A CONCEPTUAL MODEL FOR USER-CENTRED PASSIVE BUILDING DESIGN

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The integration of end user factors (EUFs) into passive building design processes is suggested to be of major importance for improving mental health and wellbeing of the building's end-user (E-U). Currently, there is a lack of a robust approach that helps the designer to integrate these factors into the design processes. There is also a need to understand what the most relevant E-U factors are and how to integrate them into passive design processes. Hence, the thesis of this work is to address this challenge by proposing a systemic conceptual E-U centred passive building design model "UCPBDM" that integrates the E-U factors into the PD strategies. The UCPBDM approach is based on ISO 13407 and ISO 9126 standards. Accordingly, we extend the theory of passive design by systemising and incorporating E-U factors. Overall, our investigation builds knowledge by extending E-U centred design theory to passive building design context and by proving a list of effective E-U factors.

Keywords: conceptual modeling, passive building design, quantity surveying, user-centred design, user factors.

INTRODUCTION

The integration of EUFs into passive design (PD) is one of the important issues currently in the build environment. The reasons behind this interest stem from the fact that the existing building design processes do not fully incorporate the EUs' needs over the life cycle of the designed building assets. This has led to dissatisfaction with the usability, reliability, performance and operation of many building assets. The need to incorporate human factors into building design is highlighted by several authors and organisations. For example, the Ministry for the Environment: Manatū Mō Te Taiao (N/A,p.3) stated *"The design team should involve future users and facilities management staff in the design process, and develop a building user's guide to inform occupants of the building's design intent"*. Noticeably this statement advocates the integration of E-Us' needs by the designer into the design requirements and specifications. The idea at this juncture is that the designer ought to meet E-U needs before the completion of the design. This is necessary because retrofitting the design at the post-construction stage to meet E-U needs will be an expensive proposition. This view is supported by other authors: *"The area that is still not covered is the research on human factors, especially the post occupancy evaluation and the reuse or recycling of building products" (*Ismail & Hokoe, 2009, p.3). The authors indicate that

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research is limited in the area of UFs, especially in relation to post-occupancy evaluation (POE). The POE theory deals only with UFs at the post-construction stage. What is needed is a process by which UFs are considered at the early stages of the building design process. It is argued that *"the greatest challenge for HF/E today is to develop a new mission of sustainable human-centred"* (Karwowski, 2007b, p.25). The author stressed the need for EUFs and ergonomics. In this statement E-U comfort forms the main pillar on which building design is conceived. Technology Strategy Board (TSB) (2009, p.4) declared that *"more expertise in human factors research and user-centred design is needed in engineering consultancies, product manufacturers, building designers, facilities management companies and others"*. The statement recognises user-centred design (UCD) as a necessary requirement throughout the process of building, construction and operation. This work totally agrees with TSB on the need to integrate UFs into PDs. This will enhance the design sustainability in terms of E-U needs and environmental considerations. Therefore this research is aimed at contributing to the endeavour of understanding how the E-U needs are fully integrated into the PD processes. Our approach is based on ISO 9126 and ISO13407 which deal with the process of user-centred design in the software industry. This research is developing a similar process for architects and designers to capture the E-U needs during the design process in a systematic way. This paper will present the conceptual User-centred Passive Building Design Model and explain its main components. The paper also reports on the preliminary results from the EUFs effectiveness assessment survey.

METHODOLOGY:

The methodology that is followed by this research is based on literature critical analysis and prototype modelling. The analysis followed by this research is based on system development methods. We have carried out our intensive literature review into UCD methods and factors in the building, engineering and IT industries. The investigation spans from 1955 to date. The literature showed that there are no coherent models in the building industry that capture the total E-U factors as portrayed in ISO standards. However, in the IT industry the theory of UCD is well advanced and developed. Thus, the extracted knowledge from literature was classified according to ISO 13407 and ISO 9126 standards. Also, these standards are developed based on system development methods. Hence, we used ISO 9126 to generate EUFs and ISO 13407 is used for developing a systematic process for integrating UFs into PD. We have extracted 132 E-U factors. The selected UFs are currently being assessed for their effectiveness in satisfying E-U needs. The next stage of this research will test the validity of one of the selected prototype models in real-world design projects.

