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An Empirical Study of the Technoparks in Turkey in Investigating the Challenges and Potential of Designing Intelligent Spaces

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Abstract: The use of innovative technologies in workspaces, such as the Internet of Things (IoT) and smart systems, has been increasing, yet it remains in the minority of the total number of smart system applications. However, universities and technopoles are part of open innovation that can encourage experimental IoT and smart system projects in places. This research considers the challenges and advantages of developing intelligent environments with smart systems in the Technology Development Zones (TDZs) of Turkey. The growth of Silicon Valley has inspired many technopoles in different countries. Thus, the article includes first a comprehensive survey of the story of Silicon Valley and the emerging technological potential of open and responsible innovation for intelligent spaces and technoparks with rising innovative interest. The study then conducts empirical research in inspecting the performance of TDZs in Turkey. In the research, machine learning and Artificial Intelligence (AI) models are applied in the analyses of critical performance indicators for encouraging incentives and investments in innovative attempts and productivity in TDZs; the challenges, potential, and need for intelligent spaces are evaluated accordingly. This article also reports on the minority of the design staff and the lack of innovation in developing intelligent spaces in the organization of the creative class in Turkey. Consequently, the research proposes a set of implementations for deploying intelligent spaces to be practiced in new and existing TDZs by considering their potential for sustainable and responsible innovation.

Keywords: innovation; Turkey; Technology Development Zones; open innovation; intelligent environments; Artificial Intelligence; Silicon Valley; creative class; responsible innovation

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1. Introduction

Technoparks, Technology Development Zones (TDZ)s, Research and Development (R&D) centers, and firms are the primary actors in open innovation and national innovation systems. They can thus be easily encouraged to develop sustainable digital ecosystems for responsible innovation with state-of-the-art technologies, such as intelligent spaces, which still need to be more frequently applied in workplaces and industries. In this regard, the aim of this research is to explore the challenges and opportunities for planning and designing intelligent spaces in the spatiotemporal practices of Turkey by considering the potential of TDZs and R&D centers in open innovation and the national innovation system.

The research initially surveys influential cases of technoparks, such as Silicon Valley. The inspiring examples of intelligent spaces that became apparent in the period called Industry 4.0 are also considered in this survey, with their rising impact towards Industry 5.0, to examine the potential and need of technoparks for smart environments. Thus, the study conducts empirical research by evaluating the performance parameters of and facts from TDZs in Turkey, which are investigated through the related indicators and data that have been available since 2011. The aim of the empirical research reported in this study is to gather the necessary information and evaluate the potential for and need to encourage incentives and investments for innovative practices of intelligent spaces. The study evaluates the role of intelligent spaces for responsible innovation to overcome the emerging social issues related to unemployment and productivity [1–3] regarding the critical facts from the creative class in TDZs and research centers in Turkey.

Technological innovation has increased with the rise of Silicon Valley, and the idea of the creative class emerged as a sign of hope for laborers holding at least bachelor-level degrees [4]. Nevertheless, it is "counter-productive" to compare the scale of growth in Silicon Valley with the technopoles extant in other geographies such as Turkey [5,6]. It is also possible to recognize the imbalance between the distribution of working staff and the number of R&D and design centers, ignoring the role of designing the networked intelligent spaces and individual performance for the productivity of workspaces.

The abovementioned condition is similarly encountered in the digital paradigm of architecture. Cache's seminal concept of Objectile, defining the flow of production of the technological object, becomes widespread and extensively discussed with the advancing circumstances of Industry 4.0 [7–10] (Figure 1). Nevertheless, the role of the individual experience and productivity in designing [1], and accordingly Subjectile, which can even be better described by the emerging concept of Industry 5.0 or Society 5.0 [11], is not deliberately emphasized for responsible innovation in an overarching manner during the coeval period [3,12] (Figure 1). Based on this argument, it can be maintained that the role of planning and designing with regard to collectivism and individual performance together, which cohere with a form of intelligence [12], has had little impact on the relations of production and the built environment for the creative class. On the other hand, intelligent spaces can generate the form of networked interrelations between emerging concepts and existing production means, as well as between Objectile and Subjectile, and also between productivity and innovative technologies, as well as individual and social experiences, in a digital ecosystem of sustainable and responsible innovation [2,3,12–17] (Figure 1).

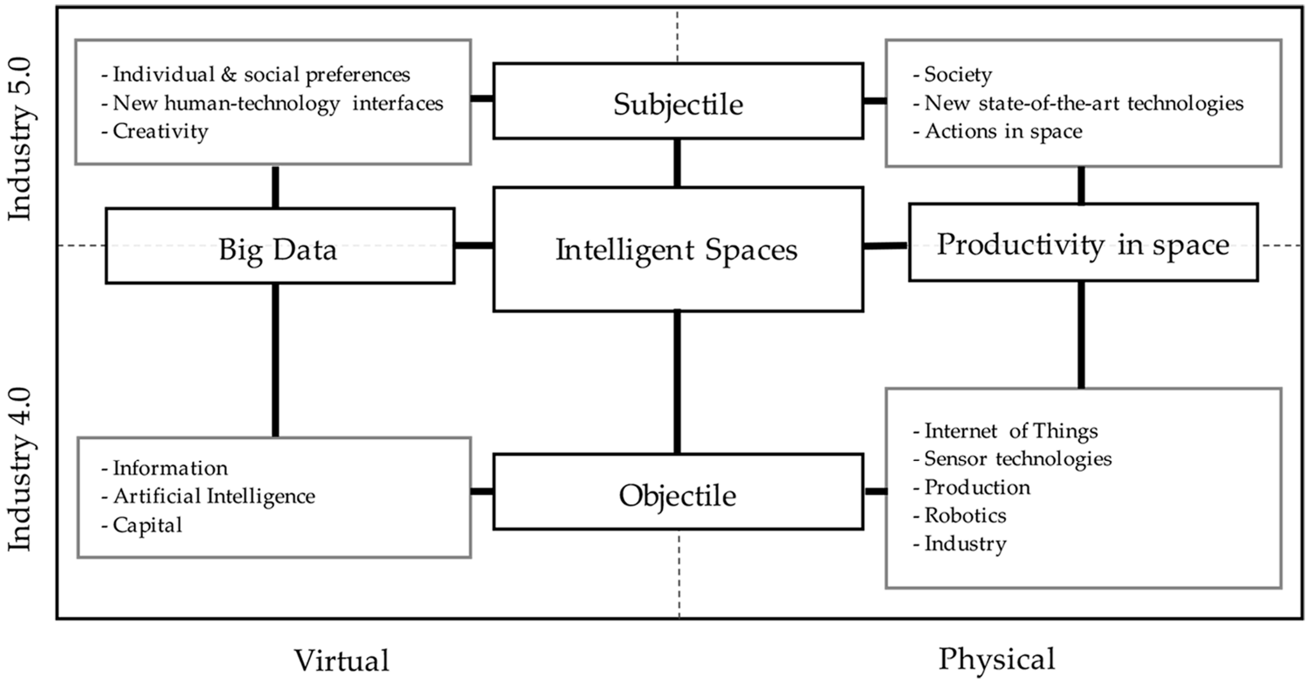

Figure 1. The conceptual framework for discovering the role of intelligent spaces.

