**Developing a User Perception Model for Smart Living: A Partial Least Squares Structural Equation Modelling Approach**

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**Abstract**

Smart living is highly advocated to improve the quality of life by involving original and innovative solutions. This trend has been jointly driven by policymakers and domain specialists such as urban planners, property developers, and computer engineers. However, little attention has been paid to understanding the perception of the actual users, whose opinions should have been considered in the design and development of smart living systems. To address the gap, this study aims to investigate the user perceptions towards smart living by adopting an exploratory sequential quantitative research method. A user perception model is proposed based on a comprehensive literature review. Using smart student residence as an example scenario, 221 valid data was obtained through open-ended questionnaires, which were then analysed using a partial least squares structural equation modelling approach. This approach analysed the complex relationship among the identified latent dimensions in realising smart living based on the users’ perceptions. The finding demonstrated four significant dimensions to consider in realising smart living: system-to-user conditions, system-to-system conformity conditions, safety and service-related conditions, and tracking and monitoring-related conditions. The proposed model explained 78.3% of the variance in realising smart living for the users considered in the study’s context. The study makes a unique contribution to the knowledge body by proposing a model to understand smart living from users’ perspectives. It reflects the increasing clamour to incorporate user perspectives into the design of smart living systems. The developed model could serve as a decision-support tool to fulfil users’ expectations of smart living.

**Keywords:** Smart living, Intelligent/smart building, User perception, Technology acceptance, Human-centred design, Partial least squares structural equation modelling (PLS-SEM).

**1. Introduction**

It is projected that the global population will reach 8.6 billion by 2030, among which more than 60% are urban residents [1]. With such a large population swarming into cities, maintaining people’s quality of life while sustaining the cities’ competitiveness becomes a notable challenge. Smart living, as a critical ingredient for smart city [2], is a highly advocated solution to this challenge. Intille [3] defined smart living as an idea to integrate technology with humanity, which has been promoted in the architecture, engineering, construction and operations (AECO) sector for achieving smartness in buildings. Based on Intille’s [3] definition, the European Commission (EC) [4] considers smart living as the involvement of original and innovative solutions to make life in buildings more efficient, more controllable, economical, productive, integrated, and sustainable. This is closely linked with the idea of smart buildings where digital technologies, such as the Internet of Things [IoT], artificial intelligence [AI], big data, cloud computing, digital twin, etc. are implemented in buildings [5-9], allowing buildings to become people and environment-friendly [10]. The EC’s [4] definition embraced the functionality and the technologies adopted; hence, followed by this study. The global advancement of smart living in a specific context enables the development of new types of products adapted to the specifications and needs of its occupants during operations and maintenance (O&M). This paradigm shift has pushed the construction managers, operators, and facility managers to upscale their domain and capabilities by encouraging the adoption of emerging digital technologies to meet the dynamic taste of users in buildings [10]. Extending EC’s [4] definition, smart living in the context of buildings at the O&M phase can be described as innovative, quicker, economical, and sustainable methods that aim to make life more efficient, controllable, cheaper, productive, and productive integrated, and sustainable.

The AECO industry and academia have been pushing forward smart living jointly. Many studies have reported on innovative proposals and industrial works on smart living in buildings through laboratory works and experiments, case studies, etc. For instance, Lee et al. [11] reported on developing smart living technology in Taiwan by integrating technologies with the Taiwan culture. From a design perspective, Kymäläinen et al. [12] presented a co-design and development process for a home control system in a healthcare ecology for older people accessing care home services. Apanaviciene et al. [13], from a smart building and city concept, explored the smart building technologies to enable smart living. Other studies have also focused on smart living limited to technology from different perspectives, including energy management systems, green building systems, indoor environmental quality, etc. [14-17]. These are achieved depending on the effective collaboration between the AECO industry and academia, resulting in a great effort to create the awareness, knowledge, understanding and experience in smart living across different perspectives.

Despite the progress achieved, the efforts are mainly made by domain specialists, aiming at designing and implementing smart living from the top down. While this approach has played critical role in the development of smart living, attention also needs to be paid to understand users’ perspectives on smart living from the bottom up. Here, we refer to user perception as the measures of perceived usability and degree of understanding of smart living applications by the users [18]. By involving users, professionals find direct data and information from them, understand their needs and help them have an initial understanding of the smart living systems [19]. Existing studies have developed approaches to understanding user perception from different perspectives in buildings. For example, Leaman and Bordass [20], Leaman et al. [21] and Bird and Field [22] considered users’ perceptions from the perspective of green buildings and sustainable buildings. However, they did not specifically focus on smart living in smart buildings defined by this study. Nikou [23] explored the relationship between the determinant factors influencing users’ intentions for smart living. The author argued that multiple factors impact users’ perception and adoption decisions toward smart living; however, the study was limited to the influencers of the adoption decisions rather than listing the smart features available to users to understand the function of a smart facility. Sultan and Yusuf [24] also discovered users’ perceptions of smart homes and their interactions with the technologies. The authors listed the aspects that smart home technologies providers must consider for owners to be comfortable but did not tend to receive actual viewpoints from the users on their choices for smart living. The International Organization for Standardization (ISO) [25] stipulated the consideration of building context and users’ perception in designing an interactive building system to achieve smart living following the established guideline: ISO 9241-210. Though it mandates designers to know the users’ needs in an interactive building, it is still challenging. Other studies have also considered the inclusiveness of users’ perceptions of smart living from different perspectives [25-28]. Though existing studies have touched on the user’s perceptions, a comprehensive model to understand how users define and desire smart living in buildings is still missing and unclear on a contextual basis.

Based on existing body of literature, this study aims at investigating users’ perception and the occupants’s expectations on smart living in buildings. It considers the specific context of a smart student residence yet to be constructed in Hong Kong. To do that, the study identified and categorised the users’ expected smart living conditions/requirements in buildings using partial least squares structural equation modelling (PLS-SEM) supported by literature and other analytical tools. The PLS-SEM estimated the complex relationship among the identified latent dimensions in predicting smart living based on the users’ perceptions [29]. This study provides useful insights on user perception for policy makers and industrial practitioners to consider when designing and constructing smart living systems (e.g., smart student residence). The paper is structured as follows: Following this introductory section, relevant studies in the knowledge domain are reviewed in Section 2; Section 3 presents the research methods; Section 4 narrates the results and findings; Section 5 discusses the results; Section 6 deliberates on the practical and theoretical implications; and lastly, section 7 concludes on the study.

