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Article

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Research Article

The integration of digital twin and serious game framework for new normal virtual urban exploration and social interaction

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ABSTRACT

COVID-19 has disconnected humanity, reduced social interaction in physical urban areas, and led to the new normal, which describes the anticipated changes in human life and professionals due to the impact of the pandemic. In addition, as part of digital transformation, the post-pandemic New Normal includes accelerating digital solutions and new standards for virtual urban exploration and planning. This study applies the concept of digital twin and serious game design and uses Minecraft, a game-based platform that inspires creative, inclusive learning through play, for virtual urban exploration and the development of social interaction among participants. Dadaocheng, a historical area of Taipei city, is then studied as a case study with the Geoboxers application to develop the prototype for a co-creation experiment in Minecraft. The prototype development and the results of the experiment are then used in the Analytic Hierarchical Process (AHP) method to evaluate a set of influential criteria proposed in this study through pairwise comparisons by expert panelists. The results of the AHP analysis reveal users' simultaneous preferences for urban planning and social interaction with urban characteristics (22.14%), urban exploration (12.29%), and 3D models (11.97%). Subsequently, the research results showed a need to promote the integration of digital twins and serious game applications as digital tools for urban exploration and social interaction, increasing post-pandemic virtual urban planning and applying new urban design techniques. This study also contributes to the acceleration of digital transformation in urban planning and management.

1. Introduction

In response to the COVID-19 pandemic, an atypical situation during the New Normal is restrictions on public space use, which have created radical changes in the physical aspects of social interaction. Consequently, life during the pandemic affected people's lives in general and altered their behavior in private and public spaces (Honey-Rosés et al., 2021). Steadily, the vaccine has loosened the requirement for social distancing, although victims of the pandemic developed fear and other psychosocial problems due to uncertainty in the public spaces, which require a full-scale improvement in public spaces (Megahed & Ghoneim, 2020; Alraouf, 2021; Schneiders et al., 2022). However, despite all the negative impacts, another profound change that was already occurring in cities at the time of the outbreak is the emergence of undiscovered potentials and challenges from climate change, digital transformation, sustainable development, urban reexamination and regeneration, and inclusion of disadvantaged groups in the new society (Pinto & Akhavan, 2022). In

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addition, digital transformation offers the New Normal with major digital solutions such as digital twin, collaborative computing, the Internet of Things (IoT), deep learning technologies, and many more.

The decrease in urban public space usage during the COVID-19 pandemic has led users to move on to virtual spaces (Bingöl & Terzi, 2022). With the current pace of digital transformation and technological advancement in the post-pandemic, humanity's future will end up with dozens of popular virtual worlds and platforms. However, despite being a social environment, virtual worlds lack a considerable impact on human's sense of belonging, social resilience, and lifestyle due to being disconnected from the physical environment unless they incorporate technology such as digital twins to simulate 3D representations of physical urban spaces. This integration advances urban planning and management by providing more urban characteristics to digital environments for remote working and urban planning (Yu et al., 2019). It alters the characteristics of collaborative lifestyles and sharing nature of co-working by online means. Yan (2019) stated that “sharing is a natural response to planning challenges” and “sharing makes efficient use of resources”, but up to this point, most urban planning and management have been conducted in closed environments. Thus, new digital solutions should break the distance barrier, make use of knowledge and resources, and allow more actors to participate and interact virtually.

Designing and developing an open virtual urban platform can contribute to the new societal resilience where urban planning in the post-pandemic improves social interaction to be more natural and less confusing similar to the normal before. Accordingly, the new social and urban state requires adaptation of an open-urban digital twin which can capture the physical urban reality, with engagement and data from the virtual for planning. Urban digital twin and case studies from other projects also need review, while a gaming and post-pandemic urban design theory that regards emotion are required to induce motivation and participation. Additionally, this paper explores the urban digital twin concept in games such as Minecraft, using its block-to-block gameplay to reconstruct an identical virtual version of a specific urban area. This study implements the SWOT and AHP method. A factor and criterion analysis is conducted with SWOT to examine strengths (S), weaknesses (W), opportunities (O), and threats (T) to present positive and dominant factors for social interaction in the virtual urban world for the post-pandemic urban planning. Similarly, Fig. 1 presents the methodological framework of this paper.

This study also includes a case study of the prototype system of the digital twin of Dihua Street, Dadaocheng. COVID-19 has impacted the global tourism industries, including Taiwan. Before the pandemic, in addition to popular tourist attractions such as Taipei 101, tourists also visited Taipei's old streets, which offer cultural and historical value. Dihua Street is one of the old streets and it belongs to Dadaocheng, a historical area famous for its traditional street shops and unique architecture, a heritage of colonial memories. Several research projects have been conducted in this area to understand the process of townhouse architecture and urban regeneration to preserve the harmony between old and the new urban structures while attracting new generations to conserve and promote historical urban landscapes (Chohan & Ki, 2005; Fu, 2016; Go & Lai, 2019).

2. Literature review

2.1. The urban planning in the new normal post-pandemic

In the normal before the COVID-19 pandemic, the phenomenon of observation of urban places and walking activities allow one to interpret and develop a sense of belonging to urban environments (JannatPour, KarimiAzeri, & Safari, 2018). As social distancing policies are lifting, the memory of COVID-19 should remain a reference to help the vision of new urban areas with increased community participation and resilience (Alraouf, 2021). The sudden arrival of the pandemic has left societies with a massive change in many fields, such as service provision, digital infrastructure, resource management, environmental health, economies, city densities, space use, communities, and institutions (Syal, 2021). However, in addition to these changes and new lifestyles in the New Normal of post-COVID-19, a revisit of the unsolved problems of the normal before is needed instead of moving forward and avoiding them (Alraouf, 2021). For instance, based on Askarizad and He's (2022) study of balancing social isolation and social interaction in the public space, one of many factors that facilitated the transmission was due to poor urban management, which required data integration from the government and public sectors. As evidence, their study revealed that one form of poor urban planning in this period is the placement of public furniture in public spaces where citizens are packed next to each other during social isolation. Their study proposed a theoretical framework (Fig. 2) and a grid-based urban design technique for post-pandemic urban design to create a better solution to social interaction through proper planning. This framework highlights the interrelation between psychological, emotional, interactions, and mobility, while developing a sense of belonging plays an influential role on citizens' emotions.

Additionally, the grid-based design technique in this literature provides a view of resilient and transparent blocks for effective planning. Furthermore, building a responsive environment is necessary to improve social interaction, and urban resilience in case a similar pandemic occurs (Askarizad & He, 2022). Henceforth, by creating virtual models of urban areas and their systems, the digital twin can simulate and analyze various scenarios and their potential impacts to improve social interaction, and providing an

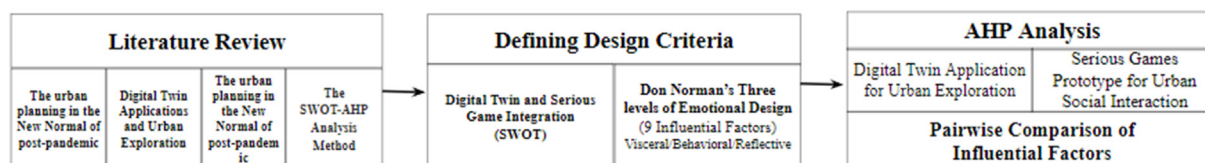


Fig. 1. Methodological framework.

