**APPENDIX**

S1: A desk literature review of potential smart living conditions

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| **No.** | **Smart living conditions** | **Brief description** | **References** |
| 1 | Real-time automated monitoring and prediction of building occupancy behaviour | The real-time function is vital, based on the demands of the sensed elements, the capacity of the system, or time and event constraints. | Langley et al. (2009);Garcia and Roofigari-Esfahan (2020) |
| 2 | Component tracking and control | The building should be capable of tracking components and control in real-time in the operations and maintenance phase. This records the current state of building components to help facilitate effective maintenance. | Wing (2006); Gubbi et al. (2013); Akanmu et al. (2021) |
| 3 | Energy efficiency monitoring | Real-time monitoring of energy usage is an effective component of the building. Systems capable of visualising real-time energy usage should be implanted into the building. Artificial intelligence (AI) could also be applied to predict real-time energy usage in buildings. | Wing (2006); Gubbi et al. (2013); Akanmu et al. (2021) |
| 4 | Real-time defect detection and protection | Focusing on the geometric model of the physical building, the DT component of the cognitive architecture provides a visual and efficient way for inspection and detection. This is done by processing forms of data, such as point clouds, digital images, thermal images, and sensor data from laser scanners, cameras, thermal imaging devices, sensors, and other devices. | Jiang et al. (2021); |
| 5 | A comprehensive view of the building’s state and improved information utilisation efficiency | Visualisation feature of such building endows systems that can allow for viewing the state of buildings and retrieving and analysing improved information utilisation efficiency. This process is automated due to the system’s autonomous nature of the building. | Lucas et al. (2017) |
| 6 | Effective structural health monitoring of facilities | System function ensuring real-time structural monitoring should be implanted into the building. This can leverage the capability of the cognitive system to predict the structural behaviour of facilities. | Boddupalli et al. (2019) |
| 7 | Human-Environment-facility social interaction | Smart living in buildings needs to consider human and environmental interaction in the cyber-physical system (CPS) loop. This is because (1) human actors and environmental factors are considered important components that need to be represented digitally on the cyber side, and (2) the interaction among the CPS components, environment, and humans. Therefore, technologies need to be implanted into the building to address needs such as tracking, monitoring, and predicting human behaviour and interaction with the environment and the CPS elements. | Cai et al. (2019); Akanmu et al. (2021); Yitmen and Alizadehsalehi (2021) |
| 8 | Rapid collection, transmission, and exchange of building services data | One of the essential features of achieving smartness in the building is bi-directional data exchange between the physical world and its cyber counterparts. This is because sensors perceive and transfer data to cyberspace, and once the data is processed, the retrieved information is sent back to the physical world through actuators. | Jain et al. (2009); Morgan et al. (2014) |
| 9 | Ability to interact with all elements in the system-processor, devices, cloud services, user, and environment (Safe and interoperable smart networked systems) | Systems implanted into the building must interact with each other while creating a heterogeneous and massive amount of shared information. Interoperability platform in the interactive building remains one of the biggest challenges to the cognitive application for user wellbeing and productivity at the facility management (FM) phase. | Schätz et al. (2015); Jahromi and Kundur (2020) |
| 10 | Real-time adaptability of facility | This serves as a decisive factor for the implementation of cognitive building. This is the capability of the building to be real-time reconfigurable and has multiple alternatives to enable adoption to dynamic environments such as room temperature, thermal conditions, etc. | Böke et al. (2020); Garcia and Roofigari-Esfahan (2020) |
| 11 | Building security enhancement | Protection of personal data and information privacy in buildings should be addressed at the root of data security issues; having a system that provides transparency and secures users’ information. | Harper (2006); Wing (2006); Gubbi et al. (2013); Xu et al. (2019) |
| 12 | Assurance of reliability and convenience | The systems must interact and work flawlessly to achieve the intended goal. Reliability and convenience need to be ascertained through various approaches, including certification, regulations, and compliance with standard requirements. | Harper (2006); Xu et al. (2019) |
| 13 | The flexibility of the automation systems in the use of the facility | Flexibility should be obtained in the functionality nature of the building. It must be embedded with systems that will ensure an automated system in its operation without complexity. | Cimino et al. (2019) |
| 14 | Effective building document management | This is an important feature of the building that ensures documents are properly managed, especially in cloud technology. Documents are protected and can be retrieved anytime and anywhere. | Wing (2006); Gubbi et al. (2013) |
| 15 | Cost-effectiveness provision | The building must be integrated with components that can work to achieve user wellbeing and productivity with minimal cost. | Wing (2006); Gubbi et al. (2013) |