USER-CENTRED PASSIVE BUILDING DESIGN MODEL

The proposed UCPBD is shown in Figure 1. The model is defined as “a passive design approach that places both E-U and passive design strategies at the centre of the design process for focusing architects’ mind on E-Us through the planning, design, development and operation of building assets”. As shown in the figure the model consists of four interactive processes. The model is created based on the knowledge gained from ISO standards. Each of the processes of the model is described in the following sections.

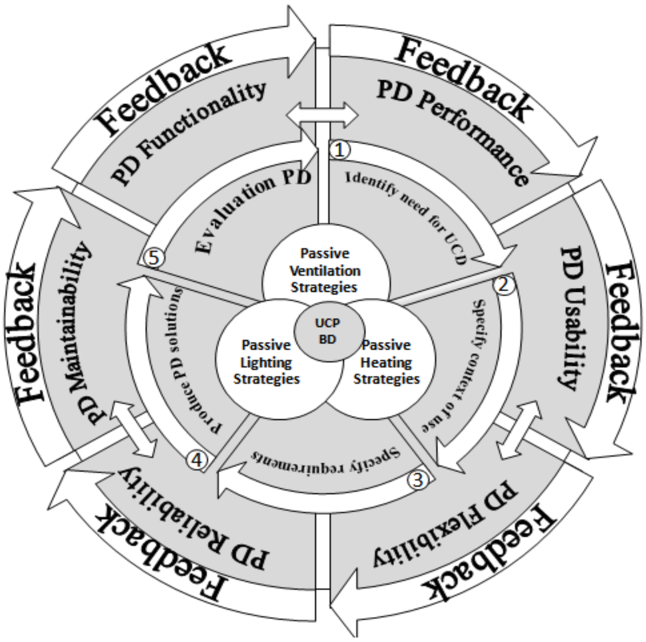

Figure 1: User-centred Passive Building Design model

6. Core PD Strategies:

PD is an approach that emerged to reduce the environmental impact by using any non-mechanical means for heating and cooling buildings. This is normally achieved through design strategies that make use of natural environment sources in a way that enhances the three dimensions of PD; that is to say, lighting, ventilation and heating (L.V.H). It is theorised that by following these design strategies it will lead to the reduction of consumption of energy and environmental pollution. The PD is based on these three main design constructs as shown in Figure 1. The PD is defined as *"an approach to building design that uses the building architecture to minimize energy consumption and improve thermal comfort. The ultimate vision of passive design is to fully eliminate requirements for active mechanical systems"* (Vancouver, 2008. p.3). Feist (2007) defined PD as *"a passive house is a building in which thermal comfort can be guaranteed by post-heating or post-cooling the fresh-air mass flow required for a good indoor air quality"*. Even though the previous definition refers to the indoor air quality and thermal comfort, these measures are considered to be part of the E-U need requirements. However, the definitions do not consider all of the E-U needs as envisaged in ISO standards. The definition of the three dimensions of PD that we adopted in this work is as follows:

Passive Ventilation (PV): This is defined as *"the introduction and/or removal of air that used both convective air flows resulting from the tendency of warm air to rise and cool air to sink, and takes advantage of prevailing winds. Many passive ventilation systems rely on building users to control their operation"* (Hotel & Association, 2010, p.30). In this definition E-Us are considered as an integral part of the passive ventilation, along with prevailing winds. This signifies that both orientation and the E-U preferences are essential construct factors in passive ventilation.

Passive Lighting (PL): This is defined thus: *"daylighting has often been recognized as a useful source of energy savings and visual comforts in buildings"* (Li & Tsang, 2008, p.1446). The statement declares that there is a need to consider the equilibrium between energy demands and E-U comfort. Daylighting is considered here as a balance between E-Us' wellbeing and energy needs.

Passive Heating (PH): The third dimension of PD is coupled with the previous two dimensions: *'thermal comfort is that condition of mind which expresses satisfaction with the thermal environment"* (Ashrae, 2004, p.4). Thus thermal comfort is dependent on how the E-U senses the surrounding environment. Satisfaction plays a pivotal role in thermal comfort of E-Us. Thermal stratification is a complex phenomenon that is based on multiple factors.