It can also be claimed that the national innovation system in Turkey defines the role of interdisciplinary research in universities and their spatiotemporalities in technoparks [11,13,18–22]. Thus, universities and TDZs are also responsible for contributing to financial development through open innovation and the evolution of further progress via experimental work, such as intelligent spaces for new human–technology interactions [11,13,18–22] (Figure 2). Indeed, significant recent articles also draw similar conceptual frameworks of open innovation in defining the circumstances for the construction of intelligent environments [11,13,18,23–25]. Intelligent learning spaces, encouraged by open innovation for smart campuses and workspaces, can offer responsible innovation through social cooperation and knowledge transfer, as networked via the new interfaces for Subjectile–Objectile (human–technology) relations, to be augmented via Artificial intelligence (AI) and Internet of Things (IoT) projects [1–3,11,12,24,26] (Figures 1 and 2). Therefore, the research critically analyzes the spatiotemporal organization of the creative class in certain significant TDZs, R&D, and design centers in Turkey. The research also investigates the essential facts for improving the technological innovation and productivity of firms and workspaces through new endeavors via intelligent spaces and thus explores the performance of TDZs in Turkey [27,28].

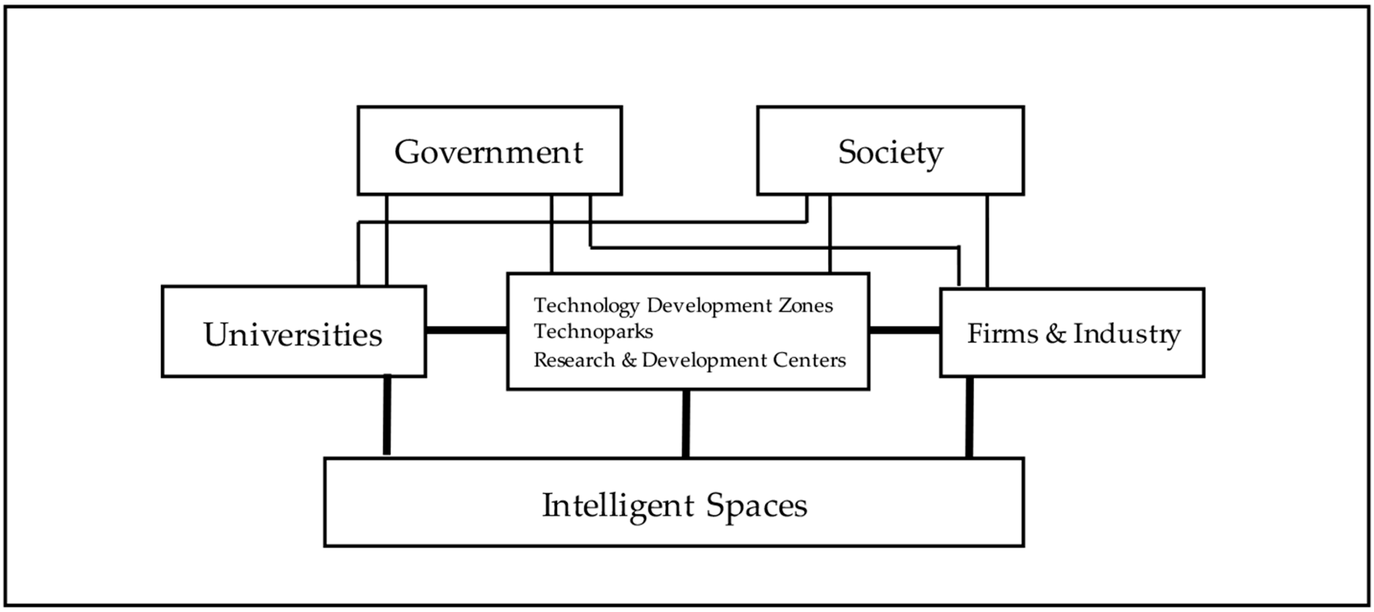

Figure 2. Investigating the role of intelligent spaces through the relations between open innovation and Turkey's national innovation systems.

In the related literature, which is explored to grasp the role of technoparks and technological developments for responsible innovation, there is no empirical research that can be found that evaluates the potential and limitations of planning the design of intelligent spaces in technoparks in national innovation systems. This article evaluates the performance of technoparks and their innovative capacities for responsible innovation in spatial practices and further attempts to contribute to the literature by exploring the challenges and potential in planning and designing intelligent spaces in the TDZs and research centers of Turkey. The study includes unique empirical research by deploying machine learning and artificial learning models in its various analyses of the performance indicators for TDZs. In addition, this study encourages the integration of Big Data and AI into spatial practices and decision-making procedures through the implementation of proposals for open and responsible innovation.

The remainder of this article is organized as follows. In Section 2, the research first reviews the inspirational success story of Silicon Valley according to the spatiotemporal organizations and economy–politics that shape production and marketing relations for the creative class. The study then investigates the related literature on intelligent spaces, research centers, campuses, and technopoles with regard to the potential of technological and responsible innovation. The article underlines the significance of intelligent spaces for value-based assessment of individual productivity and social preferences and in deriving new human–technology interactions and cooperation within the creative class. In Section 3, the study investigates the cases of technopoles from Turkey by identifying the condition of the design centers, firms, and staff in the creative class that are examined for their potential in the planning and development of intelligent spaces. This article scrutinizes the related performance indicators and performance indexes of TDZs with regard to the empirical research on ODTU Teknokent, Bilkent CYBERPARK, İTU Arı TDZ, and Yıldız Teknopark. In Section 4, the article discusses the facts from Turkey in relation to the potential and advantages of intelligent spaces to be developed in the country's TDZs. The limitations of this research and future work are discussed in detail in Section 4. Section 5 offers a brief set of concluding remarks to the research.

2. Literature Review

Silicon Valley has implemented various successful practices, with remarkable associated examples of technoparks and university–industry relations [29–31], and indeed the development of TDZs in Turkey was initially influenced by the case of Silicon Valley [12,32,33]. Thus, Silicon Valley acts as an example of an inspirational success story that has been followed by technopoles across various countries, representing a new opportunity for the creative class [5,6,34–36]. Since the 1970s, Silicon Valley has developed into the site of high technology for a miniature society, the creative class, which includes the technological inventors, investors, scientists, and engineers of the 20th and 21st centuries, surrounded by university campuses and R&D centers [37]. Silicon Valley's success story originates from the development of universities and research campuses in the region, such as Stanford University [37]. The University of California (UC), Berkeley, UCLA, The California Institute of Technology, and many other universities around have also accelerated financial and infrastructural investment, transforming Silicon Valley from a suburban region to the home of technological innovation and investment. The generation of knowledge by universities and the individuals hired by the technology companies such as Hewlett and Packard, Microsoft, Apple, Google, and Facebook have only continued Silicon Valley's success story [21,29].

Castells and Hall [29] enumerate the interrelated features of Silicon Valley culture by regarding it to be at the core of informational relations of the professionalization of the creative class [30,38]. The recent constructions of the Technology Park of Apple and Google's Googleplex maintain this same tradition through the ideals of professionalization [12]. The regional developments for high technology investments in Silicon Valley and Boston Route 128 are also indicative of the infrastructural reinforcements at the core of production and marketing relations [29,39].

For several reasons, however, most technology companies have remained uninterested in developing larger-scale intelligent environments with sensors for an extended period, and only a relatively small number of companies have started to disseminate their smart home applications in recent years [40]. The reason for such strategies appears to be dependent on the type of production, because architectural and infrastructural edifices require production-in-situ procedures. For the majority of technology companies, the design of spaces means dealing with context-based problems, with the need for immediacy in obtaining and processing contextual information as well as the capital from projects operating in place. The on-site type of production also reveals the ultimate problem of the interconnection and interoperability of multiple agencies for companies in terms of their spatiotemporal experiences.