**2. Smart Living**

Smart living has become a buzzphrase in recent years, and many countries are promoting the idea as one of the six elements of smart cities; others include smart environment, smart economy, smart government, smart people, and smart mobility [2]. Intille [3] related the smart living concept to integrating technology into humanity, while the EC [4] defined smart living as original and innovative solutions that make life in buildings more efficient, controlled, inexpensive, productive, integrated, and sustainable. The smart living notion integrates technology into humanity to enhance human efficiency in human activities and building performance through the building lifecycle phases. This popular notion raises standards in daily life, including the home, workplaces, construction sites, and how people travel within cities [11]. This links the idea of smart buildings where digital technologies are implemented, allowing buildings to become people and environment-friendly [10]. This study follows the definition by EC [4], as it embraces the functionality and the technologies adopted. Hence, smart living in the context of buildings at the O&M phase can be described as innovative, quicker, economical, and sustainable methods in buildings that aims at making life more efficient, controllable, cheaper, productive, integrated, and sustainable.

The origin of smart living is technology-driven, and this is recognised at the O&M phase depending on the adopted smart building technology, functionality, and purpose [30,31]. For instance, King and Perry [15] identified smart building technologies, including automated controls, networked sensors and meters, advanced building automation, data analytics software, energy management and information system, and monitoring-based commissioning. These technologies were noted to improve the building performance, focusing more on setting up the systems. Hoy et al. [16] highlighted the smart technologies combing energy efficiency, networked sensors, and data recording in building in exciting ways. They asserted that modern buildings could adjust light, heating, and cooling output to maximise efficiency, provide better physical security, and improve wayfinding for occupants. Other studies have considered integrating smart technologies into buildings for improved performance [32,33] toward the smart living concept. Therefore, it is important to note that throughout this study, the terms “building” and “smart building,” unless otherwise mentioned, are used synonymously.

Smart living promotion in AECO has made buildings undergo a digital transformation from traditional buildings to automated buildings to smart buildings, thereby achieving a massive digital transformation [15,34]. These depict that users and facility managers are smartly connected to buildings, which could increase the accuracy of decision-making from data [35]. Hence, making buildings adaptable and responsive to the dynamics of users’ needs [36].

There is a paradigm shift from a solely expert-based form of smart living in building to a complex form that incorporates users’ perceptions in the design of buildings. User perception goes back to the 70s when Yi Fu Tuan studied environmental perceptions and attitudes [37]. Taking a wider view, users’ perceptions of buildings have been related to different perspectives. For instance, from a green building perspective, Leaman and Bordass [20] explored how the users perceive the green building as better. The author’s findings pointed out improvements in some areas, such as how the users’ needs are met, but the green buildings were found in danger of repeating past mistakes, particularly if the users find it challenging to manage. From a sustainable building perspective, Baird and Field [22] analysed the users’ overall perceptions of thermal comfort conditions, such as temperature and air quality in sustainable buildings. The results indicated a good degree of user satisfaction with internal thermal comfort conditions when attention is given to the design and operations whilst considering the user perceptions. However, according to EC [4], Chen et al. [5] and Bolchini et al. [10], smart living in smart buildings takes a distinct stance from the other perspectives, so as its users’ perceptions.

In this study, it is worthwhile to appreciate the user-centred theory since the smart building supports the activities it shelters, including the user [38-40]. The user-centred theory was originally coined by Donald Norman, a cognitive science researcher, as a design decision based on the needs and wants of users [41]. The theory uses support for users’ needs and activities as a measure of effective smart living; hence assumes that inadequate support for users constitutes a negative situation with an adverse effect on the users’ satisfaction and comfort [42]. As a result, the user-centred theory in this study denotes that users and their related activities and needs in smart buildings should be at heart during the design of smart living in smart buildings.

Buildings can provide comfort and efficiently respond to occupants’ needs via smart living systems [27] if the users’ perceptions are considered. Previous studies have touched on the user’s perceptions of smart living in smart buildings [23,24,26-28]. However, a comprehensive model that considers context to know and comprehend how users define and desire smart living in buildings is still lacking. This study, therefore, reviewed desk literature to explore the potential smart living conditions across different fields (Appendix S1). The knowledge gap uncovered revealed that though smart living conditions were estimated to occur in the building, it does not necessarily guarantee the users’ comfort and satisfaction. Therefore, users will be given a potential list of identified conditions to guide their choice of smart living in buildings. This will help understand the users’ perceptions that could be integrated into the design and construction of smart living in buildings. The potential smart living conditions were noted to relate to the users’ comfortability and the processes in a building environment to ensure user satisfaction.

**3. Research method**

The method of this study is informed by ISO 9241-210 [25], which settles on the ergonomics of human-centred interactive design such as smart living systems. It provides the requirements and recommendations for human-centred design principles and activities throughout the lifecycle of computer-based interactive systems. This is intended to be used by those managing design processes and is concerned with how software and hardware elements of interactive systems can improve human-machine interaction. This study aligns with the notion stated explicitly in the ISO 9241-210 that the design of an interactive system to achieve smart living is based upon a clear understanding of the user’s needs, tasks, and environment.

The PLS-SEM approach is adopted in examining the users’ perceptions concerning smart living conditions in buildings, and it is proven to be successful in other domains in different contexts, including operations management [43], hospitality, and tourism [44] etc. It measures and analyses the significant relationships between the observed and the latent variables following the five logical steps: specification, identification, parameter estimation, model evaluation, and model modification [29]. This study meets the PLS-SEM criteria, including the exploratory stage of the study for smart living prediction based on users’ perspectives and the formative and reflective relationship nature of the anticipated model [45]. This follows three main steps: a literature review, an open-ended questionnaire survey, and data analysis (see Figure 1).