| 16 | Efficient logistics and material tracking | The building possesses the features to ensure efficient tracking of materials usage. This optimises materials usage towards productivity. | Wing (2006); Gubbi et al. (2013) |
| 17 | Maintenance management efficiency via predictive systems | The capability of building to predict systems assures proper maintenance of building components as preventive measures are taken to manage systems. | Becerik-Gerber (2011); Wong et al. (2018); Yitmen and Alizadehsalehi (2021) |
| 18 | Accurate detection of building occupancy pattern | Systems ensuring accurate detection and analysis of user behaviour and pattern must be needed to ensure building productivity. This is facilitated with AI applications and other cognitive application tools. | Dong and Lam (2011) |
| 19 | Effective measurement of environmental conditions of the facility | The building achieves productivity by effectively measuring the environmental conditions that affect the building and user conditions. This becomes possible due to its effective interactions with the environment and a real-time collection of data in such domain. | Wong et al. (2018) |
| 20 | Remember previous interactions in a process and return suitable information | This constitutes a knowledge database in cyberspace that is informed by cognitive computing. This knowledge consists of historical data from previous interactions, and they are dependent on making future predictions on user wellbeing and productivity. | Yitmen (2021) |
| 21 | Autonomous decision-making using reinforced learning | The capability of the building to autonomously processes raw data and provide valuable insight to humans. At this stage, a higher level of automation, such as automatic updates of building and user information, is needed. | Garcia and Roofigari-Esfahan (2020) |
| 22 | Well-deﬁned services to support various activities such as monitoring, maintenance, management, optimisation, and safety | The building must be tailored to the specific needs of the problem sought to be solved. This can be achieved by ensuring well-defined services by including a network of nodes that need processing, storage, and communication. | Cimino et al. (2019); Garcia and Roofigari-Esfahan (2020) |
| 23 | Reliable decision-making workflow | The knowledge base implanted in the building must be reliable for decision-making towards user wellbeing and productivity. Cognitive computing must provide a result capable of providing high probabilistic solutions. | Yitmen and Alizadehsalehi (2021) |
| 24 | Increasing use of spaces | Systems in buildings must interact to provide feedback that can be used to optimise spaces in buildings. Spaces in facilities can be monitored and visualised when there are efficient interactions among systems. | Yitmen and Alizadehsalehi (2021) |
| 25 | Easier problem identification in facilities | The building must be capable of visualising and identifying the problems in a physical facility. This is done by transferring data using sensors from the physical to cyberspace. The transferred data are processed and analysed, and insights are drawn using cognitive computing. | Yitmen and Alizadehsalehi (2021); |
| 26 | Automated work order management/planning | This is attained in building due to the interactive building nature of the systems. The building needs to apply and utilise all accessible information and understand how it impacts user wellbeing and productivity. | Yitmen and Alizadehsalehi (2021) |
| 27 | Enhancement of occupant’s comfort and satisfaction | The cognitive computing feature integrated into the building’s function analyses data to produce insight applicable to enhance user wellbeing and productivity. | NASEM (2016); Chen et al. (2016); Xu et al. (2019); Yitmen and Alizadehsalehi (2021) |
| 28 | Responsiveness to occupant’s needs in the facility | The cognitive computing capability implanted into the building must provide insight to enhance the value of FM that ensures user wellbeing and productivity. This is facilitated by proper interaction of the IoT data, which ingests data and loads into the database for further analysis. | Xu et al. (2019) |
| 29 | Automatic facility identity recognition | The automated system in the building must be used to identify and check an individual’s identity in just a few seconds based on collected historical data. This is facilitated by the digital shadow of the physical entity incorporated with cognitive computing. | Langley et al. (2009) |
| 30 | Occupant behaviour centred building design | The design of the interactive building is tailored to monitor user behaviour. The system augments the processes in facilities and its interactions with users and environments. It monitors the behaviour pattern of users and makes future predictions based on the data available. | Akanmu et al. (2021) |
| 31 | Mimic the ability of the human brain to learn and provide valuable insight on asset usage and current performance through learning | Systems are implanted into the building to mimic human intelligence, which helps produce results on asset usage and performance. This becomes possible due to cognitive technology integration. | Yitmen and Alizadehsalehi (2021); Yitmen (2021) |
| 32 | Identify contextual elements such as meaning, syntax, time, location, user’s profile, etc. | Contextual identification is a critical feature of the building. The system should be designed to recognise user profile, location, time, and other elements that contribute to the users’ wellbeing and productivity. It also relates significantly to physical occurrences at specific locations and times. | Langley et al. (2009); Yitmen (2021) |

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**S2: Informed consent form**

**Informed Consent form**

Dear student,

**Invitation to Participate in a** **survey**

You are invited to participate in an ongoing study by Mr Frank Ato Ghansah.