Consequently, intelligent systems and smart spaces have remained in the realm of experimental academic research, or are preferred for specific usages such as exhibitions, pavilions, or smart homes with automation systems [12,27,41,42]. Arbib [43] surveys one of the initial examples of intelligent spaces, the ADA Project, which was realized in 2002 for the Swiss National Exhibition. The project deployed earlier versions of embedded computation and AI [41,43] with the aim of learning subjective reactions by recognizing the inputs acquired by the sensors in the special exhibition rooms [43].

Reminding us of Cache's interpretations of the mirror stage in psychology, Arbib's explorations remain essential research for intelligent spaces regarding the critical role of mirror neurons [7,41,43]. Intelligent environments to be developed for such functional capacities also imply the new relations and cognitive shifts between technology and the individual, Objectile and Subjectile, towards Industry 5.0 [12] (Figure 1). Accordingly, it can be claimed that the creative class in architecture in Industry 5.0 will be engaged with the design of smart spaces, buildings, and the interfaces of Objectile–Subjectile relations that will be operated via sensors and AI [12,44] (Figure 1). In this regard, the recent rise of state-of-the-art technologies, such as brainwave–computer interfaces for intelligent environments, can be envisioned as the pedigrees of research and practice in the construction processes [12,45,46] (Figure 1).

Lehman's seminal study, "Adaptive Sensory Environments", should be introduced at this stage to exemplify intelligent environments that can make predictions about usage patterns and environmental changes [47]. This can be seen as the most innovative feature of architectonic and architectural innovations, namely, to be adaptive to ubiquitous changes through integrating smart systems with the design of self-sufficient materials on the production scale [47]. Following "Adaptive Sensory Environments" as one of the significant milestones in architectural literature, the rising role of artificial neural networks in the automation of smart systems and infrastructures has also accordingly received considerable attention [44–47].

The challenging rise of Big Data from environmental inputs also necessitates the allocation of complex smart systems by considering the role of Subjectile on the scale of urban computing and social spaces [12,48]. The increasing number of smart city projects also reveals the necessity to regard IoT-based and AI-based smart system developments to produce and process Big Data to meet the expectations and preferences of urban dwellers [24,49–51]. Thus, designing according to the informational data of environmental inputs from sensors is becoming increasingly critical, and the limits and potentials of technology inevitably influence and challenge the spatial design of the built environment [47,49]. However, this can also be seen as an opportunity for some professionals in the creative class to design and decide on the necessities and critical attraction points that ensure innovative technological solutions in space [49].

In recent years, the deployment of smart home applications has also gained popularity in various countries, such as China and South Korea [27,42]. Some technology giants such as Apple, Google, Microsoft, Samsung, and Xiaomi have even started disseminating their smart home applications [40,42]. Indeed, smart home applications and intelligent environments are extremely beneficial in supporting user activity and safety, monitoring occupant movements and space use by providing value-based data (Table 1) [26,42,49,50]. On the other hand, the security concerns about smart systems intended for public places is another issue that requires further study and that needs to be overcome through advanced technological investigations and research, such as secure and context-aware IoT applications [52,53].

Table 1. Survey results [26] regarding the type of use of IoT applications in different places.

Types of Use [26]	The Number of Surveyed IoT Applications [26]	IoT Applications in Workspaces [26]
Location-based user occupancy	18	1
Monitoring user movements	13	-
Building services optimization	13	2
Building energy simulation	5	-
Space use monitoring	5	1
Telecare of users	4	2
User detection	2	-
Social activity	2	1
Safety	1	-
Total	63	7

Respectively, IoT technologies and smart systems have still been limited to pilot projects, experimental works, and academic research, except for a small number of applications in workspaces [26] (Table 1). In a seminal research article, sixty-three IoT projects were surveyed to understand the frequency, types of use, and appropriate places regarding where and how IoT projects have been applied over the last few decades (Table 1) [26]. It is apparent from the results of this research that IoT applications in workspaces also remain in a minority of the total number of such applications (Table 1).

From another perspective, universities produce knowledge and are the agent for human resources in the development of technology-based research and social, cultural, and economy–political practices through closer interactions with the environment [11,13,21,54,55]. Stares emphasizes the role of collective being and public engagement in science and technology in Europe [56], which should be considered primarily for responsible and open innovation [2,3,18]. As another fact, the universities and new technology campuses with research-based companies reveal dependent relations for open and responsible innovation [1–3,11,13]. Thus, the increasing influence of technology transfer compels this research to regard the performance of research universities in close connection with industry, start-up companies, and research-based institutions [12,57]. Reports and scientific studies also reveal that the national innovations system of Turkey encourages firms and universities to invest in R&D activities and, thus, technopoles for innovative growth [19,20] (Figures 1 and 2). Technopoles and firms committed to R&D are indicated to be the primary actors in the growth of the national innovation system of Turkey [19,20]. The role of technopoles with research institutions and firms also becomes apparent in cognitive sciences, learning environments, and in developing new-generation technologies for collective spaces that organize the creative class [12] (Figures 1 and 2). Technopoles are also part of open innovation to organize the enterprise relations between universities and business firms that can contribute to circular economy models by organizing international firms and investments for responsible innovation [1–3,11,19,20] (Figure 2).

Respectively, the experimental research projects conducted in smart campuses in Europe have deployed IoT technologies for collective spaces organizing the creative class [26,58]. For instance, the pilot projects conducted at TU Delft, TU Eindhoven, Radboud, and Wageningen Universities for smart campus development were governed by the pipeline of IoT projects to facilitate larger-scale technology investments, cognitive research, and the production of information-intense knowledge that allows for appropriate decision making [26]. Moreover, applying state-of-the-art IoT and AI technologies in universities and TDZs is extremely significant with regard to open and responsible innovation through offering value-based innovative networks for sustainable digital ecosystems, which can overcome the problems of productivity of firms and labor as well as unemployment within the creative class [1–4,11,12,14,22,24,27,59,60]. In one seminal piece of research, for instance, the innovativeness of incubation centers for offering job opportunities in two countries, the US and Poland, are compared regarding the conceptualized social, financial, scientific, and organizational indicators from a broader perspective [61]. Thus, intelligent spaces for research and incubation centers and university campuses can be encouraged to allow for job opportunities for the creative class [12]. The unemployment problems in the creative class in Turkey, dealing with the digital means who need alternative and flexible working spaces [4], can also be overcome via corporate social responsibility (CSR) in encouraging new job opportunities through designing intelligent spaces in TDZs and research centers [3,62,63].

Furthermore, there is a branch of emerging research that defines the factors for innovative capabilities of firms in China and Spain, and the potential of technoparks is being explored in countries such as Taiwan [23–25,35,36]. For instance, an empirical study on the innovative capabilities of construction companies in Spain has been conducted [25]. Similarly, an empirical study has been conducted on the potential of firms with regard to intelligent construction development in China [23]. In another recent article, the role of science parks, such as Hsinchu Science Park, in economic growth has been evaluated through analyses of the selected criteria and indicators [35]. The abovementioned studies also enable this article to conceptualize the general framework and circumstances in planning and designing intelligent spaces [49,64] that can be grounded to compare the potential of technoparks and the challenges of deploying intelligent spaces in different countries. Respectively, the role of research campuses and especially technoparks in Turkey are inspected through the lenses of related indicators in offering intelligent environments for responsible innovation, productivity, economic growth, and social cooperation.