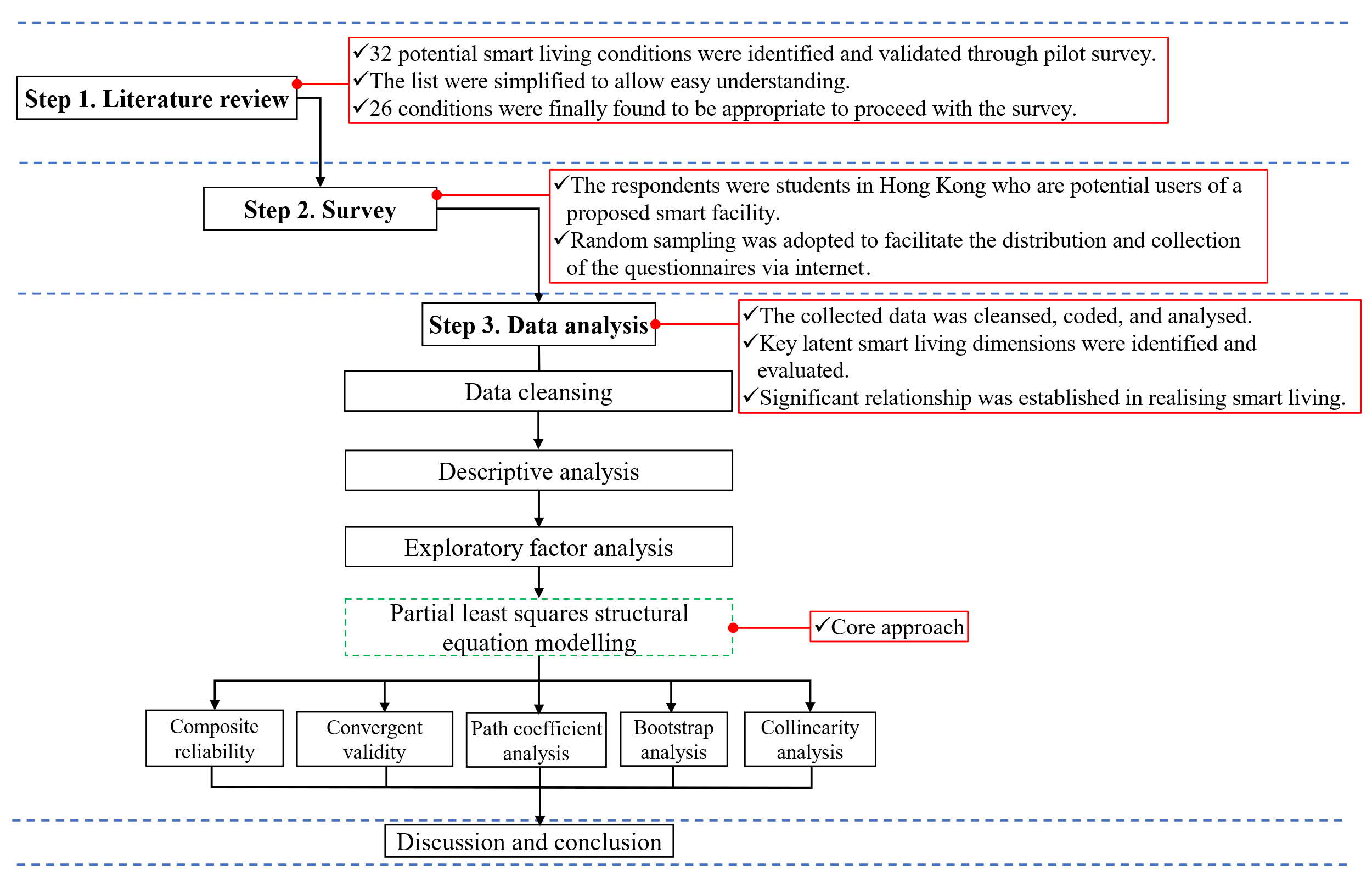


Figure 1: Flowchart of the research method

***3.1 Identifying smart living conditions by literature review***

The study conducted a literature review to identify thirty-two potential smart living conditions/requirements in buildings, as shown in Appendix S1. The potential list was filtered and validated in a pilot study that included designers, facility managers, and academicians. Twenty-six conditions were found appropriate to proceed with the survey (Table 1) as some conditions were merged, whilst others were removed due to repetition.

***3.2 Collecting user perception by questionnaire survey***

As approved by ISO 9241:210, a survey can be used to collect the users’ requirements though it may come with a limitation. As a large response is needed for this study, a survey is appropriate to get perceptions from many students.

The survey was conducted online using *“Qualtrics XM”* [46] by contacting University of Hong Kong (HKU) students to rank the importance of the potential smart living conditions in smart students’ residences using the Likert scale: “11-not important all”, “12=slightly important”, 13= “moderately important”, 14= “very important”, and “15= extremely important”. It also encouraged the respondents to make inputs aside from the variables stated in the questionnaire. The online questionnaire link distribution was made available to the huge student population of HKU [47] using the *“university’s mass email delivery system”*. With simple random sampling in mind, each student had an equal chance of responding to the online survey, following the minimum sample size of 100 proposed by Kock and Hadaya [48]. The duration for the data collection lasted for almost a semester (from 1 October 2021 to 31 December 2021). This paved the way for the study to take more data as much as possible. Reminders were also sent to students prompting them to respond to the questionnaire.

***3.3 Analysing the data by*** ***statistical modelling***

First, data cleansing was done to remove double/repeated responses and uncompleted questionnaires. This was detected due to double email addresses appearing in the data. To deal with the double responses, the study accepted the old response and removed the latest response. Descriptive statistics, including means score, was then calculated for the constructs at a 95% confidence interval. The data’s normality was assessed using kurtosis and skewness. The Kruskal-Wallis test (KWt) was also employed to see if the respondents’ educational level influenced the pattern in which they ranked the variables at a 95% confidence level.

