feasibility of using VR technology to represent physical scenarios with a significant degree of realism, bridging the gap between design intent and user experience. This is especially relevant in healthcare facility design, where effective communication with stakeholders is crucial [27,43]. The integration of BIM, game engines, and VR in our approach extends the potential of VR-BIM integration as a tool for exploring end-user perceptions and preferences in healthcare design.

Previous studies have explored the use of digital tools to facilitate co-design processes in healthcare buildings [42]. Our work builds upon these efforts and contributes to the growing body of research that emphasizes the importance of involving end-users in design decisions. By integrating VR technology within a user-centered design decision support approach, we offer designers a powerful workflow to engage stakeholders, including stroke survivors, in the co-design process. This enables a more inclusive and user-centered approach to healthcare facility design.

4.3. Feasibility

4.3.1. Financial Feasibility

Our study highlights the clear advantages of VR mockups over traditional physical constructs, especially in terms of cost-effectiveness, time savings, and versatility in the workflow of healthcare environment development. Physical mockups demand considerable investment for construction, space, and time, not to mention the impracticalities of demolition post-testing [3,44]. Conversely, our VR-integrated approach offers a more efficient, cost-effective, and flexible solution. It not only reduces the need for physical space and eliminates the time and resources associated with construction and teardown but also allows for the hardware to be repurposed for subsequent research, enhancing its long-term value. Changes in VR scenarios can be made instantaneously without the need for reconstruction. This feature is particularly valuable when examining the impacts of different design variables in isolation, such as lighting, sound, and spatial arrangements, which can be individually adjusted and tested. Thus, VR not only accelerates the design process but also offers a robust visualization tool that transcends the limitations of conventional mockups, streamlining the architectural design process.

4.3.2. Feasibility of Using VR with Vulnerable Group

A key contribution to knowledge of this study is the involvement of vulnerable groups, such as stroke survivors, in the design research process of healthcare facilities, enriching our understanding of patient-centered care through their unique perspectives. The results of our interactive Pick-A-Mood Scale (PAMS) and Visual Analogue Scales (VAS) indicate their effectiveness in identifying participants' preferences for different environmental variables, providing valuable evidence to inform design decision-making. For example, our findings suggest that exposure to a green perspective reduces the likelihood of irritation, which can inform decisions regarding window view design. However, further exploration with a larger sample size is necessary to determine the exact factors influencing these preferences and obtain statistically significant results.

Involving patients in healthcare facility design is crucial, particularly for vulnerable groups like stroke survivors, to achieve patient-centered care. Our pilot study demonstrates the feasibility and safety of using VR technology in health design studies with stroke survivors, as none of the participants withdrew due to VR use, indicating their ability to participate without adverse effects. While this is a pilot study requiring further research, our findings offer a promising starting point. This unique exploration of stroke survivors' perceptions of physical variables in-patient rooms using VR technology not only contributes to the field of health design studies but also holds potential for broader applications in various healthcare contexts. One potential application is in obtaining user feedback on health services. VR can be used to create simulated environments that replicate real-life healthcare service settings, such as hospitals, clinics, or even home care scenarios. By immersing users in these virtual environments, we can collect data on their experiences, interactions, and preferences regarding different aspects of healthcare services. For example, we can explore how patients perceive waiting areas, reception processes, communication with healthcare providers, or the overall care delivery experience. This feedback can inform improvements in service design, communication strategies, and patients' satisfaction. Existing studies have employed VR to assess wayfinding among the public [45,46] and investigate the perceptions of nurses and clinical staff regarding healthcare design [17,22,47]. In line with this research, our study expands the horizon by demonstrating the potential and feasibility of utilizing VR to explore the experiences of patients, including stroke survivors.