3. Material and Methods for Empirical Research on the TDZs in Turkey

The aim of this research is to investigate the challenges and opportunities of planning and designing intelligent spaces in the scope of responsible innovation in the TDZs and R&D centers of Turkey, which are the primary actors of the country's national innovation system. Thus, the study conducts empirical research in examining the potential and progress—as well as limitations—of the TDZs and research centers in Turkey, also by regarding the condition of the creative class as the human infrastructure for designing and implementing intelligent spaces. In this regard, the performances of technoparks are first evaluated with regard to the related financial indicators, data, and facts from TDZs in Turkey, as have been available since 2011 [33,65–69]. The four TDZs, ODTU Teknokent, Bilkent CYBERPARK, İTU Arı TDZ, and Yıldız Teknopark, are evaluated as having greater potential and innovative progress that can develop intelligent spaces and have thus been selected for consideration in this empirical study. The performance indicators and the calculation methods, which influence the share of incentives by the government in the evaluation of TDZs, are critically analyzed through the available data [65,66]. The information about the general facts and the composition of firms in TDZs [33,65–69] are included in this empirical research to understand the innovative potential of technoparks in Turkey. The activities in TDZs and research centers are analyzed to investigate the potential, limitations, and opportunities for planning and designing intelligent spaces. The development of Esenler TDZ for the smart city of İstanbul by İTU Arı TDZ and Yıldız Teknopark in 2021 is also discussed to encourage the planning and design of intelligent spaces and new innovative spatial practices. In this regard, the selected technoparks are explored in terms of the potential and the challenges to the development of intelligent spaces, together with the facts about the creative class in TDZs and research centers of Turkey.

In brief, regarding the referred literature on the influential examples and the experimental projects that emerged in Industry 4.0, the article conducts empirical research on the TDZs in Turkey by investigating the potential and need for the innovative design activity of intelligent spaces deploying IoT and AI technologies. The research also presents the evaluation criteria for the performance of technopoles. Accordingly, the process and evaluation methods in the generation of performance indexes of TDZs are explained first. The four most successful TDZs in Turkey are selected together with R&D and design centers. The general facts about the number and composition of firms, staff, and firm activities in technoparks are also studied as the principal economic indicators. As part of this empirical research, the scalar weights of indicators in assessing the performance of TDZs are re-calculated using the applied methods. Machine learning and AI models are also deployed herein to re-calculate the scalar weights of the indicators that will be compared with our applied methods in calculating the performance points. Thus, the roles of indicators focusing on the facts about the exports of firms and their innovative capacities, and, most significantly, institutionalization, sustainability, and capacity to develop an innovative ecosystem in changing the performance of technoparks are emphasized. Regarding the empirical research, the strong and weak aspects of TDZs and research centers in Turkey are evaluated together with the reported facts and indicators. Accordingly, the investigation evaluates the opportunities to encourage the rise of design centers and staff to inspect the potential for the development of intelligent learning spaces. Regarding the research on TDZs, a critical survey of the architects in the creative class in Turkey [4] is discussed in order to evaluate the results and outcomes of the research into responsible innovation.

3.1. The Performance Index of TDZs in Turkey

The technopoles in Turkey are founded with reference to the 'Technology Development Zones, Law No. 4691' and are called TDZs [65]. The development and performance of each TDZ, to be supported by the incentives, is evaluated with regard to its progress and growth by the government. In following the performance of TDZs, the Ministry of Industry and Technology [65,66] announces the performance indexes of technopoles and their rankings each year. The four different university-based TDZs are ranked first since the evaluation of performance indexing was first introduced in 2011: ODTU Teknokent, İTU Arı Teknokent TDZ, Bilkent CYBERPARK, and Yıldız Teknopark TDZ (Table 2). In this study, these four TDZs are selected as having the innovative potential to be analyzed according to their rankings of performance indexes (Table 2). The rankings of the selected TDZs, as announced by the Ministry [65,66], are reported in this research in Table 2.

Table 2. The performance index rankings of selected TDZs in Turkey [65,66].

Years of Assessment	ODTU Teknokent	İTU Arı Teknokent TDZ	Bilkent CYBERPARK	Yıldız Teknopark
2011	1	2	5	11
2012	1	3	2	19
2013	1	3	4	7
2014	1	2	3	9
2015	1	2	3	11
2016	1	2	3	7
2017	2	1	3	5
2018	2	3	4	1
2019	2	3	4	1
2020	3	4	2	1
2021	2	4	1	3

The performance indexes are regarded as significant in terms of monitoring the outcomes of TDZs and the influences of the incentives supplied by the government. The assessment also reveals the strong and weak aspects of each TDZ. Thus, the opportunities for further development of technopoles are evaluated in this research accordingly [65]. The assessment process in Turkey includes four main stages [65]. The first stage is the collection of data from each TDZ. The data for each foundation is acquired by the common web portal provided by the Ministry of Industry and Technology [65]. The second stage is the validation of the acquired data, which needs to be certified by the TDZs. In the third and most crucial stage, the acquired data are processed through the selected method [65]. The evaluation method used by the Ministry to calculate the performance index is developed using the 'min-max' method that is commonly used in Europe and the Organization for Economic Cooperation and Development (OECD) countries to support the R&D activities and the development of technopoles [65]. In the final stage, the calculated performance points or rankings of TDZs are announced by the Ministry, and they are assessed according to the evaluation criteria decided by specialists [65].

3.2. The Evaluation Method for the Performance Indexes of the TDZs in Turkey

The evaluation of the acquired data in the third stage of the assessment also includes four main steps [65]. The first step in evaluating the acquired data is winsorization by excluding maximum and minimum marginal values from the dataset for each indicator [65]. The data acquired from TDZs are related to different indicators in evaluating the performance indexes. Thus, the second step needs to decide on the scalar weights of the indicators in the calculation of the performance index of TDZs. The specialists decide the scalar values each year as the ratio of each indicator with regard to all indicators and the total performance of TDZs [65]. The Ministry reported the scalar values for each indicator in 2012–2015 (Table 3). Accordingly, the incentives and firm expenditures, R&D activities, R&D outcomes, R&D results and internationalization, the number of intellectual property rights, incubation services, technology transfer and cooperation with different institutions, institutionalization, and investments for technological innovation are evaluated as the primary indicators by the Ministry in calculating the performance index points of TDZs [65] (Table 3). It should be noted that the Ministry ceased including 'exports and composition of firms' as an indicator after 2012 (Table 3). Nevertheless, 'export and firm composition' is commonly used in various countries as an indicator [28] and is regarded as significant in terms of further empirical research, including this indicator and other indicators for the development of sustainable innovation ecosystems.

Table 3. The scalar weights for indicators in the calculation of performance index points of TDZs in Turkey (2012–2015).

Years of Assessment	Incentives and Firm Expenditures	R&D Activity	R&D Outcomes	R&D Results and Internationalization	Exports and Composition of Firms	Intellectual Property Rights	Incubation Services	TT and Cooperation	Institutionalization, Sustainability and Developing an Ecosystem	Investments in Technological Products
2012 [65]	0.16	0.29	-	-	0.2	0.12	0.08	0.15	-	-
2013 [65]	0.15	0.21	0.26	-	-	0.09	0.13	0.16	-	-
2014 [65]	0.15	0.21	0.26	-	-	0.09	0.13	0.16	-	-
2015 [65]	0.1667	0.14	0.0667	0.1967	-	0.0599	0.09	0.13	0.12	0.03
Mean (μ)	0.156	0.213	0.147	0.049	0.05	0.09	0.107	0.15	0.03	0.008
Standard deviation (σ)	0.007	0.053	0.116	0.085	0.087	0.021	0.023	0.012	0.052	0.013
Normal distribution (2015, ours)	0.194	0.018	0.051	0.201	0.059	0.016	0.046	0.011	0.201	0.201
Medium Gaussian SVM (2015, prediction)	0.020	0.077	0.071	0.178	0.070	0.070	0.086	0.071	0.179	0.179
Trilayered Neural Network (2016, prediction)	0.137	0.066	0	0.187	0.067	0.064	0.056	0.087	0.159	0.177

The errors in the numeric values are less than 0.0005.