Second, exploratory factor analysis (EFA), using IBM Statistical Package for the Social Sciences (SPSS) version 26, was adopted to uncover the underlying dimensions of the study’s large number of variables (more than 20) in the questionnaire and reveal the latent dimensions of the smart living condition as perceived by users [49].

PLS-SEM was lastly adopted using SPSS-AMOS software (version 24) by following the criteria: (1) the outer loadings of a measurement item on its associated construct ≥0.3 [50]; (2) Composite reliability (CR) ≥0.7 [51]; and (3) the average variance extracted (AVE) value of the construct ≥0.5 [52]. Path coefficients of the structural model were determined using partial least squares algorithms, as well as their significant levels utilising bootstrapping analysis [53], suggesting a significant path at P ≤0.05 at a 95% confidence level. To avoid multicollinearity problems, the variance inflation factor (VIF) among the predicting constructs in the structural model was determined. A VIF value <5 signifies the absence of multicollinearity issues [54]. The coefficient of determination (R2) of the endogenous constructs was estimated to indicate the amount of variance that the predicting construct can explain.

Table 1: Potential Smart Living Conditions After Piloting

|  |  |  |
| --- | --- | --- |
| **Code** | **Potential smart living conditions** | **References** |
| SL1 | Ability to interact with user and environment effectively. | [55-57] |
| SL2 | Ability to effectively collect, transmit and exchange building services data. | [58] |
| SL3 | Capacity to effectively interact with all elements in the system (processor, devices, and cloud services). | [59] |
| SL4 | Capability to adapt in real-time to changing environment interaction. | [60,61] |
| SL5 | Ability to be responsive to users’ needs. | [57,62] |
| SL6 | Detect and analyse users’ behaviour patterns to space utilisation. | [63] |
| SL7 | Ability to identify and check users’ identities in just a few seconds based on collected historical data. | [64,65] |
| SL8 | Apply and utilise all accessible information and understand how it impacts user wellbeing and productivity. | [57,61,62,66,67] |
| SL9 | Ability to identify contextual elements such as meaning, syntax, time, location, and user’s profile. | [64,65] |
| SL10 | Ability to detect falls and accidents and send emergency rescue signals. | [57,65] |
| SL11 | Track, predict, monitor, and control the behaviour of users, state of building components, and defects in buildings in real-time. | [61,64] |
| SL12 | Visualise and monitor in real-time the energy and water usage. | [68,69] |
| SL13 | Tracks and minimise energy usage and save operation cost in real-time. | [56,69] |
| SL14 | Track and optimise material usage in real-time. | [68] |
| SL15 | Provide real-time safety and security. | [60,61,62] |
| SL16 | Ability to ensure smart door’ opening and locking’ and active emergency response service. | [61,70] |
| SL17 | Effectively manage building service documents. | [68] |
| SL18 | Ability to protect personal data and information privacy. | [71] |
| SL19 | Ability to provide a convenient and reliable system to achieve users’ goals of wellbeing and productivity. | [62] |
| SL20 | Capability to provide flexible automation system in its operation without complexity. | [70] |
| SL21 | Predict to achieve proper maintenance of heating, ventilation, and air conditioning (HVAC) systems. | [57,66,67] |
| SL22 | Effectively measure environmental conditions such as temperature, humidity, and indoor air quality. | [57,62] |
| SL23 | Remember previous interactions in a process and return suitable information. | [63] |
| SL24 | Make effective autonomous decisions for the user. | [61] |
| SL25 | Ability to provide efficient feedback to ensure effective space optimisation. | [57] |
| SL26 | Ability to ensure effective schedule management and provide daily life information such as weather. | [57] |

**4. Results and findings**

***4.1 Sample characteristics***

The study received two hundred and twenty-one (221) responses from students in Hong Kong. As a rule of thumb, a response of 100 and above provide an acceptable margin of error [48,72]. The distribution of respondents is shown in Table 2.

Table 2: Overview of research respondents

|  |  |  |
| --- | --- | --- |
| **Item** | **Group** | **Frequency** |
| Gender | Male | 96 |
| Female | 125 |
| Educational level | Undergraduate | 97 |
| Taught postgraduate | 47 |
| Research Postgraduate | 77 |
| Type of Residence | University residence | 84 |
| Residential building | 127 |
| Chinese house | 1 |
| Village house | 4 |
| Other | 5 |

***4.2 Descriptive statistics***

Table 3 shows the absolute values of skewness and kurtosis, which indicate that the data does not unduly deviate from the normal distribution. The mean rating on the variables ranged from 13.37 - 14.41 based on the Likert scale adopted. The 95% confidence intervals were shown in Table 3 as well.

The Kruskal-Wallis test (KWt) was employed to see if respondents’ educational backgrounds influenced their perceptions of possible smart living conditions in smart students’ residences. The respondent’s educational qualifications were used as “grouping variables”, while the smart living conditions were used as “testing variables”. From Table 3, the Kruskal-Wallis coefficient (KWc) suggests that only one of the smart living potential conditions was perceived differently by the respondents (P<0.05). Other conditions have their P-value >0.05. This suggests that merging all the respondents’ responses has no significant effect on the findings’ overall reliability, except for “effectively manage building service documents” (SL17), which had a P-value of 0.031.