4.3.3. Feasibility of Collecting Evidence to Inform Design Decisions

Our study demonstrates the practicality and effectiveness of utilizing a VR-integrated approach to gather concrete evidence that can directly inform design decisions in healthcare environments. Although the sample size limited our ability to achieve statistically significant results, the quantitative analysis of stroke survivors' responses, both emotional and preference-based, to varied physical environments, has still yielded clear, actionable insights. For instance, a marked preference for greenery outlooks, as indicated by the VAS scores, underscores the positive impact of natural elements on patient well-being. Similarly, the PAMS results highlight how specific environmental variables, such as room type and the presence of greenery, can influence emotional states, providing valuable data for designing spaces that enhance patient comfort and emotional health. This finding aligns with the empirical study in evidence-based design by Ulrich (1984), who discovered that patients recover more quickly post-surgery and use less medication when placed in a room with a greenery view compared to one with a brick wall view.

4.4. Limitations

The test case findings revealed limitations in the proposed approach, providing insights for future improvements. One primary limitation was the absence of a comparison between participants' responses in virtual and physical environments, a gap that future research could aim to fill to validate the effectiveness of VR simulation more thoroughly. Additionally, while our test case focused on four specific variables, it did not examine other significant factors such as lighting and furniture layouts. Acknowledging these limitations underscores the necessity for a broader scope in subsequent studies to fully explore the impact of environmental variables on patient well-being. This omission highlights the need for future studies to consider a wider range of design elements. Determining the optimal amount of greenery for effective design decision making emerged as another area requiring further exploration. While the approach is feasible in healthcare design studies and the healthcare design process, the requirement for involving technicians with VR development skills presents a barrier in general design practice. Finally, the study's focus on stroke survivors, while providing valuable insights, may not cover the full spectrum of healthcare facility users, suggesting the need for a more diverse sample in future research to enhance the comprehensiveness of findings. Additionally, conducting the study during the COVID-19 pandemic introduced significant challenges in recruiting participants, which in turn impacted our ability to achieve statistically significant results. Future studies may require larger sample sizes to overcome similar challenges and ensure robust findings.

4.5. Future Research Direction

Acknowledging the identified limitations provides a clear vision for enhancing future research efforts. With this foundation, we outline several key directions for future studies:

Comparative Analysis: Future studies should aim to include a comparative analysis between virtual and physical environments to enhance the validation of VR simulations.

Technological Advancements: The rapid evolution of VR technologies, with higher-resolution displays and standalone devices, presents opportunities for more realistic and immersive simulations. Integrating eye-tracking technology could enable detailed assessments of visual attention, enhancing our understanding of user–environment interactions. Future research should leverage these advancements to explore a wider variety of healthcare facility designs and ensure a diverse and representative dataset.

Investigation of broader Variables: Utilizing the approach proposed in our study, future research should further investigate aspects such as legibility of space, accessibility within the building, aesthetics, and other fundamental variables identified by Lipson-Smith et al. [48], focusing on other specific spaces like gyms and corridors.

In-Depth Investigation of Specific Variables: This study explored the impact of window views with and without greenery, and the results aligned with Ulrich's empirical findings on surgery patients [49]. To inform the design decisions, further research is needed to understand how different compositions of greenery affect survivors, the percentage of greenery required, the influence of other window views (e.g., sky views), and whether indoor plants have a similar impact to outdoor greenery. Future studies could delve deeper into these questions using our VR-integrated approach.

Diverse User Groups and Larger Sample Size: While our research focused on stroke survivors, recognizing them as primary users of inpatient rooms, it is essential to expand future studies to encompass diverse user groups. Incorporating perspectives from other healthcare professionals, such as nurses and clinicians, alongside patients could provide a more holistic view of user needs. To achieve statistically significant data, future studies should prioritize obtaining larger sample sizes.

Overall, the results discussed here offer a glimpse into the effectiveness and potential of our methodological approach.