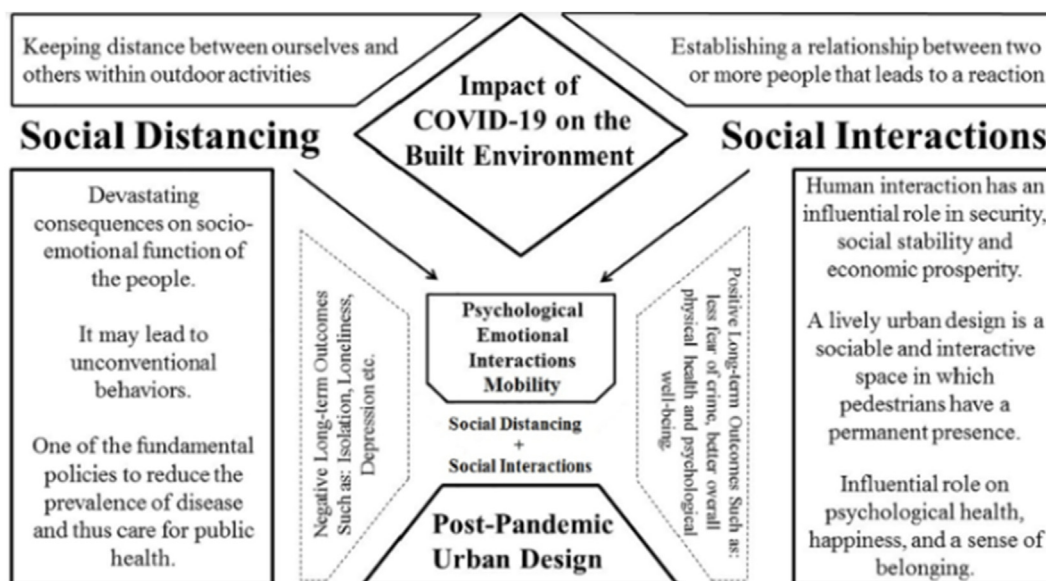


Fig. 2. Post-pandemic urban design theoretical framework (Askarizad & He, 2022).

emotion-related insight and sense of belonging should be considered.

2.2. The development and application of digital twin

In the era of technological advancement, technology such as the Internet of Things (IoT) enabled the digital presentation of physical environments (Angelakis et al., 2016). Such a description is close to the definition of digital twin (DT), where different domains and literature provide different definition but are similar in terms of digital representation or replicas based on the data of physical entities (Dembski et al., 2020; El Saddik, 2018; Riemer & Seymour, 2021; Wang, 2020). A critical aspect of the digital twin is the multi-physical modeling that the accurate reflection of a physical entity in virtual space contributes to the simulation, detection, prediction, and control functions. COVID-19's uncertainty has expanded the reality with more virtual worlds such as the metaverse, but without the familiar physical urban characteristics, it is unlikely to develop a sense of belonging for resilience in the post-pandemic. Thus, a collective of literature has extended digital twins from the manufacturing domain to the urban domain, leading to digital twin cities (DTC) or urban digital twins (UDT). However, UDT relies heavily on the use case applied (Alva et al., 2022). Examples of excellent case studies are Herrenberg Town DT, Germany (Dembski et al., 2020) and the Zurich City DT (Schrotter & Hürzeler, 2020), where users can access online platforms to support urban planning by interacting with the digital models and with each other.

The Herrenberg Town case study developed a 3D city model based on geographic data provided by regional authorities with complex systems such as using a 3D Faro laser scanner, Building Information System (BIM), and Simulation of Urban Mobility (SUMO). The Herrenberg Town case study's evaluation method uses a pairwise comparison survey of six pairs of opposite attributes from −3.00 to +3.00 from two perspectives between citizens and official local representatives. The results revealed that the Herrenberg Town DT is interesting, comprehensible, concrete, clearly arranged, entertaining, and straightforward. The study also revealed the limitation of not being able to include all the information, including social data and similarities, compared to the physical world, which requires future studies on these problems. On the other hand, the Zurich City case study revealed the collaboration between multiple organizations and the usage of laser scanning and photogrammetry in digital twinning into an interactive web-based 3D map platform. The study focused on the Zurich City description of the twinning process and revealed potential platforms or web applications for ease of access to urban planners. Additionally, the study mentioned Minecraft as one possible form of active and playful participation in urban planning and discussed future work that examines the preferred tools between Minecraft and web-based platforms.

According to the case study of Herrenberg Town, "digital tools can support citizen participation but must be embedded with serious dialogues" (Dembski et al., 2020). Additionally, motivations are the driving force behind urban activity (Bolshakov & Golovnykh, 2004). With the increase in screen time during the pandemic, video games have become more approachable and a source of motivation to advance new social skills such as cooperation and negotiation (Yogman et al., 2018; Colley et al., 2020; De Vos, 2020; Wong et al., 2021). Additionally, game-based solutions encourage voluntary consciousness of social interaction and activity participation while extending opportunities to forecast upcoming challenges (Osterman, 1998; Ravyse et al., 2017). These cases highlight that the professional and public sectors can collaborate to tackle urban challenges in one place. Features such as communication, model interaction, and leaving feedback impact the participants' decision-making while inducing awareness of the geospatial, city development trends, or certain concepts from the virtual urban area as they explore.

2.3. Serious game with emotional design for urban planning social interaction

According to the case study of Zurich city, Minecraft, which has significant features on modeling and modifiability, has the potential as a platform that intrigues active participation in planning (Schrotter & Hürzeler, 2020). During the pandemic, the Gather (Gather.-town) was a popular live-virtual application in response to the pandemic. The reason for its mention in this literature review is that as a platform with gamified elements, it improves the social interaction and virtual environment interaction from the case study of Gather by McClure and Williams (2021). However, despite being a popular gamified platform, Gather is incompatible with the integration of digital twin and serious game concept, where the environment provides working space and the ability to add or generate content by users.

In this research, we will use Minecraft as a platform to develop a prototype for urban exploration and social interaction in urban planning. The Minecraft is a sandbox game with block-to-block gameplay similar to LEGO empowers its players of all ages with creativity and problem-solving skills. Maintaining the similarity of urban characteristics and architectural models is essential in Minecraft as it positively impacts users for virtual world spatial recognition and navigation skills (Elmerghany & Paulus, 2017; Hewett et al., 2020). Additionally, from the grid-based urban design technique proposed by Askarizad and He (2022), Minecraft is compatible with its block-by-block display and highlighting the gridlines between blocks, which is suitable to integrate with concept and knowledge to develop serious game for urban planning. Minecraft players or virtual urban platform participants can roam through the mirrored space of an urban area with their virtual 3D avatar, analyze and learn the development process, and perform urban planning collaboratively.