The third step can be defined as the standardization of the values calculated in the first step from the data for the TDZs, which helps to determine the maximum value for each indicator as 100, the minimum value as zero, and the median value as fifty. The values that differ from the maximum, median, and minimum values are calculated according to Equations (1) and (2) [65]. Accordingly, if the real value for an indicator is larger than the median value, then

$$Value = 50 + \frac{[50 \times (Real\ value\ of\ the\ indicator\ -\ Median\ value)]}{(Maximum\ value\ -\ Median\ value)} \tag{1}$$

and if the real value for an indicator is smaller than its median value, then

$$Value = 50 + \frac{[50 \times (Median\ value\ -\ Real\ value\ of\ the\ indicator)]}{(Median\ value\ -\ Minimum\ value)} \tag{2}$$

The final step is the computation of the performance index points for each TDZ by summing the weighted indicator points ($v_i.c_i$), calculated by multiplying the values (v) evaluated for each indicator (i) with the scalar weight of the related indicator (c) (Table 3), as in Equation (3). According to this evaluation criterion, the Ministry of Industry and

Technology [65,66] continued to report detailed performance points for all TDZs until 2016 (Table 4).

$$Performance\ index\ point\ = \sum_{i=1}^{n} v_i * c_i \tag{3}$$

Table 4. The performance index points of selected TDZs in Turkey (2012–2015).

Years of Assessment	ODTU Teknokent	İTU Arı Teknokent TDZ	Bilkent CYBERPARK	Yıldız Teknopark
2011 [65]	57.4	54.6	48.8	39.6
2012 [65]	60.5	50.5	52.5	35.4
2013 [65]	60.7	56.3	52.9	49
2014 [65]	67.2	58.4	55	47.3
2015 [65]	62.5	54.9	50.4	43.7
Mean	61.66	54.94	51.92	43
2015, (ours) (Calculated by mean values)	59.8	54.9	51.7	47.6
2015, (ours) (Calculated by normal distribution)	64.70	52.15	51.00	41.11
2015 (Medium Gaussian SVM, prediction)	65.07	53.95	51.01	42.05

The errors in the numeric values are less than 0.005.

3.3. Our Method for Calculating the Performance Index Points of TDZs

The empirical research reported herein has been conducted to observe the influence of the change of the applied calculation method and of adding the removed indicator, 'exports and composition of firms', in the re-calculation of the performance of TDZs. Accordingly, the mean scalar values (μ), announced for each indicator over four years, have been calculated, as reported in Table 3. Moreover, based on the calculated mean (μ) and standard deviation (σ) values, the normal distribution function in Equation (4) is applied as the method to calculate the scalar values for each indicator (c_i), the results from which are scaled and redistributed via probability distribution function between zero and one (Table 3).

$$c_i = \frac{1}{\sigma * \sqrt{2\pi}} e^{-\frac{(c-\mu)^2}{2\sigma^2}} \tag{4}$$

In this empirical research, the performance index points of the selected TDZs for 2015 are also re-calculated. According to our method, the new scalar weights of the indicators, according to both mean and normal distribution values in Table 3, are used in Equation (3) to calculate the points (Table 4). The missing indicator values are re-calculated and reported in Table 5. It can be observed that the change in the method and inclusion of the removed values for the 'exports and composition of firms' indicator also changes the results for the performance points of some TDZs quite significantly (Table 4). It should be noted that the scalar weights for the institutionalization, developing sustainable ecosystems, and investments in technological products indicators increase significantly and reveal the importance of reconsideration for innovative growth in TDZs in Turkey (Table 3).

In order to compare our results with various mathematical models regarding the redistribution of scalar weights for the indicators, the MATLAB Regression Learner software is applied to run twenty-six predefined machine learning and AI models. Thus, the experiments are conducted on existing values, as reported from 2012 to 2015 in Table 3, and the learning models are used to predict the 2015 and 2016 values. During the experiments, the cross-validation option is set to ten folds, and principal component analysis (PCA) is disabled. Accordingly, the most efficient methods are found to be Medium Gaussian Support Vector Machine (SVM) and Trilayered Neural Network by comparing the prediction results of the models with ours (Table 3). Medium Gaussian SVM returns the best root-mean-square-error (RMSE) value, 0.066589, in the regression experiments for 2015;

Trilayered Neural Network returns the best RMSE value, 0.055756, for 2016 (Table 3). The values from the learning models are again scaled and redistributed between zero and one. The performance index points for the selected TDZs in 2015 are predicted regarding the results of Medium Gaussian SVM, even though the performance points for 2016 cannot be calculated since the raw data and values from TDZs have not been accessible and are not announced by the Ministry.

Regarding the indicator for the composition of firms, ODTU Teknokent, for instance, announces the details about their organization, and thus the calculations about exports and firm compositions for the case of ODTU Teknokent are possible [33] (Table 5). The empirical research is also conducted on the firm composition of İTU Arı TDZ (Tables 5 and 6), which is significant to evaluate the productivity of firms and labor with the opportunities for further development of TDZs, such as investments in technological innovation and products, and thus, intelligent spaces. From Table 6, it is possible to conclude that most of the firm compositions in ODTU Teknokent and other TDZs in Turkey are similar. However, there is still much less effort in TDZs in Turkey to design architectural spaces and smart buildings with state-of-the-art technologies (Tables 5 and 6).

Table 5. The general facts about TDZs in Turkey.

	TURKEY TDZs [65]	**ODTU Teknokent [33]**	**İTU Arı TDZ [67]**	**Bilkent CYBERPARK [68]**	**Yıldız Teknopark [69]**
Foundation year Number of firms	2001 8793	2001 440	2003 300+	2002 240	2003 330
Notes	364 foreign firms, 2268 incubation centers, 1807 firms with academic stakeholders	90 percent of the staff has a Bachelor's degree or above	Nine construction firms	Five research centers, one microchip factory	120+ incubation centers, 70+ firms with academic stakeholders
Number of staff (R&D) (Design)	91,466 76465 1220	10,000+ - -	8800+ 8800+ -	4500 - -	8000+ 8000+ -
Number of projects (Ongoing) (Completed)	13,794 49,756	- -	- 3600+	- -	800+ 3000+
Total sales (Billion USD)	11.60 (2023)	-	4 (2020)	-	-
Total export (Billion USD)	7.9	-	0.089 (2020)	-	0.25+
Total closed area (sq m)	-	170,000	624,319	115,000	148,000
Values for exports and composition of firms (2015, ours)	-	65.65	68.75	58.65	64

The errors in the numeric values are less than 0.005.

Table 6. The composition of firms in TDZs in Turkey.