It is evident from these definitions that there is a large element of coupling between PD strategies and the E-Us' comfort. Hence, it is unimaginable that we can deliver sustainable buildings without considering the E-U needs as the main drivers for the design of efficient building assets. Thus, embedding these PD strategies with E-U needs into the design process will assist the designer to optimize E-Us' aspirations. This in turn would result in prolonging the design service life of buildings.

1- User-centred Passive Building Design Process:

The second component in our proposed conceptual model (see Figure 1) is the process by which PD strategies are interrelated with E-U needs. The process proposed for implementing this component is shown in Figure 3. The UCD theory has evolved from the software and computer science disciplines. Its main purpose is to promote the designing of software based on E-U needs. UCD is defined thus: *"User-centred design is a broad term, used to describe a design philosophy and a variety of methods in which the needs, wants, and limitations of end users are placed at the centre of attention at each stage of the design process*" (Uckelmann *et al.* 2011, p.68). Prähofer *et al.* (2002, p.1) clarified the reason for considering E-U needs thus: "users are able to customize and adapt the software systems in use to their particular needs at hand, so that they can perform their work more efficiently and effectively". As stated in the introduction, the research in this field has accumulated into ISO 13407 and ISO 9126 standards. The aim of these two standards is to help the software designers to integrate E-U needs during the software design process. ISO 13407 deals with the process that the designer needs to follow for integrating E-U needs into product design. We have adapted this process to develop our UCPBD approach. The process of this standard as cited in ISO 13407 (1999) is shown in Figure 3. Jokela *et al.* (2003) summarised the process stages 2-5 as:

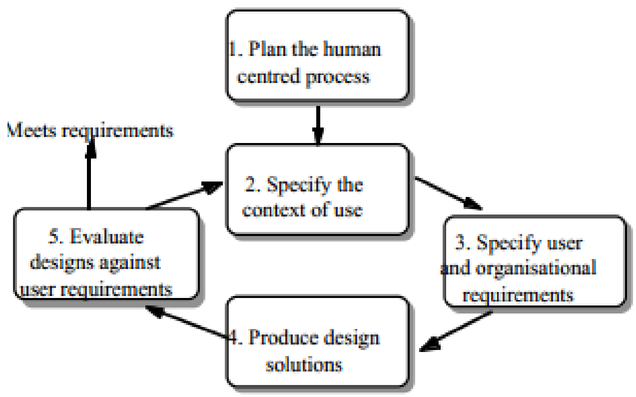

Figure 2 : ISO 13407 process (ISO 13407, 1999, p.6)

- *Specify the Context of Use*: the purpose of this stage is to identify the E-U, usage environment and the need for using the product.
- *Specify User and Organizational Requirements:* identifying the factors that can enhance E-U role to use the product without any obstacles.
- *Produce Design Solutions:* the solutions that have been suggested to fulfill E-U needs such as interaction, interoperability and portability of the product.

- *Evaluate Designs against Requirements*: answers the question to what extent the end product meets E-U needs.

We consider these stages as vital for linking between PD strategies and E-U needs aspiration. These stages are used as a foundation for our UCD process theory. The first stage is the planning stage. This stage determines the harmonisation between E-U needs and the system design components. The final stage is to evaluate generated solutions against a predetermined list of E-U aspirations. If these aspirations are not met then the designer needs to go back again to specify the context of use.

We have modified this process to reflect the special characteristics of the building design processes. The modified UCPBD process is shown in Figure 3. The process is conceived based on the assumption that the architect at all stages of the PD process will keep E-U needs in their minds. The process shown in Figure 3 is a sub-process in our conceptual model illustrated in Figure 1 (the sub-process is denoted by numerical steps, i.e., 1-5, in Figure 1). This process is divided into five main stages as shown in the following figure.