Table 3: Descriptive statistics result

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Smart living conditions** | **Mean** | **95% confidence interval** | | **Skewness** | **Kurtosis** | **KWc (P-value)** |
| **Lower bound** | **Upper bound** |
| SL1 | 13.86 | 13.76 | 13.96 | -0.294 | -0.017 | 0.606 |
| SL2 | 13.62 | 13.50 | 13.74 | -0.377 | -0.278 | 0.960 |
| SL3 | 13.63 | 13.52 | 13.75 | -0.167 | -0.241 | 0.718 |
| SL4 | 13.95 | 13.84 | 14.06 | -0.442 | -0.346 | 0.707 |
| SL5 | 14.41 | 14.31 | 14.51 | -1.220 | 0.922 | 0.310 |
| SL6 | 13.69 | 13.56 | 13.82 | -0.670 | 0.396 | 0.613 |
| SL7 | 13.41 | 13.25 | 13.56 | -0.593 | -0.312 | 0.060 |
| SL8 | 13.71 | 13.59 | 13.83 | -0.702 | 0.746 | 0.699 |
| SL9 | 13.37 | 13.22 | 13.51 | -0.351 | -0.218 | 0.414 |
| SL10 | 14.21 | 14.09 | 14.33 | -0.892 | 0.058 | 0.740 |
| SL11 | 13.63 | 13.50 | 13.75 | -0.554 | 0.179 | 0.136 |
| SL12 | 13.76 | 13.64 | 13.88 | -0.756 | 0.390 | 0.258 |
| SL13 | 13.99 | 13.88 | 14.10 | -0.518 | -0.215 | 0.155 |
| SL14 | 13.72 | 13.59 | 13.85 | -0.555 | -0.221 | 0.972 |
| SL15 | 14.26 | 14.15 | 14.37 | -0.867 | 0.225 | 0.921 |
| SL16 | 13.86 | 13.74 | 13.99 | -0.596 | -0.203 | 0.612 |
| SL17 | 13.38 | 13.25 | 13.52 | -0.475 | 0.127 | 0.031\*\*\* |
| SL18 | 14.42 | 14.32 | 14.52 | -1.415 | 2.338 | 0.741 |
| SL19 | 14.00 | 13.88 | 14.12 | -1.096 | 1.305 | 0.802 |
| SL20 | 13.94 | 13.84 | 14.04 | -0.408 | -0.044 | 0.914 |
| SL21 | 14.10 | 13.99 | 14.21 | -1.055 | 1.700 | 0.453 |
| SL22 | 13.99 | 13.89 | 14.09 | -0.419 | -0.136 | 0.972 |
| SL23 | 13.56 | 13.44 | 13.68 | -0.387 | -0.013 | 0.898 |
| SL24 | 13.39 | 13.25 | 13.53 | -0.373 | -0.216 | 0.329 |
| SL25 | 13.54 | 13.41 | 13.67 | -0.562 | 0.133 | 0.949 |
| SL26 | 13.61 | 13.49 | 13.73 | -0.446 | 0.030 | 0.259 |

*\*\*\* Significant at a 95% confidence level.*

***4.3 Exploratory factor analysis***

The data obtained were adequate, using Kaiser-Meyer-Olkin (KMO) and Bartlett’s tests in examining the correlation between the variables [73]. From Table 4, the test revealed an adequate factor analysis of 87.1% of the collected data at a substantial significance of P<0.05.

Table 4: Kaiser-Meyer-Olkin (KMO) and Bartlett’s test

|  |  |  |
| --- | --- | --- |
| Measure of sampling adequacy using KMO | | 0.871 |
| Bartlett’s test of sphericity | Approx. Chi-Square | 3370.751 |
| Degree of freedom | 325 |
| Sig. (P-Value) | 0.000 |

*\*P-Value at 95% confidence level.*

Based on the respondents’ perception, the exploratory factor analysis (EFA) uncovered five latent dimensions which are deemed related to smart living conditions: “System-to-User Conditions (SUC)”, “System-to-System Conformity Conditions (SCC)”, “Safety and Service-related Conditions (SSC)”, “Tracking and Monitoring-related Conditions (TMC)”, and “Detection Ability (DA)” (see Appendix S2). DA was noticed to have only one observable, SL10, which relates to the observables in SSC. Due to this, the study added SL10 to SSC, making up four latent dimensions. Internal consistency was determined using Cronbach’s Alpha (CA), ranging from 0-1, of which ≥0.7 signifies an acceptable consistency [74]. The CA suggested that all the conditions contribute to the dataset’s reliability; hence, settling on the four underlying dimensions for smart living: SUC, SCC, SSC, and TMC. Also, there was an internal consistency after adding SL10 to SSC (CA=0.759).

***4.4 Partial least squares structural equation modelling***

Partial least squares structural equation modelling (PLS-SEM) is adopted to test the relationships between the identified latent dimensions and the observables related to smart living for smart students’ residence. SEM identifies the significant variable based on the magnitude of the established relationships among the variables. It comprises factor analysis, regression analysis, multiple correlations, and path analysis, making it a robust tool [52]. SEM considers the measurement error and may estimate and visualise the multiple interrelated relationships [75].

*4.4.1 Hypothetical model development*

The four underlying dimensions for smart living were shown as first-order latent variables, reflecting the observed variables. The second-order variables consisted of the formative relation of the underlying latent dimensions in realising smart living. After confirming this, the relationship between the four underlying latent dimensions was established for smart living for smart students’ residence. Based on this, a two-step approach consisting of measurement modelling and structural modelling was used, as suggested by [76]. Hence, this study’s model combined the measurement and structural models to form the initial model to be tested (Figure 2).

Diagram, schematic

Description automatically generated

Figure 2: Initial model for smart living

*4.4.2 Model testing*

From Figure 3, the reasonable reliability and validity of the measured variables were proposed as all the outer loadings were >0.3; hence considered stable. The model proved satisfactory as the four latent dimensions for smart living passed the reliability test with their CR ranging from 0.812 to 0.902, meeting the required threshold of greater than 0.7 [51]. The convergent validity test with AVE portrayed acceptable values, except SCC, which portrayed a value less than the threshold of 0.5 [52]. Due to the high values of the CR, the study regarded the model as reliable and consistent (see Table 5).

As shown in Figure 3, the path coefficient of the structural model toward smart living, which is of focus, ranges from 0.227 to 0.328, showing a relatively fair positive correlation between the latent dimensions and smart living based on the correlation threshold [77]. A significant path was revealed in the structural model for predicting smart living, as the estimated P <0.05 (see Table 5) for each latent variable using bootstrapping technique [78]. TMC was noted to have the highest path coefficient among the latent factors. Also, a positive correlation was revealed among the latent dimensions with values ranging from 0.339 to 0.862, with SUC and SCC exhibiting the highest positive correlation. The measurement model also exhibited a fairly strong positive correlation ranging from 0.379 to 0.865, showing how strong the latent variables reflect the observables. From Table 5, the outcome of the VIF values suggested the absence of multicollinearity issues. Overall, the proposed model explained 78.3% of the variance in smart living. Therefore, the proposed model (Figure 3) is introduced as a real and unique contribution of this study for guiding the design and construction of smart students’ residences for smart living.