Types of Firms in TDZs		**TURKEY TDZs [65] (Percent)**	**ODTU Teknokent [33] (Percent)**	**İTU Arı TDZ [67] (Percent)**
Software and information technology developments	Software development Other information technologies Manufacture of computers and software Software advisors	48.08 1.12 0.85 1.56	50	43.48
Electronics	Electronic cards Radiation-based electronic technologies Production of parts for electronic circuits Engineering in industry and production	1.07 0.57 0.75 1.27	20	13.04
Mechanics and design	Mechanics and design Special machinery	6.08 0.96	15	7.83
Research in energy and environment	Engineering and consultation on energy Natural sciences and engineering studies Biotechnology	0.95 3.47 3	6	11.3 6.09 -

Table 6. *Cont.*

Types of Firms in TDZs		**TURKEY TDZs [65] (Percent)**	**ODTU Teknokent [33] (Percent)**	**İTU Arı TDZ [67] (Percent)**
Medical technologies		-	6	6.96
Other	Administrative advisors	0.69	3	-
	Agriculture, legumes	1.39		-
	Automotive industry	-		3.48
	Engineering advisors	1.07		-
	Production of parts for aircraft	27.12		7.83

The errors in the numeric values are less than 0.005.

Table 5 informs us about the potential and size of the selected technoparks in Turkey with regard to their innovative capacities and practices (Tables 5 and 6) [61]. For instance, the total export values of Yıldız Teknopark and İTU Arı TDZ (2020) are much greater than the annual budgets of some of the exemplar technoparks and incubation centers (2019) in the US and Poland [61]. Moreover, ODTU Teknokent has more than 400 firms and 10,000 staff for innovative R&D activities. ITU Arı TDZ has approximately 9000 staff and more than 300 firms, but there is no information about the design staff, and there are only nine construction firms. Similarly, Table 6 reports that firms in Turkey are focusing more on innovation for software, electronics, and technologies for the defense industry, as in selected technoparks (Table 6). Thus, it is not possible to mention the lack of innovation and potential of TDZs in Turkey; however, there is a significant difference between the composition of firms focusing on technological solutions and spatial design and construction. On the other hand, the research from different countries, such as China and Spain, reveals that there could be the potential of design and construction companies for innovative practices. Thus, the absence of innovative spatial design depends on the lack of encouraged design staff in Turkey. This compels the analysis of the limits and potentials of research and design centers and their staff by exploring the general facts about the design and construction companies and human resources in the research centers of Turkey for responsible innovation through spatial practices.

3.4. The Potential and Limitations in the Composition of the Research Centers and Creative Class in Turkey for Intelligent Spaces

Following the successful examples of Silicon Valley in the initial incubation centers established by ODTU TEKMER in 1992, the construction of ODTU Teknokent's first building started in 2000 under the administrative organization of ODTU to be managed by the specific state-regulated investment policy [33]. The legislative rule of "Technology Development Zones, Law No. 4691" in 2001 has legitimized the technology development regions in Turkey and has enabled tax-free entrepreneurship of R&D centers and start-up companies founded in TDZs, such as ODTU Teknokent [33]. Thus, ODTU Teknokent can be introduced as a milieu for working on significant engineering studies and informational technologies for the creative class in Turkey. Following the case in ODTU Teknokent, CYBERPARK of Bilkent University was founded in 2002 according to the law with a similar administration organization schema, even though Bilkent University is a non-governmental educational institution (Table 5). The institute has also shown remarkable progress in information-based research and innovative projects (Tables 2 and 5).

Thus, it is important to recognize other rising TDZs and their interests in satisfying the criteria set by the Ministry (Tables 2 and 5). According to the Ministry [65,66], there were ninety-seven TDZs in Turkey in February 2023, eighty-two of which are active, including the abovementioned four technopoles and fifteen TDZs in progress. One of these ongoing projects is the Esenler Smart City-based TDZ in İstanbul. The project was begun in 2021 as a technology development zone by the consortium of İstanbul Technical University (İTU), Yıldız Technical University (YTU), and İbni Haldun University to acquire and process big data about İstanbul. The project can be regarded as the sole example of an innovative attempt in Turkey to include urban-related issues and smart system concerns in the foundation of a new TDZ. Following the results of the performance points of TDZs, it becomes necessary to analyze and compare the composition of firms and staff in the R&D and design centers. This is also necessary to explore the possibilities and limitations of the national innovation system in Turkey with regard to novel design activities in investigating the intelligent spaces for further responsible innovation and productivity in TDZ and research centers (Table 7).

Table 7. The comparison of R&D and design centers in Turkey.

	R&D Centers [65]	**Design Centers [65]**
Number of centers	1260	320
Total staff	75,117	7733
(Bachelor)	45,035	4797
(Master's)	13,780	646
(PhD)	1218	26
Number of completed projects	52,229	9648
Number of ongoing projects	14,714	2324
Patent	31,811	612
(Approved)	10,028	191
(Application)	21,783	421
Foreign Firms	198	33
Notes	Any architecture firm on smart system projects	Only 41 of 320 firms are classified as Engineering/Architecture firms. There is no activity of firms designing intelligent spaces.

The composition of firms and staff, including the designers in TDZs and research and design centers, is significant regarding similar cases from China and Spain, together with the research exploring the potential of technoparks in different countries such as Taiwan [23,25,35]. However, from Table 7, it can be noted that there are still limitations inherent to the data and innovative capacities of the design centers and staff, and only certain firms can be reported as dealing with the innovative practices of additive manufacturing or software development. In Table 7, it is important to recognize that there are fewer PhD graduates in design centers compared to R&D centers. Similarly, the number of staff working in the design centers is in the minority of the creative class in Turkey (Tables 5–7). This reveals a significant limitation of human resources in the creative class that should be extended for planning and designing innovative workplaces. In the planning and design of intelligent environments, foreign firms can help to provide innovative solutions. However, foreign firms are also observed to be limited and remain in the minority of the total number of firms (Table 7). On the other hand, the necessity for the collaboration of qualified labor in Turkey can only be met again by proposing and developing sustainable ecosystems and networked workspaces through innovative design [20].

Moreover, planning proposals for innovative workspaces such as intelligent environments can offer new job opportunities. Although Turkey's annual GDP and total exports are increasing each year, and TDZs have considerable potential for innovative practices (Tables 5, 6 and 8), a minority of the design staff in research centers (Table 7), as well as the risk of unemployment [4] (Table 8), are two particular problems that should be considered with job opportunities through investment in innovative technologies, industry, and production. In this regard, increasing the number of design and incubation centers and working staff, as in the US and Poland [61], could well be a solution to generate new workplaces and job opportunities for members of the creative class for responsible innovation and economic growth in overcoming the problem of rising or fluctuating unemployment in Turkey (Table 8).

Table 8. Selected facts about Turkey's economy.

TURKEY	Total Exports [70,71] (Billion USD)	Annual GDP [71,72] (Billion USD)	Unemployment [73] (Percent)
2013	151.8	957.8	9.7
2014	157.6	939	9.9
2015	143.8	864.3	10.3
2016	142.5	869.7	10.9
2017	157	859	10.9
2018	177.2	778.5	11
2019	180.8	759.9	13.4
2020	169.6	720.3	13.1
2021	225.3	819	13.4
2022	254.2	853.5 *	10.2

*: Estimation. The errors in the numeric values are less than 0.05.

4. Discussion

This research contributes to the limited literature on planning, design, and construction of intelligent environments for workspaces (Table 1) by considering the role of TDZs and research centers in responsible and open innovation and their limitations and potential in Turkey's national innovation system. The potential of TDZs and research centers in Turkey is investigated through empirical research on performance index points and the methods by which they are calculated (Tables 2–4). The general facts about TDZs, firms, and the staff composition of research centers in the national innovation system are also reported with regard to the human resources of the creative class (Tables 5–7).