Some other sociability features of Minecraft are that players can access online multiplayer mode to share or access other players' worlds to help co-building. According to Fauzan et al. (2018), Minecraft encourages its players to develop their user-generated content of any form, which requires precision observation skills and collaboration between team members for a large-scale project to recreate objects of specific themes like a city landmark or the whole city from physical to virtual (Fauzan et al., 2018). Similarly, multiple research projects explored Minecraft's utility as an environment and geo-design tool to encourage urban planning from the public sector while aiming for a gamified spatial simulation. In a separate publication, Scholten (2017) developed a version called Geocraft to effectively replicate the physical world with the Geo-ICT framework of UK LIDAR and OSM to provide a prediction simulation of future smart cities. However, Geocraft is limited to the location within UK only and has not been up-to-date for years. The result of importing actual geospatial data into gaming environments allows younger participants to engage in urban planning and raise awareness of urban-related challenges (Scholten et al., 2017).

In addition to their intrinsic motivational power, serious games evoke a range of emotions, including happiness and sadness, thus requiring a design strategy involving emotion (Nazry & Romano, 2017). Based on the framework where emotion plays a role in post-pandemic urban design, frameworks such as the one from Baharom combine learning domains with Norman's three levels of emotional design to expand the motives of system engagement (Baharom et al., 2014). The three levels include visceral, behavioral, and reflective, associated with the visual, operation, and insights. These reflect to Don Norman's theory of emotional design involves three different levels. "Visceral design concerns itself with appearances" (Norman, 2003). Key elements for the visceral level are those that make first impressions and determine how users perceive and react to it. The second level is behavioral, where the product fails if users give up knowing what to do next, similar to interface exploration (Norman, 2003). A focus on operational features can improve users' product usage experience. Reflective is one complex system as it depends on multiple elements such as culture, experience, knowledge, and many more (Norman, 2003). To be precise, this level refers to the outcome after product usage; hence it is influenced by the first two levels. In serious game design, where the game is played not fully for entertainment, emotional design factors influence product usage and social interaction experience.

2.4. The SWOT-AHP analysis method

In this study, SWOT is implemented to indicate factors and as it is insufficient in quantification and prioritization (Büyükoçkan et al., 2021) and thus requires the Analytical Hierarchy Process (AHP) integrated to solve decision-making problems. AHP is a relative measurement of intangible criteria theory (Saaty, 1977). AHP involves the decision-making process of a pairwise comparison of influential factors to determine the priority factors and provide quantitative measurement. AHP is used in the game theory literature for user behavior evaluation (Cui et al., 2019) and user experience optimization (Lin et al., 2021). To assess better urban planning, Parry, Ganaie, and Sultan Bhat (2018) and Zannat, Adnan, and Dewan (2020) applied a GIS-AHP, while Alam and Mondal (2019) and Afroj et al. (2021) assessed the quality of service in the city through a SERVQUAL-AHP model to define and evaluate dominant factors for the satisfaction with urban quality of life.

However, multiple pieces of academic literature indicate that SWOT is a standard tool for detecting internal and external influential factors and development strategies. The mixed method, SWOT-AHP, is used for participatory and management planning (Margles et al., 2010). In this study, a workshop is conducted with five stakeholders to discuss and vote for the influential factors associated with the management of Nyungwe National Park Buffer Zone. A total of 78 factors were decrypted with further adjustments to convert 15 'Strengths' to three, 17 'Weaknesses' to four, 25 'Opportunities' to four, and 21 'Threats' to five. The results revealed a significant score in 'Threats' that require interpretation from 'Strengths' or 'Opportunities' and that a constraint of their study is the limited number of participants. Overall, SWOT-AHP in this study effectively enabled open contributions and quantifiably delineated differences in preferences and priorities between interest groups.

On the other hand, the SWOT-AHP method is also widely used in the literature on other domains. For instance, in strategy development and evaluating sustainable planning, this method is used for sustainable manufacturing (Khatrı & Metri, 2016), sustainable

energy planning (Solangi et al., 2019), sustainable tourism development strategies (Saha & Paul, 2020) or urban strategic planning and policy-making such as strategic planning and urban development for Urmia city (Mobaraki, 2014) and urban policy-making for developing cities (Rajput et al., 2021). Overall, AHP is suitable for evaluating game theory and urban-related research. Furthermore, the lack of quantification of social interaction and urban planning factors with urban digital twin and serious game integration requires a review and justification. Fig. 3 presents the procedure of AHP in this study.

3. Research design and evaluation

3.1. Proposition of research structure

In this study, Minecraft is a tool or platform for implementing serious game-based development for urban exploration and social interaction for urban planning in the New Normal. Following the theoretical framework proposed by Askarizad and He (2022), this study proposed a modified one for urban planning in the New Normal which is built from urban exploration and social interaction mechanism based on the digital twin application (Fig. 4). Urban exploration helps users better know the city and identify the current problems. Social interaction encourages people to participate in the urban planning process cohesively.

Social interaction refers to the act of developing relationships between entities. Generally, the entities are often two people, but also it could be between people and the urban environment (Askarizad & Safari, 2020). With the digital transformation, the urban environments in the post-pandemic should be viewed as an interface, and they can provide playful, engaging, and immersive experiences to encourage participatory planning. Participants can work collaboratively to collect, analyze, and visualize the geospatial data of the urban area to promote a sense of place, a sense of belonging, and a sense of community. More desirable results can be delivered through this form of social interaction, which facilitates the exchange of ideas and resources, leading to more innovation and collaboration in designing cities of the future.

Urban exploration refers to the perception of the urban environments to discover unsolved problems (JannatPour et al., 2018). Having explored the urban environments, participants can collaboratively interact with the urban structures and architecture to examine the constitution of spaces through urban planning. For urban planners and practitioners, having a responsive and open

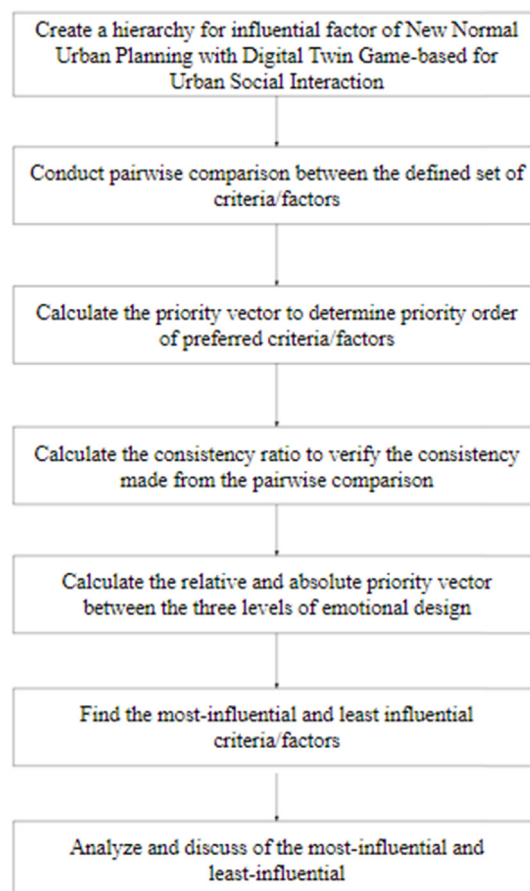


Fig. 3. AHP procedure.