Diagram, schematic

Description automatically generated

Figure 3: User perception model for smart living

Table 5: Maximum likelihood estimate and value of fit statistics

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Relationship** | | | **AVE** | **CR** | **P-value** | **VIF** | **R2** |
| ***Measurement model (first-order)*** | | | | | | | |
| SL1 | 🡨 | SUC | 0.594 | 0.902 | 0.016 | - | 0.457 |
| SL2 | 🡨 | SUC | 0.020 | - | 0.435 |
| SL4 | 🡨 | SUC | 0.020 | - | 0.468 |
| SL5 | 🡨 | SUC | 0.012 | - | 0.194 |
| SL6 | 🡨 | SUC | 0.009 | - | 0.473 |
| SL11 | 🡨 | SUC | 0.005 | - | 0.397 |
| SL23 | 🡨 | SUC | 0.007 | - | 0.510 |
| SL24 | 🡨 | SUC | 0.013 | - | 0.518 |
| SL25 | 🡨 | SUC | 0.016 | - | 0.536 |
| SL26 | 🡨 | SUC | 0.012 | - | 0.442 |
| SL3 | 🡨 | SCC | 0.514 | 0.864 | 0.028 | - | 0.490 |
| SL7 | 🡨 | SCC | 0.025 | - | 0.466 |
| SL8 | 🡨 | SCC | 0.013 | - | 0.582 |
| SL9 | 🡨 | SCC | 0.012 | - | 0.582 |
| SL16 | 🡨 | SCC | 0.007 | - | 0.452 |
| SL17 | 🡨 | SCC | 0.021 | - | 0.513 |
| SL10 | 🡨 | SSC | 0.300 | 0.826 | 0.007 | - | 0.144 |
| SL15 | 🡨 | SSC | 0.009 |  | 0.452 |
| SL18 | 🡨 | SSC | 0.005 | - | 0.348 |
| SL19 | 🡨 | SSC | 0.006 |  | 0.263 |
| SL20 | 🡨 | SSC | 0.006 | - | 0.320 |
| SL21 | 🡨 | SSC | 0.021 | - | 0.508 |
| SL22 | 🡨 | SSC | 0.011 | - | 0.447 |
| SL12 | 🡨 | TMC | 0.712 | 0.819 | 0.009 | - | 0.581 |
| SL13 | 🡨 | TMC | 0.009 | - | 0.748 |
| SL14 | 🡨 | TMC | 0.041 | - | 0.479 |
| ***Structural model (second-order)*** | | | | | | | |
| SUC | 🡪 | SL | - | - | 0.007 | 1.054 | 0.783 |
| SSC | 🡪 | SL | 0.005 | 1.071 |
| TMC | 🡪 | SL | 0.005 | 1.121 |
| SCC | 🡪 | SL | 0.021 | 1.088 |

*CR= Composite reliability, P-Value = Two-tailed significance level at 95% confidence level after bootstrapping, VIF = Variance inflation factor, R2 = Coefficient of determination*

**5. Discussion**

The discussion is twofold, premised upon the statistical analysis results.

***5.1 Test of the significant difference in the smart living conditions***

The only condition which differed based on the perception is the “effectively manage building service documents (SL17)”, which had a P-value of 0.031 using KWt (P≥0.05). This suggests that while users (students) are considering smart living conditions, SL17 is not a priority to their condition. Therefore, there is a need for practitioners/professionals to realise that smart living conditions depend on the context of the building, and this influences the type of digital technologies to be integrated into the building. This does not cease SL17 from being an important smart living feature, as it is evident that SL17 is an essential feature of smart living in a building, especially in a workplace setting. It ensures that documents are effectively managed [68], especially in cloud technology, where documents are protected and retrieved anytime and anywhere [79]. Hence, the expectations of the smart living conditions from the user will depend on the context (i.e., the student residential setting differs from the workplace setting and other settings).

* 1. ***The User perception model and the underlying dimensions***

Findings of the PLS-SEM showed that the twenty-six identified conditions could be categorised into four significant underlying dimensions through EFA: system-to-user conditions; system-to-system conformity conditions; safety and service-related conditions; and tracking and monitoring-related conditions. The dimensions are noted as significant pillars of this study’s user perception model for smart living regarding smart students’ residence, representing a real and unique contribution. This is strongly reliant on the user-centred theory as explained by Vischer [42]: using support for user activities as a measure of effective smart living, adequate support for users’ activities constitutes a positive situation with a positive effect on the users’ satisfaction and comfort. The user perception model for smart living, based on the study’s finding, can be described as a set of unified significant requirements from users’ perspectives capable of guiding professionals to design and develop smart living facilities to ensure user satisfaction and comfort. The model paves the way for understanding the students’ requirements for satisfaction and comfort when designing and constructing students’ residences to achieve smart living, with reference to the ISO 9241-210 in the AECO industry [25].

The underlying dimensions positively correlated among themselves whilst realising smart living at a predictive accuracy of 78.3% (see Figure 3). It is also worthwhile to understand the dynamics of each dimension as well as their relationships to the entire users’ perception model for smart living in smart students’ residences. As a result, these are discussed further.

*5.2.1 System-to-user conditions*

A dimension to realising smart living in students’ residences is the system-to-user conditions (SUC), which reflected significant observable with R2 ranging from 19.4% to 53.6% at P-values <0.05. SUC has a significant direct contribution to smart living in smart students’ residences with a path coefficient of 0.227, and it consists of conditions such as SL1, SL2, SL4, SL5, SL6, SL11, SL23, SL24, SL25, and SL26. The ability to provide efficient feedback to ensure effective space optimisation of students’ rooms, SL25, was noted to have the highest coefficient among the observables aligning with the findings from Panchalingam and Chan [80] and Yitmen and Alizadehsalehi [57] when they identified space optimisation us a vital activity in smart buildings including smart students’ residences. It requires the smart systems to efficiently interact with the students to respond to their needs, which is a critical requirement for adopting smart technological systems [81].