It can be observed from the results that even though there is innovative and financial potential for technoparks, it is barely possible to discuss the design of larger-scale intelligent buildings or the usage of state-of-the-art smart systems in workspaces and TDZs in Turkey (Tables 5–7). This also unveils the faint segregation in the creative class, disregarding the role of design, the usage patterns in space, and the assessment of individual productivity in performative activities (Tables 5 and 7). The comparison of TDZs, R&D, and design centers in Turkey reveals that a minority of the design staff in the creative class are at risk of unemployment (Tables 5–8). On the other hand, it is significant to understand the role of planning and designing intelligent spaces and the activities of different firms and the design staff to offer new and innovative technological proposals.

For instance, following the use patterns in workspaces can be significant in developing novel value-based empirical research and decision-making models in the organization of institutions and places [26]. Exemplar decision-making models were applied for the pilot projects at TU Delft, TU Eindhoven, Radboud, and Wageningen Universities [26]. More information about the staff and occupation of closed workspaces in technopoles can be acquired by the pilot projects of smart systems and intelligent spaces in crowdsourcing usage patterns and activities. Following the quantitative data about usage patterns might also be an apparent performance indicator for innovative activities in the decision-making models and in the assessment of both value-based as well as actor-based outcomes. Thus, considering the big data about the location-based user occupation and frequency of the activity of users in workspaces can be achieved by the transformation of existing workspaces into smart buildings and intelligent environments [26,49,50,58]. Moreover, the data from intelligent spaces can be used to develop context-aware blockchain applications [52,53]. More significantly, real-time data acquisition and even certification can be made possible by designing intelligent spaces and context-aware IoT applications that increase performance with regard to technology transfer, interaction, and cooperation with other institutions [50,52,53]. Briefly, intelligent spaces can generate real-time big data about the use of space, activities, and even the composition of staff for the development of new fields of empirical research and innovation in increasing the performance of TDZs.

In our method for the re-calculation of performance index points of TDZs (Tables 3 and 4), it would become possible to consider the firm composition with regard to the role of productivity in design and innovative technological research (Table 5) [28]. From the results, it is observed that changing the scalar weights of the indicators also changes the performance index points of TDZs, which may influence the incentives from the government and investments of TDZs in innovative technologies such as intelligent spaces. Further empirical research for statistical models, such as lasso regularization, can also be applied to calculate the scalar weights of years for indicators (Table 3) for innovation and productivity in designing, staff, and firm performance to overcome the conundrum of calculating the performance of TDZs and R&D centers [28]. Thus, the practice of intelligent spaces can also help to develop value-based innovative networks, deploying AI models for calculating and increasing technology transfer, R&D activities and outcomes, technological innovation, cooperation, and institutionalization in real time (Table 3) and thus can develop an intelligent ecosystem in the TDZs of Turkey [12,20,27,50].

Turkey's national innovation system encourages the development of innovative and technology-based ecosystems in TDZs [19,20]. ODTU Teknokent's mission and vision statements also support designing and sustaining an ecosystem with further smart system infrastructure for R&D centers and buildings [74]. Thus, it is significant to reconsider the performance indicators of the TDZs in Turkey, as calculated in this empirical research, by applying AI and machine learning models to encourage incentives and improve the innovative enterprises of firms and research centers via intelligent spaces deploying state-of-the-art AI and IoT technologies (Tables 3 and 4). The potential benefits of intelligent spaces to be developed in TDZs can be briefly discussed as follows.

The higher functional necessities of the environmental inputs and user interactions for labs, offices, simulation centers, and research clusters can be met by the acquisition of real-time data from both indoor and outdoor spaces [50]. Similarly, AI and IoT technologies are believed to enable the new interfaces of human–computer interactions and institutional cooperation for the research-related experimental actions of the creative class [75]. It may also be appropriate to develop decision-making models through AI and machine learning models in intelligent spaces in deciding the performance indicators to evaluate firms' productivity in real time. The larger-scale practice of intelligent environments in research campuses will bring Big Data about human–computer interactions through novel crowdsourcing means, requiring closer inspection of the physical condition of spaces with wide-ranging technological possibilities [49]. Intelligent spaces will facilitate social and institutional interactions and cooperation, as well as improve the capabilities to develop sustainable ecosystems for firms and research centers [61]. The collective endeavor for responsible innovation by the new human–technology relations networked in research-based environments can enable the generation and processing of Big Data based on the research-related act of the creative class. Thus, the development of intelligent spaces in technopoles of Turkey can generate Big Data about labor productivity. Furthermore, new job opportunities for the creative class can be offered with the rising necessity for the practices of smart buildings and intelligent spaces. Thus, the design of smart spaces in technopoles can help overcome the rising or fluctuating unemployment problem amongst the creative class in Turkey (Table 8).

Furthermore, it can be observed that some technopoles in Turkey—other than ODTU Teknokent—have increased their investments in the construction of new closed areas, which are apparent in the cases of İTU Arı Teknokent and Yıldız Teknopark (Tables 2 and 5). There is another ongoing TDZ project for the infrastructural transformation of İstanbul as a smart city by the consortium formed by İTU, YTU, and İbni Haldun University. In this regard, the investments of two technoparks in developing a TDZ for the smart city of İstanbul are exemplified to encourage intelligent spaces and innovative spatial solutions in Turkey. Thus, the TDZs of universities in İstanbul also inspire this research to evaluate the alternatives for technopoles in Turkey, such as ODTU Teknokent and Bilkent CYBERPARK, that can be encouraged to invest in planning, designing, and developing smart buildings and intelligent spaces in new, as well as existing, technology development zones for the generation of Big Data.

Respectively, the total closed areas of TDZs (Table 5) can be a very important factor, and even as an indicator in comparing the performance and efficiency of TDZs that are missed in indexing the performance of technopoles in Turkey (Table 3). On the other hand, the quantitative largeness of the closed areas cannot be the ultimate criterion for assessing the performance of technopoles. Rather than adding new areas to the existing environments, transforming the existing workspaces and laboratories into intelligent spaces by refurbishing campuses and technopoles with smart systems could well represent an efficient, sustainable solution for responsible technological innovation [1–3,22,49,50,58,76] (Figure 3).

Figure 3. An example of intelligent spaces through the refurbishment of campus environments with smart systems [58,77].

It would be useful to note the limitations of this research and propose future work regarding the challenges and potential for developing intelligent environments as follows:

- The survey of the related literature and existing environments for workspaces and research centers shows that the research into and application of intelligent spaces remains in its infancy (Table 1). Despite this, there are emerging, significant studies that can be encouraged to propose the development of intelligent environments, as in this research.
- As another challenge to this empirical research, the limited data about the performance indicators of TDZs from 2012 to 2015 (Tables 3 and 4) hamper the prediction of exact economic facts about technoparks in Turkey.
- The limited data also restrict this empirical research in deciding about the robust mathematical methods for the scalar weights of the indicators, which are tested through machine learning and AI models via the MATLAB Regression Learner (Tables 3 and 4).
- Additionally, the removal of the indicator for 'exports and composition of firms' by the Ministry in 2013 (Table 3) is another limitation in comparing the different cases and environments from different countries. Nevertheless, there is potential for TDZs in Turkey, even when compared to the significant examples from different countries for responsible innovation. Applying intelligent environments in increasing the digital ecosystem of research campuses and deploying common state-of-the-art technologies, AI, and machine learning models can enable the acquisition of raw data from TDZs in real time and allow us to compare the results on R&D activities as well as the productivity of the agents with regard to the indicators explored.