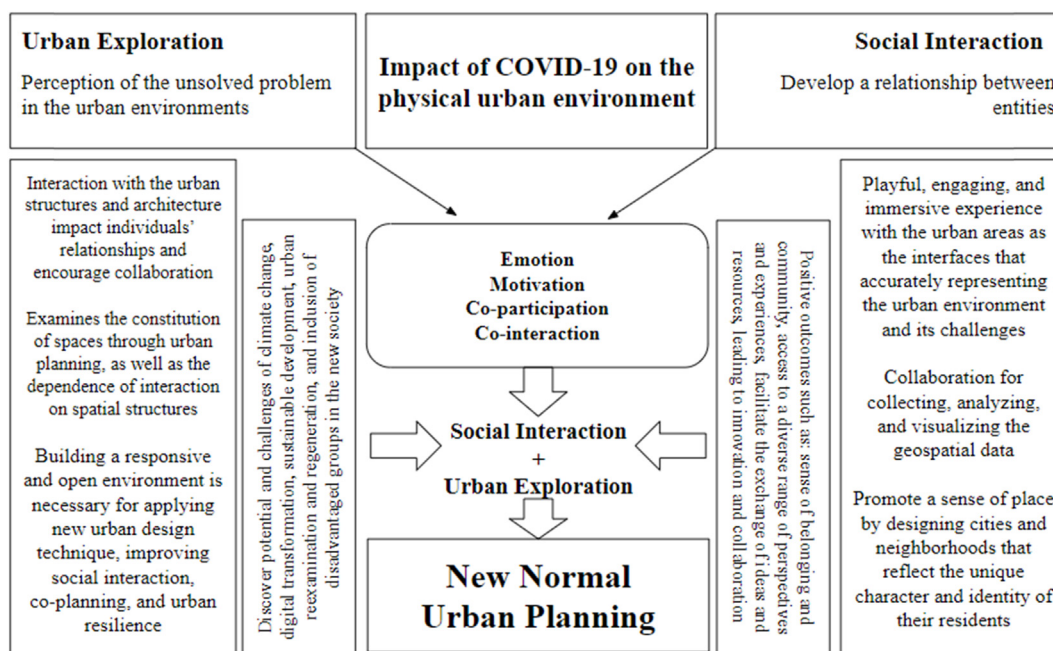


Fig. 4. A modified framework based on Askarizad and He (2022) for urban planning in the New Normal.

environment that simulates the actual one helps them manage and apply new urban design skills. The outcomes enable social interaction in co-planning and urban resilience to discover potential solutions and challenges of the all-time problems in the urban systems. With emotion, motivation, co-participation, and co-interaction as key elements for social interaction and urban exploration.

3.2. Influential factor data identification

The two-round identification in this study involves 30 experts, 11 from interaction and game design, seven from geospatial engineering, and 12 from architecture and urban planning. The participants have more than six years of experience in their expertise and are familiar with digital tools to design virtual environments and architecture models and to visualize spatial data for planning with geographic data mapping technologies. In the first phase of identification process, the criteria are developed through a SWOT analysis to identify the influential factors of a virtual open platform with Minecraft that apply urban digital twins. SWOT is developed based on Burke's (2014) macro-analysis, the proposed modified framework, and participants' preliminary testing with a Minecraft prototype developed from a previous study (Vu & Wang, 2021).

Fig. 5 presents the influential factors identified with SWOT. In the 'Strength' identification of digital twin and serious game implemented in Minecraft for urban planning, factors such as simplified user interface without blocking the view are identified first. Factors of digital twin modeling with Minecraft as a tool are also identified compared to geospatial visualization tools that can only present simple shapes and lack customization and complex model creation. A block-to-block model interaction is Minecraft's core gameplay interaction. The participants found it to be a feature that empowers creativity, and complex architecture models can be assessed with it. From a gaming perspective, open-world online games with participation mechanisms such as Genshin Impact have been popular since its first release in 2020, and Minecraft in Creative mode provides users with a similar and unlimited space to build and explore.

In the 'Weaknesses' identification, participants develop arguments towards data integration compared to other digital twin platforms connecting directly to a database. Compared to the digital twin platforms, players of a digital game may get frustrated if the newly updated data stay mostly the same, but overwrite the creation they invested with much time and effort. Additionally, the large-scale digital twin will require many participants to update without an autonomous update. However, other issues, such as unrealistic pixel-like graphics in the original game, require 'shaders' modification to improve the graphic content. Other modification packs are available online to enhance the gameplay experience, such as more content or more techniques, although some require an older version to run, and some require an understanding of programming prompt commands. During preliminary testing, one significant weakness that simultaneously produces a threat occurs only if the in-game 3D avatar is "dead". Once the 3D avatar respawns, the virtual world is reset to the empty canvas, overwriting all the progress as Minecraft saves constantly. Therefore, a manual backup is required to prevent similar incidents from reoccurring.

Factors such as the digital twin concept and urban planning for social interaction are identified in the 'Opportunities'. Furthermore, with digital twin characteristics, mirroring the urban environment in virtual becomes less complex and participants can 'walk' in the virtual urban to analyze the urban structure and buildings from real life, which is a potential for spatial simulation. Multiplayer allows all