In parallel with this study, other studies have suggested system-to-user conditions as a requirement for realising smart living. System-to-user conditions are related to the system’s ability to smartly relate and respond to students’ conditions/behaviours without forgetting the environment and the state of the building. For instance, Langley et al. [64] asserted the need for the building system to track, predict, monitor, and control the behaviour of users and the state of building components in real-time, which is not different as expected from smart residence for students. The building’s ability to effectively interact with a student and environment is critical in ensuring better living in buildings [55]. Also, the system’s ability to adapt in real-time to the changing student’s environment is a critical feature in realising smart living in responding to the environment and user needs [60,61]. Therefore, it is important to consider the human-machine interface of smart technologies adopted in buildings to achieve ease of use of such technologies in students’ residences toward understanding human conditions and behaviour.

Supporting the findings of this study, other authors have highlighted system-to-user conditions to assist in various building activities, such as effective decision-making and space optimisations. For example, a building system’s capacity to collect, transmit, and exchange data on buildings services is crucial in ensuring smart living to assist users. From a distinct perspective, Yitmen and Alizadehsalehi [57] suggested that smart systems in buildings must provide users feedback in optimising spaces in buildings via smart monitoring and effective visualisation due to efficient interactions among the systems and users. To achieve smart living in smart students’ residences, buildings must be designed to actively interact with students toward meeting their needs without impeding the environment. This is particularly necessary as it enhances autonomous decisions for students and stores previous interactions in the buildings for their satisfaction and comfortability [61].

*5.2.2* *System-to-system conformity conditions*

System-to-system conformity conditions (SCC) exist as a dimension to ensure seamless smart living in students’ residences. This dimension was noted to reflect six observables with R2 ranging from 45.2% to 58.4% at P-value <0.05. SCC significantly contributes to smart living with a path coefficient of 0.284, comprising SL3, SL7, SL8, SL9, SL16, and SL17. The ability to identify contextual elements, SL9, popped out to have the highest coefficient among the observables. This supports the assertion by Langley et al. [64], who identified contextual identification as a critical feature of smart living in buildings. Systems, therefore, need to interact with other systems to recognise user profile, location, time, and other elements contributing to user wellbeing and productivity.

Managing heterogeneous systems in smart buildings, such as smart students’ residences, has always been elusive due to the lack of interoperability factor of the system [82]. Hence, system-to-system conformity deals with the systems’ ability to agree, understand, and interoperate with other systems regardless of their formatting type. This can cost buildings to properly define context, such as understanding students’ activities in buildings. For instance, heterogeneous systems like HVAC, digital surveillance systems, access control and fire management are significant infrastructures that shape smart living in buildings [83]. Hence, smart living is concerned with improving the interoperability among the system components integrated into the building.

The finding is consistent with other previous authors who similarly pronounced system-to-system conformity and interoperability as a dimension for realising smart living in smart students’ residences. For instance, Jahromi and Kundur [59] explained that the systems’ capacity to interact with all elements in the system is that processors, devices, and cloud services could contribute to smart living. This improves the system’s ability to identify and check students’ identities in just a few seconds based on collected data made of different formats [64]. Yitmen and Alizadehsalehi [57] argued that effective system-to-system conformity applies and utilises all accessible forms of data, understands how it impacts students’ wellbeing and productivity, and detects and sends emergency signals [65]. This can also understand context such as smart door’ opening and locking’ and active emergency response service [70]. Therefore, the findings of this study suggest that smart students’ residences must be designed and constructed to also pay attention to the system-to-system conformity and interoperability in understanding the environment and students (users).

*5.2.3 Safety and service-related conditions*

Safety and service-related conditions (SSC) is also confirmed as a dimension in realising smart living in smart students’ residences and mirrored five observables with R2 ranging from 14.4% to 67.2% at P-value <0.05. SSC is noted to significantly contribute to smart living with a path coefficient of 0.257. This dimension constitutes SL10, SL15, SL18, SL19, SL20, SL21 and SL22, with predictive maintenance, SL21, emerging as the observable with the highest coefficient. This finding is paralleled with the assertion made by Becerik-Gerber et al. [66] and Wong et al. [67] when they stated that the system’s ability to predict maintenance management of HVAC systems could be a smart living feature in buildings. The observables of this dimension were found to be aligned with safety and services, as well as being important in students’ residences as the AECO industry gears toward smart living.

Safety and services are explained by this study as the system’s ability to achieve productivity through smart living whilst protecting the privacy of students and ensuring their safety. The finding is buttressed by earlier studies, which posited safety and services as a significant dimension in ensuring smart living in buildings. For instance, Böke et al. [60] postulated that providing real-time safety and security in a building should also be considered smart living features. This is extended to protecting personal data and information privacy [71]. Yitmen and Alizadehsalehi [57] also added a predictive maintenance feature to ensure proper maintenance management of sub-systems in buildings such as HVAC systems, etc.

To improve service whilst ensuring smart living in smart students’ residences, a building can be integrated with the capability to provide flexible automation systems in its operations without complexity. Services can be enhanced by adequately measuring environmental conditions such as temperature, humidity, and indoor air quality and adjusting automatically to achieve a safe living environment for students [84], and this could attain smart living. The findings of this study attest to the fact that safety is a key consideration in attaining smart living, and this increases services if considered during the design and construction of smart students’ residences.