As part of our efforts to ensure smart living in a student residence, we hope to collect data based on your knowledge and experience (i.e., as a student) on what you wish to be needed in residence for smart living.

The survey would only take you about **10-15 minutes** to complete, and you can choose to terminate the survey at any time without negative consequences. I want to stress that all information collected will remain strictly confidential. Individual details will not be disclosed or identifiable from this survey.

If you have any questions about the research, don’t hesitate to contact Mr Frank Ato Ghansah (66554852)/(fghansah@connect.hku.hk). If you have questions about your rights as a research participant, please contact the Human Research Ethics Committee, The University of Hong Kong (HKU) (2241-5267).

HREC Reference Number: EA210435

**S3: The questionnaire adopted for the study**

**Questionnaire**

**PART A**

1. What is your gender?
2. Female ( ) b. Male ( ) c. Other ( ), please, specify……………….
3. What is your current level of education?
4. Undergraduate ( ) b. Taught postgraduate ( ) c. Research postgraduate ( ) d. LLB ( )
5. What type of house are you residing?
6. University residence ( ) b. Residential building ( ) c. Chinese house ( ) d. Village house ( ) e. Other ( ), please, specify……………….

**PART B**

1. Kindly rate by ticking (**✓**) the **“level of importance”** of each sub functional statement **(SFF)** contributing to the main functional feature **(FF)** in ensuring smart living condition:

**“11=Not at all important; 12=Slightly important; 13=Moderately important; 14=Very important; 15=Extremely important “**

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| **Code** | **Features** | **11** | **12** | **13** | **14** | **15** |
| SFF1 | Ability to interact with user and environment effectively. |  |  |  |  |  |
| SFF2 | Ability to effectively collect, transmit and exchange building services data. |  |  |  |  |  |
| SFF3 | Capacity to effectively interact with all elements in the system (processor, devices, and cloud services). |  |  |  |  |  |
| SFF4 | Capability to adapt in real-time to changing environment interaction. |  |  |  |  |  |
| SFF5 | Ability to be responsive to users’ needs. |  |  |  |  |  |
| SFF6 | Detect and analyse users’ behaviour patterns to space utilisation. |  |  |  |  |  |
| SFF7 | Ability to identify and check users’ identities in just a few seconds based on collected historical data. |  |  |  |  |  |
| SFF8 | Apply and utilise all accessible information and understand how it impacts user wellbeing and productivity. |  |  |  |  |  |
| SFF9 | Ability to identify contextual elements such as meaning, syntax, time, location, and user’s profile. |  |  |  |  |  |
| SFF10 | Ability to detect falls and accidents and send emergency rescue signals. |  |  |  |  |  |
| SFF11 | Track, predict, monitor, and control the behaviour of users, state of building components, and defects in buildings in real-time. |  |  |  |  |  |
| SFF12 | Visualise and monitor in real-time the energy and water usage. |  |  |  |  |  |
| SFF13 | Tracks and minimise energy usage and save operation cost in real-time. |  |  |  |  |  |
| SFF14 | Track and optimise material usage in real-time. |  |  |  |  |  |
| SFF15 | Provide real-time safety and security. |  |  |  |  |  |
| SFF16 | Ability to ensure smart door’ opening and locking’ and active emergency response service. |  |  |  |  |  |
| SFF17 | Effectively manage building service documents. |  |  |  |  |  |
| SFF18 | Ability to protect personal data and information privacy. |  |  |  |  |  |
| SFF19 | Ability to provide a convenient and reliable system to achieve users’ goals of wellbeing and productivity. |  |  |  |  |  |
| SFF20 | Capability to provide flexible automation system in its operation without complexity. |  |  |  |  |  |
| SFF21 | Predict to achieve proper maintenance of heating, ventilation, and air conditioning (HVAC) systems. |  |  |  |  |  |
| SFF22 | Effectively measure environmental conditions such as temperature, humidity, and indoor air quality. |  |  |  |  |  |
| SFF23 | Remember previous interactions in a process and return suitable information. |  |  |  |  |  |
| SFF24 | Make effective autonomous decisions for the user. |  |  |  |  |  |
| SFF25 | Ability to provide efficient feedback to ensure effective space optimisation. |  |  |  |  |  |
| SFF26 | Ability to ensure effective schedule management and provide daily life information such as weather. |  |  |  |  |  |
|  | **Others, please specify and rank appropriately** |  |  |  |  |  |
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**S4: Exploratory factor analysis result**