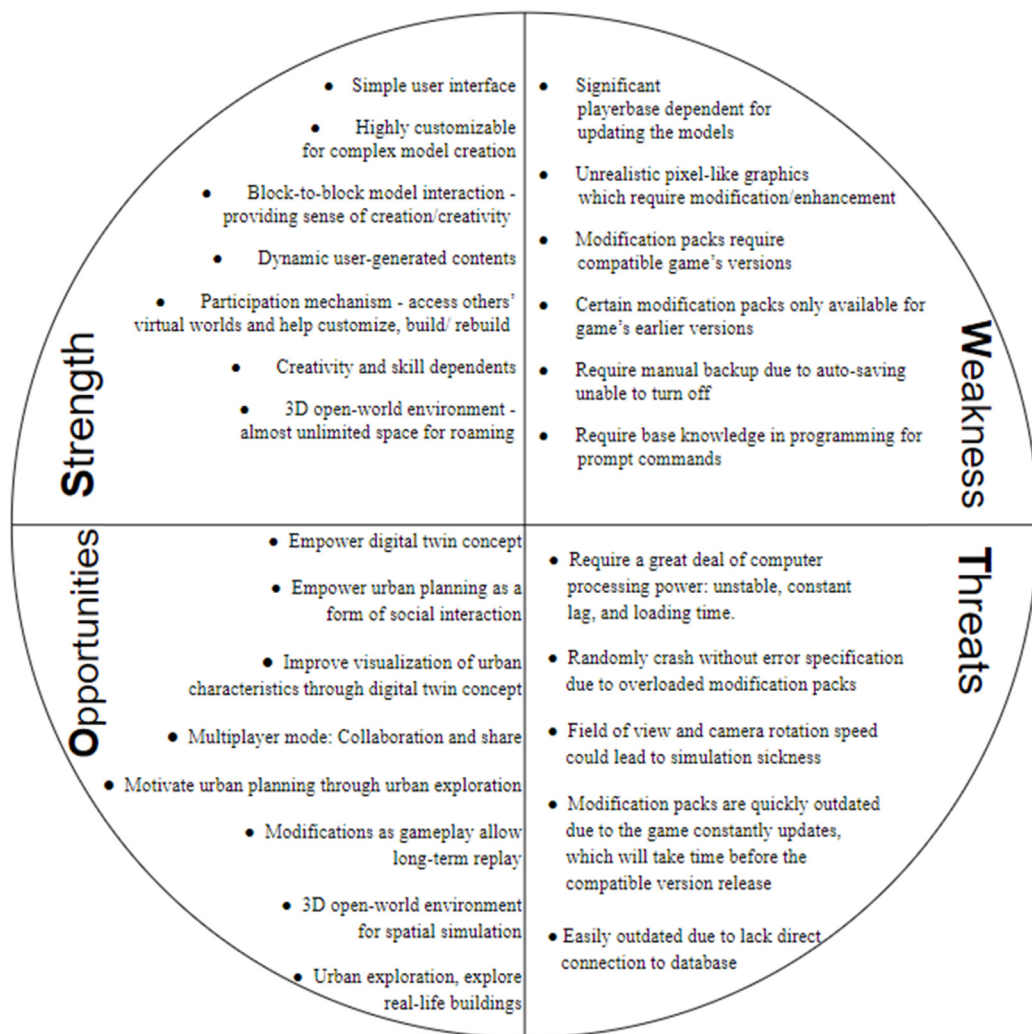


Fig. 5. Influential factors data identification with SWOT for New Normal urban planning with digital twin-integrated Minecraft serious game.

Table 1

Influential factors of each level of emotional design.

Level of Emotional Design	Relation to product	Influential Factors
Visceral Attractiveness (Initial instinct impression)	<ul style="list-style-type: none"> • Virtual urban spaces appeal to the emotions of users • The ability to identify elements of arts such as shape, texture, space, material, color, and value. • Location and space recognition based on memory and emotional cognition 	<ul style="list-style-type: none"> • 3D Model Similarity (S) • Simple User Interface (S) • Urban Exploration (O)
Behavioral Usability (Effectiveness usage)	<ul style="list-style-type: none"> • The pleasure and satisfaction of interacting with the product. • Effective and reliable functionalities • Availability for multiple operators 	<ul style="list-style-type: none"> • Block-to-Block Model Interaction (S) • Participation Mechanism (S) • Collaborative and Share Mechanism (O)
Reflective Conscious thought (Self-image and meaningful message)	<ul style="list-style-type: none"> • Reflection of users to newly obtained knowledge, concept • Acknowledgment of the concealed value in daily lives before the COVID-19 pandemic • Appreciation and awareness towards human and environmental factors 	<ul style="list-style-type: none"> • Digital Twin Concept (O) • Urban Characteristics (O) • Spatial Simulation (O)

participants to collaborate and share their knowledge in the preliminary testing process.

In the ‘Threats’, most factors are related to Minecraft performance, such as random crashes or particular groups facing simulation sickness during the process.

3.3. Norman's emotional design theory data categorization

The second round requires a classification of the elements corresponding to Don Norman's three levels of emotional design and the Baharom framework (Baharom et al., 2014). Only nine elements from S and O were extracted to match the description of each emotional level and product relationship (Table 1) to simplify and improve the pairwise comparison of multiple criteria with AHP in the data evaluation stage.

In the second round, more description was added based on the three levels related to the remaining factors, such as appearance, effectiveness usage, or gameplay interaction, and important context or knowledge gained. For instance, in the visceral level, the extended description is “the attractiveness or the initial instinct stimulation contributes to the user's visceral experience”, which should reflect the virtual model similarity characteristics of a digital twin. From the interface aspect, simplicity is preferred, especially since Minecraft is a game designed for a younger age. The other two factors relate to the virtual urban platform with implemented digital twins. Taking into account users' first impression upon entering the virtual urban world and the likeliness of the accurate architecture model and urban presentation, “3D Model Similarity” and “Urban Characteristics” were chosen.

On the behavioral level, with Minecraft gameplay as the core interactive feature, “Minecraft Model Interaction” was chosen as the operational factor for users to interact with others and the virtual environments. On the contrary, taking the pandemic scenario into account, virtual settings through “Spatial Simulation” and “Collaborative and Share Mechanisms” were chosen as practices for collaboration in the pandemic scenarios where all need to follow the social distancing policy and crowdsourcing contribution of data to mitigate the spread in the future in a more straightforward and less time-consuming approach.

The important aspect of this virtual urban platform in this study is to raise awareness of the “Digital Twin Concept”. Additionally, as an open virtual urban platform, social interaction in the virtual urban can be improved by raising awareness of the “Participation Mechanism”. Another expectation from the virtual urban is the “walk” like in the physical urban; using the Minecraft game engine in a virtual urban area encourages the digital citizens to control their virtual avatar for “Urban Exploration”. Altogether, virtual urban participation can permanently impact societies through changes in virtual replicas, such as advancing cities' greenness and citizens' wellbeing.

4. Research results evaluation and discussion

4.1. System prototype development

Dihua Street, an old street in the Dadaocheng old town area full of traditional shops, inherited the unique architectural structure from the colonial era. The pandemic's impact has turned this area from one that was once a flourishing area crowded with visitors into deserted compared to the period before COVID-19. Thus, the Taiwanese government and urban researchers have attempted to preserve the cultural and historical value while expecting architecture and urban regeneration to maintain the old and new (Chohan & Ki, 2005; Fu, 2016; Go & Lai, 2019).