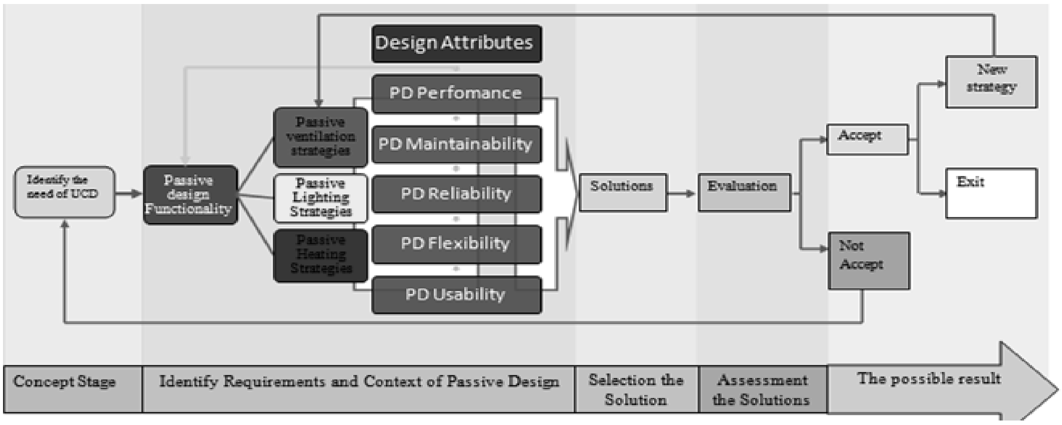

Figure 3 : User-centred Passive Building Design Process

Identify the need for user-centred design:

The main purpose of the stage is to assess whether the user-centred design approach is the appropriate route for delivering the proposed design. Normally this procedure starts at a very early stage of the design process. It is anticipated that most of this work is carried out at the concept stage as shown in Figure 3. The designer is required to identify the aspiration of the client and investigate if these aspirations can be delivered using the user-centred design method. The outcome of the stage is to set the design outline assumptions and boundaries.

Identify requirements and context of concept:

Understanding and interpreting E-U needs and design context are the main purpose of this stage. The results from the first stage are fed into this stage with a view to converting E-U needs into design solutions. PD solutions are investigated for their suitability and their functional requirements. The investigation is based on the context of use. The quest here is for the designer to elicit all E-U requirements in relation to PD strategies.

The Solution Selection:

The main purpose of this stage is to synchronize E-U needs with PD strategies. Based on the analysis from the previous stages the designers should have a list of E-U requirements and matching design solutions. To find an optimum design solution the designer needs to have access and knowledge about E-U needs determinant measures.

The challenge at this juncture is how the designer can reconcile between the conflicting demands of PD functions and the ever evolving E-U needs. It is expected at this point of time that the designer will select two or three alternative solutions that best capture E-U aspirations and integrate optimistically with PD functions.

The Solution Evaluation:

The purpose of the stage is to evaluate the selected design solutions from the previous stage. The selection should be based on pre-determined criteria and simulation results. The simulation results are from testing the design solutions in relation to E-U aspirations and PD functionality. It is expected that E-Us should be involved in the process of assessment. The results of the assessment are fed back into design strategies. It is expected that all errors etc are rectified at this stage. Beyond this point any change in the design will be costly and time-consuming.

The Possible Result:

This stage will show to what extent the designer is successful in capturing E-U aspirations and integrating them with PDs? The stage will determine if the architect meets E-U needs or not. If the selected design solution passes all of the selection criteria the solution is adopted. However, if the solution lacks in completeness the designer needs to go back to the second process to re-start the process of modifying and generating new features and requirements so that the solution will comply with the selection criteria. In the unlikely scenario that the selected solutions fail to satisfy the integration of the E-U needs with PDs, then the designer needs to go back to the concept stage to fix this anomaly and rectify the dysfunctional design solutions.

2- Passive design human attributes:

The third component of our proposed model considers the interaction between E-U requirements and PD strategies. As stated previously this was developed based on ISO 9126. This standard was developed to enhance the quality of software. It is described as "*a software product quality model, quality characteristics, and related metrics*" (Zeiss *et al.* 2007, p.2). The standard classifies E-U needs into coherent categories. There is certain similarity between the design attributes advocated by the standard and the building design performance measures. This standard includes six main attributes and their sub-attributes as shown in Figure 4.