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **Code** | **Potential Dimensions** | **CA** | **Factor Loadings** | | | | |
| **1** | **2** | **3** | **4** | **5** |
| 1. **System-to-User Conditions (SUC)** | | **0.886** |  |  |  |  |  |
| SL1 | Ability to interact with user and environment effectively. | 0.536 |  |  |  |  |
| SL2 | Ability to effectively collect, transmit and exchange building services data. | 0.657 |  |  |  |  |
| SL4 | Capability to adapt in real-time to changing environment interaction. | 0.705 |  |  |  |  |
| SL5 | Ability to be responsive to users’ needs. | 0.594 |  |  |  |  |
| SL6 | Detect and analyse users’ behaviour patterns to space utilisation. | 0.725 |  |  |  |  |
| SL11 | Track, predict, monitor, and control the behaviour of users, state of building components, and defects in buildings in real-time. | 0.485 |  |  |  |  |
| SL23 | Remember previous interactions in a process and return suitable information. | 0.617 |  |  |  |  |
| SL24 | Make effective autonomous decisions for the user. | 0.759 |  |  |  |  |
| SL25 | Ability to provide efficient feedback to ensure effective space optimisation. | 0.548 |  |  |  |  |
| SL26 | Ability to ensure effective schedule management and provide daily life information such as weather. | 0.409 |  |  |  |  |
| 1. **System-to-System Conformity Conditions (SCC)** | | **0.860** |  |  |  |  |  |
| SL3 | Capacity to effectively interact with all elements in the system (processor, devices, and cloud services). |  | 0.495 |  |  |  |
| SL7 | Ability to identify and check users’ identities in just a few seconds based on collected historical data. |  | 0.575 |  |  |  |
| SL8 | Apply and utilise all accessible information and understand how it impacts user wellbeing and productivity. |  | 0.694 |  |  |  |
| SL9 | Ability to identify contextual elements such as meaning, syntax, time, location, and user’s profile. |  | 0.779 |  |  |  |
| SL16 | Ability to ensure smart door’ opening and locking’ and active emergency response service. |  | 0.719 |  |  |  |
| SL17 | Effectively manage building service documents. |  | 0.648 |  |  |  |
| 1. **Safety and Service-related Conditions (SSC)** | | **0.778** |  |  |  |  |  |
| SL15 | Provide real-time safety and security. |  |  | 0.681 |  |  |
| SL18 | Ability to protect personal data and information privacy. |  |  | 0.792 |  |  |
| SL19 | Ability to provide a convenient and reliable system to achieve users’ goals of wellbeing and productivity. |  |  | 0.491 |  |  |
| SL20 | Capability to provide flexible automation system in its operation without complexity. |  |  |  | 0.580 |  |  |
| SL21 | Predict to achieve proper maintenance of heating, ventilation, and air conditioning (HVAC) systems. |  |  | 0.665 |  |  |
| SL22 | Effectively measure environmental conditions such as temperature, humidity, and indoor air quality. |  |  | 0.480 |  |  |
| 1. **Tracking and Monitoring-related Conditions (TMC)** | | **0.805** |  |  |  |  |  |
| SL12 | Visualise and monitor in real-time the energy and water usage. |  |  |  | 0.789 |  |
| SL13 | Tracks and minimise energy usage and save operation cost in real-time. |  |  |  | 0.797 |  |
| SL14 | Track and optimise material usage in real-time. |  |  |  | 0.719 |  |
| 1. **Detection Ability (DA)** | | **0.841** |  |  |  |  |  |
| SL10 | Ability to detect falls and accidents and send emergency rescue signals. |  |  |  |  | 0.841 |

*CA= Cronbach’s Alpha, Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization, (Rotation converged in 9 iterations)*