The prototype used in the preliminary study was developed using Geoboxers, which is data dependent on Open Street Map (OSM), to mirror the urban structure of Dihua Street in Minecraft (Vu & Wang, 2021). Geoboxers' limitations include missing buildings due to missing data, and unrecognizable and unmatching architecture. However, it is also an opportunity for participants to pre-design for urban planning or rebuilds based on existing architecture from Google Street View, actual place observation, or their preferred version. Participants can participate in urban planning in this Minecraft world through an Aternos server. Fig. 6 provides a snapshot of Dihua Street in Minecraft digital twin. Fig. 6A reveals the original building of Yongle Fabric Market obtained from Geoboxers, Fig. 6B displays the actual building from 360-degree view of Google Street View, and Fig. 6C is the result of the building after modification using Google Street View. Unlike simulation games, where game developers provide buildings, Minecraft players must build from scratch by placing

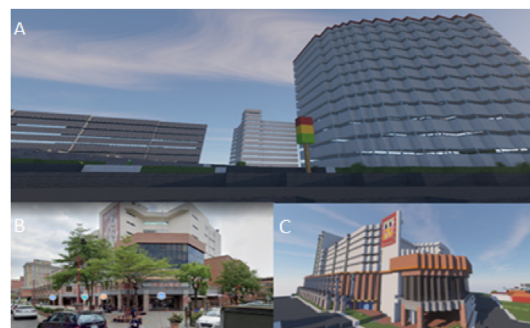


Fig. 6. The Yongle Market in the digital twin of the Dihua Street area before and after modification using Google Street View.

blocks by blocks. Fortunately, Minecraft allows modification packs and other tools to enhance the building experience and create even more detailed and complex structures. In this case, a plugin called WorldEdit is implemented for quick construction, deconstruction, and saving pre-built base models for urban planning. The result of the prebuilt models is presented in Fig. 7 with Fig. 7A displays the snapshot of the architecture within Dihua Street and Fig. 7B displays various prebuilt models using WorldEdit; the placement of the orange block defines a two-point range to store the models within a cuboid.

4.2. Analytics hierarchy progress

Using the data identified in SWOT, which mainly focuses on the ‘Strength’ and ‘Opportunities’, and enhanced with Don Norman’s three levels of emotion design theory, this study evaluates the influential factors for New Normal urban planning through a multi-hierarchy and pairwise comparison with AHP. The hierarchy structure of the influential factors to integrate the digital twin and serious game framework for New Normal urban planning is presented in Fig. 8.

4.2.1. The hierarchy structure of influential factors

Following the AHP procedure in Fig. 3, a pairwise comparison is made with the 30 participants involved to measure the priority scale. The factors are paired, such as V1 and V2, V1 and V3, and repeated until the last pair, such as R2 and R3. The scale of 1–9 unfolds in-depth user decision-making toward one-to-one comparison.

4.2.2. The priority of factors based on pairwise comparison results

Table 2 presented the consolidated data from 30 participants from the same background described in Section 3.2 to evaluate the priority vector to rank and to assess the most influential factor that motivates social interaction and urban planning in a digital twin and serious game integrated platform. Factors are ranked in prioritized order based on the impact level. Table 3 presents the normalized pairwise comparison before calculating the priority vector and organizing them in Table 4.

The consolidated data of 30 participants are calculated by the weight geometric mean by the following equation:

$$a_{ij} = (a_{1ij} * a_{2ij} * \dots * a_{kij})^{\frac{1}{k}}$$

The data in Table 2 is normalized into Table 3 using the formula: $W_i = \frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{a_{ij}} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}, i, j = 1, 2, \dots, n$

From the above formulation, the first step starts with $\sum_{i=1}^n a_{ij}$ thus: $1 + 0.68 + 1.33 + 0.38 + 1.13 + 0.73 + 0.79 + 2.39 + 0.67 \approx 9.09$

Then $\frac{a_{ij}}{\sum_{i=1}^n a_{ij}}$ thus: $1/9.09 = 0.11$ repeatedly throughout the column before $\frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{a_{ij}} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}$ of which the calculation of the first row for the matrix W_{V1} is:

$$W_{V1} = \frac{1}{9} [0.11 + 0.11 + 0.09 + 0.21 + 0.09 + 0.15 + 0.08 + 0.09 + 0.14] = 0.1197$$

As a result, the priority vector of V1 - 3D Model Similarity in the general group is 11.97%, and by repeating the calculation, the ranking of the priority vector for the other sub criteria factors are organized in Table 4.



Fig. 7. Pre-design models in Minecraft based on the actual architecture in Dihua Street, built and saved with WorldEdit plugin.

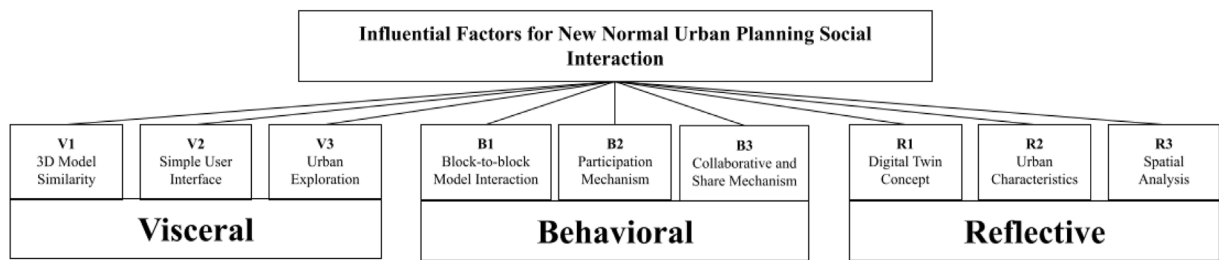


Fig. 8. Multi-criteria of the influential factors for the integration of digital twin and serious game framework for New Normal urban planning.

Table 2

Consolidated pairwise comparison of influential factors based on 30 participants.

Factors	V1	V2	V3	B1	B2	B3	R1	R2	R3
V1 - 3D Model Similarity	1.00	1.48	0.75	2.66	0.89	1.37	1.27	0.42	1.49
V2 - Simple User Interface	0.68	1.00	0.50	1.11	0.55	0.65	0.99	0.31	1.01
V3 - Urban Exploration	1.33	2.02	1.00	1.12	1.32	1.05	1.71	0.63	1.06
B1 - Block-to-block model interaction	0.38	0.90	0.89	1.00	1.08	0.63	2.50	0.35	1.00
B2 - Participation Mechanism	1.13	1.81	0.76	0.93	1.00	0.91	1.39	0.46	1.00
B3 - Collaborative and Share Mechanism	0.73	1.54	0.96	1.58	1.10	1.00	2.09	0.45	1.66
R1 - Digital Twin Concept	0.79	1.01	0.58	0.40	0.72	0.48	1.00	0.31	0.78
R2 - Urban Characteristics	2.39	3.23	1.58	2.90	2.19	2.22	3.25	1.00	1.82
R3 - Spatial Analysis	0.67	0.99	0.95	1.00	1.00	0.60	1.29	0.55	1.00

Table 3

Normalized pairwise comparison of influential factors.