5. Conclusions

This study presents a novel VR-integrated method for assessing patient responses in healthcare environments, integrating BIM and game engine technologies to create immersive and realistic virtual environments. This approach marks a significant leap forward for evidence-based design in healthcare architecture, offering a promising avenue for enhancing the architectural design process with scientific rigor. Our method's innovation bridges the gap between traditional design processes and advanced technological tools, filling a crucial gap in the literature by providing a detailed approach for better understanding patient needs and perceptions. This approach contributes to the broader term of BIM, embracing the collaborative design nature.

Through the application of this method in a test case study with stroke survivors, we have demonstrated its feasibility and potential to elicit meaningful user feedback. This feedback is instrumental in crafting healthcare environments that not only cater to aesthetic and functional requirements but are fundamentally aligned with patient well-being and recovery needs.

We have demonstrated that the adoption of this VR-integrated approach in healthcare design research can deepen our understanding of user needs and perceptions, to contribute to creating environments that are more responsive and beneficial to patients. The evidence collected within the approach is efficient and valid and could be used for informing design decisions in the future design process. In addition, our research enriches the existing body of knowledge, and the research answers the question of whether VR is a feasible research tool for stroke survivors, offering a robust scientific basis for future explorations in healthcare design. This groundwork opens avenues for further exploration with more ambitious design changes and has the potential to inform user-centered evidence-based design decisions in healthcare, thereby improving user experiences and health outcomes in other healthcare populations and environments.

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

Appendix A

Factorial design is a research design that enables the investigation of multiple variables simultaneously by creating different combinations of variables, known as levels or conditions. In this study, a $2 \times 2 \times 2 \times 2$ factorial design was used to create 16 different scenarios by combining two levels of each of the four variables, resulting in a total of 16 unique scenarios. The use of a factorial design allowed for the investigation of the main effects of each variable, as well as the interactions between variables, on participants' preferences. For the details of each scenario, please see below.

	Day Scenarios
#1	Baseline Single Baseline single-patient room with low amount of greenery outlook, small horizontal room width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background

	Day Scenarios
#2	Wide Single Baseline single-patient room, with low amount of greenery outlook, large horizontal room width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#3	Green-view Single Baseline single-patient room, with lots of greenery outlook, small horizontal room width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#4	Wide Green-view Single Baseline single-patient room, with lots of greenery outlook, large horizontal room width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#5	Baseline Multi Baseline multi-patient room, with low amount of greenery outlook, with other stroke patient present at their own bedside looking at iPad/book; small horizontal width; window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#6	Wide Multi Baseline multi-patient room, with low amount of greenery outlook, with other stroke patient present at their own bedside looking at iPad/book; large horizontal width; window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#7	Green-view Multi Baseline multi-patient room, with lots of greenery outlook, with other stroke patient present at their own bedside looking at iPad/book; small horizontal width; window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#8	Wide Green-view Multi Baseline multi-patient room, with lots of greenery outlook, with other stroke patient present at their own bedside looking at iPad/book; large horizontal width; window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#9	Social Single Baseline Single-patient room, with low amount of greenery outlook, small horizontal room width, social connectivity with own family present; participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#10	Wide Social Single Baseline Single-patient room, with low amount of greenery outlook, large horizontal room width, social connectivity with own family present; participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#11	Green-view Social Single Baseline Single-patient room, with lots of greenery outlook, small horizontal room width, social connectivity with own family present; participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#12	Wide Green-view Social Single Baseline Single-patient room, with lots of greenery outlook, large horizontal room width, social connectivity with own family present; participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background
#13	Social Multi Baseline multi-patient room, with low amount of greenery outlook, small horizontal room width, social connectivity with own family AND other patient family present; window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background (participants will be told that VR people represent THEIR family members)
#14	Wide Social Multi Baseline multi-patient room, with low amount of greenery outlook, large horizontal room width, social connectivity with own family AND other patient family present; window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background (participants will be told that VR people represent THEIR family members)