- Similarly, the performance index points of TDZs cannot be calculated by the applied methods for 2016–2021 in this empirical research (Table 4), as the raw data and values from TDZs have not been released by the Ministry since 2016.
- The lack of essential data about the export values, composition of firms, and R&D activities of some TDZs (2016–2021) can also be related to the underdeveloped digital ecosystem in Turkey. Even though the export values are not solely important, it is found from the results that without calculating the indicators and necessary values for 'exports and composition of firms', it would not be possible to correctly calculate the performance points of TDZs. Thus, including the indicator for 'exports and composition of firms' influences the share rate of indicators for the incentives and investments to TDZs (Tables 3–5) and thus the growth and innovative potential of TDZs and possible investments for intelligent spaces.
- This empirical research on the facts about TDZs is also limited to the data shared by the selected technoparks.
- The process for the validation of the data acquired from TDZs in Turkey can be seen as another limitation that goes beyond the certification period, but it can be overcome by innovative, intelligent environments with real-time learning models.
- Finally, the facts about the design and construction firms, the design staff in the research centers of Turkey, and their innovative capacities are limited. On the other hand, articles on different countries, such as China and Spain, indicate the potential of the innovative capabilities of firms and research centers for intelligent environments in technopoles.

New empirical research on similar topics and environments can investigate and increase the innovative growth and performance of TDZs and design and construction firms by considering the related existing indicators on technology transfer, the investment in state-of-the technologies, R&D activities, and patents [27,28]. Furthermore, it is proposed that the development of intelligent spaces that deploy machine learning, AI, and IoT technologies can generate and process Big Data about TDZs. Context-aware IoT and blockchain applications and real-time learning systems can also be extremely efficient in ensuring the outcomes of the implementations through research methods, data collecting and processing means, and techniques [50,52,53]. Most importantly, increasing the context-aware and real-time data validation between firms and research institutions can increase technology transfer and enable the development of sustainable ecosystems [11,13,52,53]. The research regards this proposal as crucial to responsible innovation, new job opportunities, and fields of work for the creative class in Turkey, with a need to increase the qualified workforce [19,20]. Following the successful examples and research on exploring the construction of intelligent spaces [26,49,50,58] (Figure 3), the article puts forth a series of proposals that can be followed, through five steps, to develop and sustain intelligent spaces. These implementation steps are also regarded as future work that can be applied to existing, as well as new, TDZs and research parks and for common research into ODTÜ Teknokent and Bilkent CYBERPARK, from which interested researchers can benefit. They are as follows:

1. The spatial needs and technological possibilities should first be explored through the physical environment and campus-based parameters, with limitations and possibilities [26,49].
2. Decision-making models and empirical research are to be conducted, deploying AI and machine learning models, which can be applied in intelligent spaces [26].
3. Appropriate sensor-based, IoT-based smart systems and state-of-the-art technologies can be installed in places with regard to the surveyed spatial needs and outcomes of decision-making models and empirical research [47,49,50] (Figure 3).
4. To discover the optimal learning systems, the generated sensor-based data should be processed with different learning models again, including machine and deep learning models [49,50].

5. The Big Data acquired should be processed with regard to the aims of the research and deployment of smart systems, campuses, and cities that are to be managed by the decision-making models and mechanisms using AI and IoT technologies [49].

Interested readers can also benefit from the outcomes of this article in terms of identifying the critical parameters and defining proposals for how intelligent spaces can be developed in TDZs. Thus, it is significant to recognize similar emerging research on the innovative capabilities of construction firms, as well as the potential of science parks in different countries. The sustainability of such research needs greater attention to obtain the big picture about open and responsible innovation, national innovation systems, and production in space, Objectile; the new preferences, actions, and social cooperation of individuals in space, Subjectile; and their networked interaction in intelligent spaces (Figures 1 and 2). In studying data engineering and data management through the existing learning models, research institutions should make substantial data available in a timely manner for the purpose of the stepwise transformation of these studies as part of responsible innovation.

In brief, the design of smart buildings and intelligent spaces can offer new human–technology interactions, spatiotemporal experiences, data about financial and innovative growth, and even job and investment opportunities that can improve the success of TDZs. The research finds that even though there has been no attempt made nor evaluation of intelligent spaces with smart systems and the assessment of the total closed area of technopoles in Turkey, there is the potential to increase the performance of TDZs by investing in novel, innovative solutions for intelligent buildings and environments. In providing alternatives to the rising unemployment and monitoring productivity in technopoles and campus environments, the research arrives at a series of proposals for developing intelligent spaces with state-of-the-art technologies in technopoles such as ODTU Teknokent and Bilkent CYBERPARK.

5. Conclusions

This research highlights that the number of staff and firms in the design activity of the TDZs, R&D, and even design centers in Turkey reveals the limitations and challenges inherent to planning and designing intelligent spaces in the scope of responsible innovation (Tables 1 and 5–7). However, this also reveals the potential for further progress in increasing the number of design centers and labor in the creative class within Turkey to design intelligent spaces. The results of this research reveal that the planning and calculation of performance indicators influence the potential and growth of TDZs, and indeed they need to be reconsidered regarding innovative objectives such as developing intelligent spaces (Tables 2–4).

The technology transfer and the networked cooperation between R&D centers and technopoles can be facilitated by deploying state-of-the-art IoT and AI technologies in intelligent environments. The networked closed areas of technology development zones can also improve the role of design and individual performance within such environments. Intelligent environments with IoT projects can offer real-time data acquisition that can help improve the performance of TDZs in terms of monitoring and feedback processes [50]. More significantly, context-aware blockchain technologies in assessing some of the activities of TDZs can accelerate the validation of data acquisition from each institution and overcome security concerns using IoT applications in workspaces [52,53]. The rise of pilot projects in Europe and the projects in Turkey that are in progress also need to re-evaluate the role of productivity and spatial design in increasing the number of design staff, such that there would be an increased need for the new milieu of research in increasing the performance of TDZs.

Thus, the article offers a set of implementations for designing intelligent spaces and infrastructure, even for new technoparks, as well as refurbishing the existing environment, regarding the potential development that can influence the performance indexes of TDZs. Respectively, with the potential of being closer research centers having similar local dynamics and the legislative rules that enable the development of sites of high technology, ODTU Teknokent and Bilkent CYBERPARK should be encouraged to increase their innovative attempts and investments to develop intelligent working spaces, as in the cases of İTU Arı TDZ and Yıldız Teknopark for Esenler TDZ. In this regard, the limitations and implementation proposals for the planning and development of intelligent spaces are discussed from the literature survey and empirical research conducted in this study for interested researchers.

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Abbreviations

AI	Artificial Intelligence
CSR	Corporate Social Responsibility
GDP	Gross Domestic Product
IoT	Internet of Things
İTU	İstanbul Technical University
ODTU	Orta Doğu Technical University
OECD	The Organization for Economic Cooperation and Development
PCA	Principal Component Analysis
PhD	Doctor of Philosophy
R&D	Research and Development
RMSE	Root Mean Square Error
sq m	Square Meter
SVM	Support Vector Machine
TDZ	Technology Development Zone
TT	Technology Transfer
TU	University of Technology
UC	University of California
UCLA	University of California, Los Angeles
USA	United States of America
USD	United States Dollar
YTU	Yıldız Technical University

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