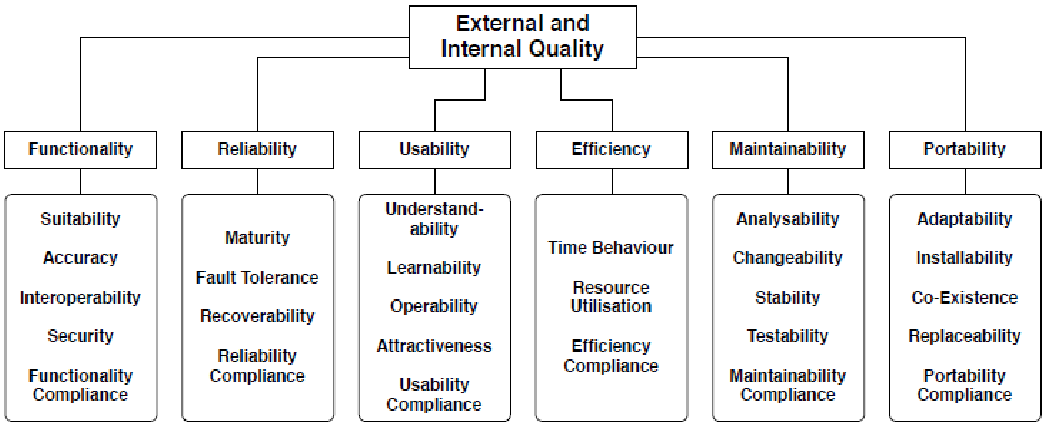

Figure 4 : ISO 9126 attributes and sub-attributes.

The main purpose of these attributes is to improve the quality of software in use. Zeiss *et al.* (2007, p.2) mentioned "*the quality perceived by an end user who executes a software product in a specific context*". The integration of E-U needs in the design of a product is the main pivotal point in this definition. Before explaining the relevance of these attributes to passive building design processes, we provide a brief definition of the attributes as envisaged in the IT industry. These are shown in Table 1.

*Table **1**: ISO 9126 design attributes definitions*

ISO 9126 Attributes	Definitions
Functionality	A set of attributes that relate to the existence of a set of functions and their specified properties. The functions are those that satisfy stated or implied needs.
Reliability	A set of attributes that relate to the capability of software to maintain its level of performance under stated conditions for a stated period of time.
Usability	A set of attributes that relate to the effort needed for use, and on the individual assessment of such use, by a stated or implied set of users.
Efficiency	A set of attributes that relate to the relationship between the level of performance of the software and the amount of resources used, under stated conditions.
Maintainability	A set of attributes that relate to the effort needed to make specified modifications.
Portability	A set of attributes that relate to the ability of software to be transferred from one environment to another.

The attributes in Table 1 are used as a base for developing our new conceptual model. We refer to them as PDHA. The researchers define PDHA as [Factors that capture the needs, wants and limitations of E-Us in relation to functionality, performance, maintainability, reliability, usability and flexibility]. We modified the attributes of efficiency and portability to be performance and flexibility respectively. This modification is necessary to reflect the characteristics of the building design process. As illustrated in Figure 5, our PDHA consists of five main attributes. These attributes are subdivided into several sub-attributes. The list of E-U sub-attributes is extracted from a literature review and case studies. In the following sub-section we provide the definition of each of the PDHA's main attributes.

Passive Design Functionality (PDF):

This attribute is defined as [A set of design determinants that relate to the existence of a set of PD functions (i.e. Ventilation, Lighting and Heating) that fulfil E-Us needs]. This driver is characterised or measured by five sub-attributes, which are (1) Site, Orientation and Vegetation (2) Building form (3) Space planning (4) Roof (5) Facade and envelope. Each of these sub-attributes is assessed by several E-U satisfaction metrics.

Passive Design Performance (PDP):

We propose to define this attribute as [A set of determinants that measure passive design functions performance under stated E-Us' conditions]. In our model, we determined seven sub-attributes for the performance driver. These are (1) Site performance, (2) Space performance (3) Thermal comfort (4) Ventilation (5) Lighting (6) Acoustic (7) Adequacy consumption and strategies. Each of these sub-attributes is composed of several E-U factors. These factors are used to assess the design performance.