Day Scenarios	
#15	Green-view Social Multi Baseline multi-patient room, with lots of greenery outlook, small horizontal room width, social connectivity with own family AND other patient family present; window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background (participants will be told that VR people represent THEIR family members)
#16	Wide Green-view Social Multi Baseline multi-patient room, with lots of greenery outlook, large horizontal room width, social connectivity with own family AND other patient family present; window located on façade wall, ensuite on corridor wall, interior window with blind and door; non-meaningful hospital sounds in background (participants will be told that VR people represent THEIR family members)

Night Scenarios	
#1	Baseline Single Baseline single-patient room with no greenery outlook, small horizontal width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn, external voices and noisy alarms in room. Low light conditions.
#2	Wide Single Baseline single-patient room with no greenery outlook, large horizontal width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn, external voices and noisy alarms in room. Low light conditions.
#3	Quiet Single Baseline single-patient room with no greenery outlook, small horizontal width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn, low ambient sounds in background. Low light conditions.
#4	Wide Quiet Single Baseline single-patient room with no greenery outlook, large horizontal width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn, low ambient sounds in background. Low light conditions.
#5	Baseline Multi Baseline multi-patient room, with no greenery outlook, small horizontal width, with other stroke patient present at their own bedside looking at iPad/book, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; external voices and noisy alarms in room. Low light conditions.
#6	Wide Multi Baseline multi-patient room, with no greenery outlook, large horizontal width, with other stroke patient present at their own bedside looking at iPad/book, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; external voices and noisy alarms in room. Low light conditions.
#7	Quiet Multi Baseline multi-patient room, with no greenery outlook, small horizontal width, with other stroke patient present at their own bedside looking at iPad/book, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; low ambient sounds in background. Low light conditions.
#8	Wide Quite Multi Baseline multi-patient room, with no greenery outlook, large horizontal width, with other stroke patient present at their own bedside looking at iPad/book, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; low ambient sounds in background. Low light conditions.
#9	Social Single Baseline single-patient room with no greenery outlook, small horizontal width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; external voices and noisy alarms in room. Low light conditions. More social connectivity with staff coming into room.
#10	Wide Social Single Baseline single-patient room with no greenery outlook, large horizontal width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; external voices and noisy alarms in room. Low light conditions. More social connectivity with staff coming into room.
#11	Quiet Social Single Baseline single-patient room with no greenery outlook, small horizontal width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; low ambient sounds in background. Low light conditions. More social connectivity with staff coming into room.

Night Scenarios	
#12	Wide Social Single Baseline single-patient room with no greenery outlook, large horizontal width, participant bed only, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; low ambient sounds in background. Low light conditions. More social connectivity with staff coming into room.
#13	Social Multi Baseline multi-patient room, with no greenery outlook, small horizontal width, with other stroke patient present at their own bedside looking at iPad/book, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; external voices and noisy alarms in room. More social connectivity with staff coming into room. Low light conditions.
#14	Wide Social Multi Baseline multi-patient room, with no greenery outlook, large horizontal width, with other stroke patient present at their own bedside looking at iPad/book, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn, external voices and noisy alarms in room. More social connectivity with staff coming into room. Low light conditions.
#15	Quiet Social Multi Baseline multi-patient room, with no greenery outlook, small horizontal width, with other stroke patient present at their own bedside looking at iPad/book, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; low ambient sounds in background. More social connectivity with staff coming into room. Low light conditions.
#16	Wide Quiet Social Multi Baseline multi-patient room, with no greenery outlook, large horizontal width, with other stroke patient present at their own bedside looking at iPad/book, window located on façade wall, ensuite on corridor wall, interior window with blind and door drawn; low ambient sounds in background. More social connectivity with staff coming into room. Low light conditions.

All other physical factors, i.e., luminosity/illuminance, temp (N/A), light fixtures, window size, and number and type of furnishings were constant (baseline SR (single patient room), baseline MPR (multi-patient room)).

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