Factors	V1	V2	V3	B1	B2	B3	R1	R2	R3
V1 - 3D Model Similarity	0.11	0.11	0.09	0.21	0.09	0.15	0.08	0.09	0.14
V2 - Simple User Interface	0.07	0.07	0.06	0.09	0.06	0.07	0.06	0.07	0.09
V3 - Urban Exploration	0.15	0.14	0.13	0.09	0.13	0.12	0.11	0.14	0.10
B1 - Block-to-block model interaction	0.04	0.06	0.11	0.08	0.11	0.07	0.16	0.08	0.09
B2 - Participation Mechanism	0.12	0.13	0.10	0.07	0.10	0.10	0.09	0.10	0.09
B3 - Collaborative and Share Mechanism	0.08	0.11	0.12	0.12	0.11	0.11	0.14	0.10	0.15
R1 - Digital Twin Concept	0.09	0.07	0.07	0.03	0.07	0.05	0.06	0.07	0.07
R2 - Urban Characteristics	0.26	0.23	0.20	0.23	0.22	0.25	0.21	0.22	0.17
R3 - Spatial Analysis	0.07	0.07	0.12	0.08	0.10	0.07	0.08	0.12	0.09

Table 4

Ranking of AHP factors.

Rank	Factors	Priority Vector
1	R2 - Urban Characteristics	22.14%
2	V3 - Urban Exploration	12.29%
3	V1 - 3D Model Similarity	11.97%
4	B3 - Collaborative and Share Mechanism	11.65%
5	B2 - Participation Mechanism	10.11%
6	R3 - Spatial Analysis	9.01%
7	B1 - Block-to-block model interaction	8.98%
8	V2 - Simple User Interface	7.23%
9	R1 - Digital Twin Concept	6.62%

4.2.3. The consistency ratio of decision-making process

The measurement of the results from pairwise comparison in the AHP is determined by the Consistency Ratio (CR), which is identified by the formula:

Table 5

Random index of analytic hierarchy process.

Size of matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

$$CR = \frac{CI}{RI} \quad CI = \frac{\lambda_{max} - n}{n - 1}$$

If the CR exceeds 0.1, the judgments are untrustworthy and need to be revised. The consistency index (CI) is calculated by finding the maximum value of Eigenvalue (λ_{max}), the random index (RI) is based on the number of factors for comparison based on Table 5. There is no reliability if the CR value is too high and the appropriate value is between 0.10 and 0.20.

$$\lambda_{max} = 9.09 * 0.1197 + 13.98 * 0.0723 + 4.47 * 0.2214 + 12.71 * 0.0898 + 10.8 * 0.0901 + 8.9 * 0.1165 + 15.48 * 0.0662 + 7.96 * 0.1229 + 9.84 * 0.1011 = 9.2405$$

$$CI = \frac{9.2405 - 9}{9 - 1} = 0.0301$$

Finally, $CR = \frac{CI}{RI}$, and based on the random index table (Table 5) since we have $n = 9$ thus $RI = 1.45$ and hence:

- $CR = \frac{0.0301}{1.45} = 2.07\% < 10\%$ so the judgments are acceptably consistent.

4.2.4. The AHP relative and absolute values

From the priority ranking in Table 4, the relative and absolute value of each factor based on the three emotional levels is calculated and presented in the hierarchy in Fig. 9.

4.2.5. AHP results analysis and discussion

From the results in Fig. 9, the priority emotional order for influencing the New Normal urban planning is, respectively, Reflective (37.78%), then Visceral (31.49%), and finally Behavioral (30.73%). From the reflective factors, the most influential factor is the “R2-Urban Characteristics” (58.63%). On the visceral, “V3-Urban Exploration” is the most influential factor, while on the behavioral, “B3-Collaborative and Share mechanism” is the most influential factor. The three most influential factors are “R2 - Urban Characteristics”, “V3 - Urban Exploration”, and “V1 - 3D Model Similarity”:

- The “R2 - Urban Characteristics” is the most favorable among the nine factors (22.14%) and the most influential factor among the reflective level. The urban characteristics are reflected in the New Normal virtual world with the digital twin principle. This similarity gives users a sense of belonging and makes urban planning and social interaction more natural.
- The “V3 - Urban Exploration”, is the second most influential factor (12.29%) and the most influential visceral factor (39.03%). Before the pandemic, users could explore their urban area and interact socially in the physical world. Due to the social distancing policy, users cannot do so as they are more often fixated at home.
- The “V1 - 3D Model Similarity” is the third most influential factor (11.97%) and the second most influential visceral factor (38.02%). Unlike the metaverse, where the digital interacts with the physical, most virtual worlds lack connection or reflection of the physical realities. Thus, the virtual world needs a digital twin to recreate the similarities between both realities to produce a sense of belonging, or a sense of presence, and a quality urban planning experience.

However, lower-ranking factors such as the “R1-Digital Twin Concept”, “V2-Simple User Interface”, and the “B1-Block-to-block Model Interaction” unfold the current issues for future development.

- The “R1-Digital Twin Concept” is a developing concept that has gained attention in recent years; therefore, not many are aware of this terminology and the differences between a digital twin and a model. Thus, this factor is the lowest (6.62%).

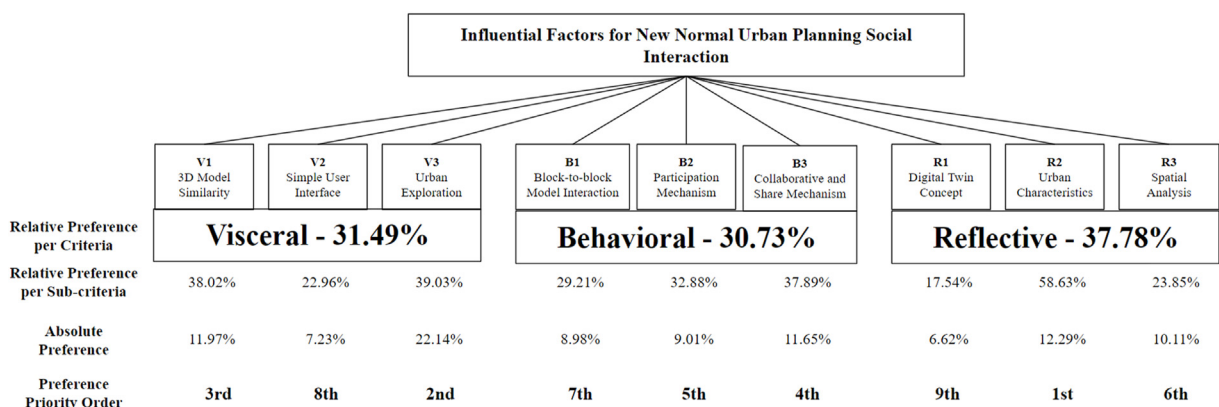


Fig. 9. Results of Multi-hierarchy of the influential factors.