*5.2.4 Tracking and monitoring-related conditions*

Another dimension of smart living in smart students’ residences is the tracking and monitoring-related conditions (TMC), reflecting three observables: SL12, SL13 and SL14. These were noted with R2 ranging from 47.9% to 74.8% at P-Value <0.05; hence, regarded as a significant dimension to realising smart living. TMC is a significant contributor to realising smart living with a path coefficient of 0.328. Among the observables, the ability of the system to track and minimise energy usage and save operation cost in real-time, SL13, was noted to possess the highest coefficient. This aligns with the study by Akanmu et al. [56] when posited the ability of real-time tracking energy usage in buildings as a potential benefit of integrating buildings with smart technologies. This measure could help save operation costs in real-time if the user’s energy usage in a building is made aware [68]. Therefore, it is important to track energy usage across all systems, including electronic gadgets integrated into smart students’ residential buildings.

Tracking and monitoring-related conditions per this study is the building’s ability to smartly track the consumption performances of utilities in buildings, including energy, water, etc. [85], particularly in students’ residences whilst enjoying smart living. The study’s finding is supported by previous studies that regarded TMC as a significant dimension in realising smart living. For example, the ability of a building system to visualise, monitor and track in real-time energy and water usage is a significant smart feature in realising smartness [69]. Other studies also generalise the context by mentioning the ability to track and optimise material usage in real-time [68]. Thus, it is expected that students’ residences must be designed and constructed to achieve smartness by tracking, visualising the consumption rate of resources such as energy, water, etc., and helping students (users) to deploy effective ways to optimise resources.

**6. Practical and theoretical implications**

While seeking expert judgement in designing to ensure smart living, it is necessary also to consider the users’ perceptions in the context. The purpose of a smart building is realised if the users’ expectations of comfort and satisfaction are highly achieved. This study suggests the need to integrate users’ perceptions of smart living into the design processes by considering the specific context of use. It is important to consider other project stakeholders in the design process, not only for professionals to shape the building design but also for them to evaluate the feasibility of users’ perceptions of smart living. Hence, preventing errors and reworks from a poor understanding of smart living design.

In all, the developed users’ perception model could serve as a decision-making tool to aid designers in designing to fulfil students’ expectations in smart students’ residences, though they may require expert judgements. As a decision-making tool, the users perception model lists the requirements to understand the students’ expectations/perceptions of smart living in the smart students’ residences. These perceptions, when considered in planning, designing and construction, influence the professionals’ choices in delivering smart buildings that assure students’ satisfaction and comfort. With this, the designers can forecast and identify possible user expectations that are needed in smart residences to ensure smart living for students, including comfortable room-space temperature to suit the body temperature of students via automatic and operable sensor-based smart air-conditioning systems, as well as effective real-time monitoring, tracking and prediction for the benefits of the students without compromising the users’ security and privacy. This is realised effectively by designers understanding the requirements from the students; hence, depending on the context. As a result, the proposed user perception model can inform decisions when considering smart living in smart students’ residences in different regions. Hence, confirming the relevance of ISO 9241-210 in the AECO industry.

The study also reflects the increasing clamour for designers to collaborate with the users on the design of smart living in buildings. Due to poor collaboration, the purpose of smartness in buildings is not achieved as users become uncomfortable and unsatisfied. This results in errors and reworks on buildings to suit the new demand of users. Rather than depending on expert judgements from professionals, it is also imperative to collaborate with the facility users for their perceptions on their expectations in smart living depending on context.

In terms of considering user perceptions, this is one of the limited studies that has expressly focused on incorporating user perceptions of smart living considering the users’ perception model in the context of smart residence for students. Through the PLS-SEM approach, underlying dimensions were identified and confirmed as significant to serves as a model for realising smart living. They demonstrated the significance of smart building theory, which advocates for a building to be designed to continuously interacts among its four basic elements: places (fabric, structure, and facilities), processes (automation, control, and systems), people (users), and management (maintenance and performance). The study theoretically implies that designing a building to achieve smart living needs to involve users in a specific context, as they can list the significant conditions expected for their satisfaction and comfortability; hence, contributing to the user-centred theory of the built environment.

**7. Conclusion**

A clear understanding of the users’ perception of smart living is an important component of planning, designing, and developing smart living systems. The design of smart living in buildings has been centred around the prescriptions and expert judgements of the professionals; meanwhile, they do not usually tend to be the users of such facilities. As the demand for smart living increases, it is imperative to consider the user perceptions and expectations of smart living in buildings. Even though it is very challenging to understand the users’ requirements for smart living due to the dynamic nature of requirements from one user to another or even the same user, it still critical to consider comprehensive model representing a clear users’ requirements to influence designs based on users’ perceptions and the context of use of the building. This study adopted an exploratory sequential quantitative research method focusing on the expectations of students in smart living on a proposed smart students’ residence. After quantitative data was collected, analysis was performed using descriptive statistics, EFA, and PLS-SEM.

The findings from the PLS-SEM suggested that system-to-user conditions, system-to-system conformity conditions, safety and service-related conditions, and tracking and monitoring-related conditions are underlying dimensions to form the users’ perception model in realising smart living in buildings from the students’ perspectives, which is a unique contribution of this study. The findings are reliant on the fact that the requirements from users stand to be different from other types of users, including the office-building users, etc. For instance, in arriving at the model using the context of students’ smart residence, the study discovered that “effectively managing building service documents” is not a priority, though it is important and maybe a priority for workers in office buildings. Hence, user expectations of smart living conditions are dependent on the context of use, and building professionals, therefore, need to acknowledge that in the planning designing and development of smart living systems, taking into consideration the ISO 9241-210.

The findings of this study depict practical and theoretical implications for proactive design and construction of smart facilities to meet user comfortability and satisfaction in buildings. It provides insight into the understanding of the smart living concept from the users’ perspectives and contributes to the significance of the smart building theory and the user-centred theory of the building environment.

Mentioned earlier, this study was conducted in Hong Kong, taking into context of student residential setting. Other research could investigate the generalisability of the result to other residential contexts or workplaces by taking data from other countries in different contexts and comparing their outcomes with this study. This will help understand the regional and contextual differences in the user perceptions of smart living in buildings. Also, this study was limited to the users’ perceptions based on a context. Future research could seek expert judgements on the proposed model and apply it in a real case example to enhance the model’s reproducibility and validity.

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