- On the other hand, the “V2-Simple User Interface” (7.23%) is based on Minecraft's in-game interface. The simplicity allows a great view of the whole virtual urban area, but it misses specific guidelines and information at once. Compared to the computer interfaces where users can navigate and click, most of Minecraft's interface requires keyboard inputs and programming-like prompt commands. Before exploring virtual urban areas and performing urban planning, spending time to explore and memorize the interface feature negatively influences the experience of urban planning and social interaction.
- The “B1-Block-to-Block Model Interaction” is based on Minecraft's gameplay as a feature for virtual urban planning and social interaction. However, although Minecraft's popularity is among the younger groups, users unfamiliar with it and used to the GIS system would not find this factor influential (8.98%).

4.3. Discussion

In this study, although a SWOT is implemented to identify the preferred influential factors for urban planning and social interaction after the pandemic, only ‘Strength’ and ‘Opportunities’ factors are extracted without any factors provided by weakness and threats. The reason is to allow a positive and proactive perspective. During the focus group categorization, participants can focus more on promising influential factors of digital twins and serious games in post-pandemic urban planning. However, based on the framework proposed by Askarizad and He (2022), where emotion plays a role in post-pandemic urban planning, the influential factor is categorized into the corresponding Don Norman emotional level of design. As a result, the evaluation in AHP is more focused on the emotional level. Nevertheless, SWOT is a valuable tool for identifying factors for decision-making, and it has been evidenced in multiple literatures (Mobaraki, 2014; Khatri & Metri, 2016; Rajput et al., 2021; Saha & Paul, 2020; Solangi et al., 2019). The analysis of ‘Weaknesses’ and ‘Threats’ in this study revealed the critical negative perspective, which should be good references for similar system development, but will need further investigation in the future study.

On the urban system prototype, SWOT-AHP has been applied in a participatory planning study by Margles (2010). The upcoming digital platform for participatory urban planning should consider such a feature for voting on the most influential factors and making immediate analysis for more prioritization and advanced planning. A similar feature has been proposed by Korsgaard and Brynskov (2014) by referring to the flaws or errors in the urban space as “bugs” from a software development perspective. This implementation has led to a consideration of the urban flaw report feature in the next stage of prototype development and that the application of the digital twin should suffice as evidence for validating the legitimacy of the reports before forwarding them to city services. More details of the prototype system developed in this study and the digital twinning process are presented in the other literature (Vu & Wang, 2021). Compared to the Herrenberg Town and Zurich City cases, the digital twin process might not be as extensive, but the prototype provides participants with more immersion and control as a game with digital twins. The previous study is more focused on evaluating satisfaction with game features for serious game design with minimum urban planning integrated and more on architectural modeling. Additionally, the significant feature revealed from the previous study was the ability to use “Output device control to move in the virtual world”, similar to the current study's second most influential factors-urban exploration. Referring to the metaverse and web 3.0, which are introduced for the next iteration of the post-pandemic system, a digital system that can simulate the majority of the physical reality and that users of such system can explore effortlessly should facilitate participatory planning. Consequently, a collaboration between game designers and urban planners is expected in the next stage of the New Normal, where both can contribute the strengths and expertise from each field.

From the emotional design for serious game and post-pandemic urban planning perspective with digital twin, AHP results that urban characteristics rank first (22.14%), followed by urban exploration (12.29%), and then 3D model similarity in third (11.97%) in line with two previous pieces of research. The first is about the simulation of urban pedestrian walking, and observation of the urban environment is required to develop a sense of belonging (JannatPour et al., 2018). The other states the importance of digital twin accurate reflection and mirror of a multi-physical model, which in this case is the urban environment (Wu et al., 2020). In addition, the 3D model similarity could imply a more preferred trend that involves modeling skills, knowledge, and presentation in 3D and beyond 3D in the digital transformation era in the New Normal. Additionally, the least influential factors, such as the digital twin concept (6.62%), the simple user interface (7.23%), and the block-to-block model interaction (8.98%), do not imply total rejection. However, participants raise the question of awareness and understanding of digital twins, which is similar to the study to distinguish between a model and a digital twin (Wright & Davidson, 2020), the serious design of the urban game interface for urban planning without discomfort, and other alternative urban planning interactions in the virtual worlds.

Overall, the integration of digital twin and serious game framework for the New Normal urban planning results in a component of a social-urban platform with a 3D model of the architecture and urban structure similar to the physical reality, which encourage urban exploration and collaboration and sharing between participants. Comprehensively, in addition to the visual elements of digital twins that generate relationships and a sense of belonging to urban areas, it also generates rationalization of the experience in urban areas of the previous normal. Consequently, by combining the two frameworks for post-pandemic urban planning (Askarizad & He, 2022) and the emotional, serious game design (Baharom et al., 2014), the digital twin raises the importance of surroundings awareness for effective urban planning to detect and prevent problems towards the upcoming challenges in the New Normal.

5. Conclusion

The findings of integrated digital twin and serious game for New Normal urban planning and social interaction are revealed in the AHP results, where urban characteristics (22.14%) become more aware as the first influential factors for social interaction and urban planning, followed by the attractiveness of urban exploration (12.29%), and 3D model similarity (11.97%) as the third factor. On the

other hand, the least influential factors, such as the concept of digital twin (6.62%), simple user interface (7.23%), and block-to-block model interaction (8.98%), require further investigation in future studies to raise awareness of digital twin through video games and proper design of a virtual urban interface. The original intention of adopting SWOT was to identify the influential factors from a macro-view perspective; therefore, the analysis of AHP does not provide information on SWOT but rather from the perspective of Don Norman's emotional design theory. However, future development of a similar prototype can be referred to the SWOT analysis, and 'Weaknesses' and 'Threats' should be considered for handling solutions and alternatives. The limitation of the prototype developed with Geoboxers in this study requires a better strategy to encourage the contribution of data to the OSM before generating the digital twin of specific urban areas. Geocraft is also applicable for generating an urban digital twin in Minecraft for UK residents. Thus, its global implementation would require gamers with an expert computer science background to modify Geocraft to extend its application globally.

Digital twin technology has indefinite potential with proper data integration to recreate an accurate presentation of the urban environment, while gaming engines and systems enable more responsive and dynamic interaction beyond the presentation of the digital twin. Through the two case studies of Zurich City and Herrenberg Town, an urban digital twin prototype involves a complex technical process, while further promotion is required to encourage public participation to contribute to their urban planning. Thus, recreating the urban environment in a game with a serious urban planning context is simpler and more fitting to increase motivation and encourage participation, considering that the digital transformation has brought resilience in the post-pandemic scenario. Additionally, the combination of the digital twin and serious game allows moving into a new system that requires collaboration between game designers and urban planners to integrate capabilities from the previous and the new normal. More dynamic and immersive can be gained from virtual urban environments enabling new possibilities for new urban design and planning techniques in the future.

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