Passive Design Usability (PDU):

This attribute is defined in our research as [A set of attributes that relate to operability and compliance of PD strategies to regulation standards and E-Us' operational efficiency]. Its sub-attributes are (1) Operability (2) Human behaviour. These sub-attributes are assessed by several factors that enhance the usability of building assets.

Passive Design Flexibility (PDFL):

The passive design flexibility is defined in our research as [A set of attributes that relate the ability of PD strategies to be remodelled to satisfy new use conditions]. The flexibility driver is composed of two sub-attributes, which are (1) Future adaptability (2) Flexible space. These sub-attributes are measured based on E-U satisfaction metrics.

Passive Design Reliability (PDR):

We define PDR as [A set of determinants that relate to the capability of PD functions to maintain their level of performance under E-Us' stated conditions within the design service life period]. This driver is made up by three sub-attributes, which are (1) Durability (2) Material reliability (3) Resilient. Each one of them is measured by several factors' reliability metrics.

Passive Design Maintainability:

Our definition of PDM is based on the definition of ISO 9126. PDM is defined as [A set of determinants that relate to the ease of inspecting, maintaining and modifying design to satisfy evolving E-Us' needs]. This driver has three sub-attributes: (1) Standardization (2) Material (3) Accessibility. Each one is measured by several factors which are extracted from the literature review in a way that enhances E-U needs.

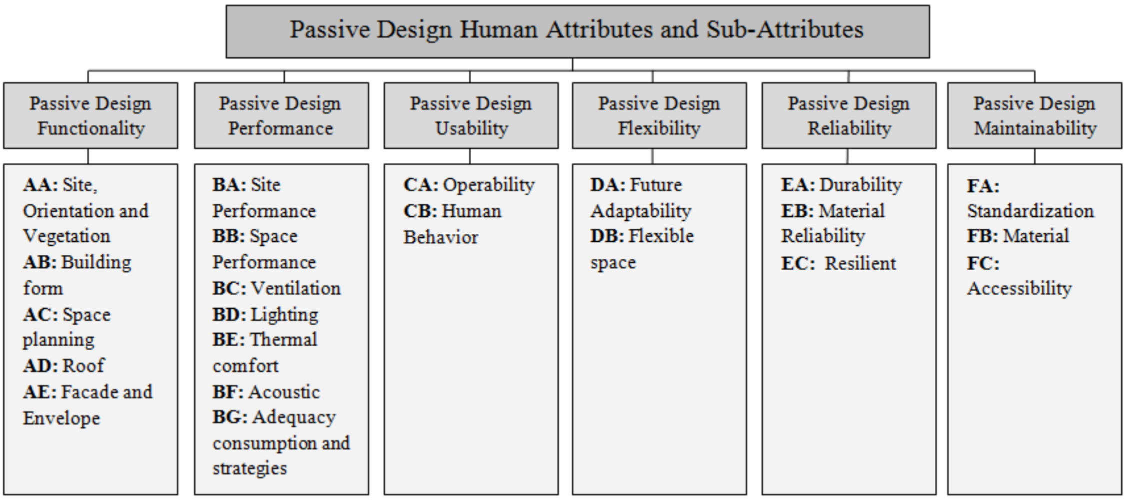

Figure 5: UCPBD attributes and sub-attributes

3- Feedback:

The last component in our proposed model is the feedback loop. The evaluation results of each generated design solution are fed back through the stages of the UCD processes. The feedback loop is considered as a dynamic process by which enabling and effectuating E-U conditions are brought together through simulation and sensitivity analysis to test the robustness of the generated design solutions. From this perspective, the designer should learn from previous E-U experiences and feed these back into future design solutions.

Before we proceed in the development of the proposed model we have to validate the effectiveness of the selected E-U factors. We are currently in the process of carrying out this assessment via a questionnaire. The following are the preliminary results from this exercise. The results are only from nine respondents. We don't consider these results at this stage of the research as statistically significant; they are reported only for illustration purposes.

PRELIMINARY RESULT

The result was extracted from the views of nine practising architects in the UK. The end product of this research is mainly aimed for designers in the building industry. Thus, architects are used as a survey instrument. Their views were sought regarding the effectiveness of the UCPBD factors. Their views are grouped under the six headings of E-U main attributes show in Figure 5.

Passive Deign Functionality:

The orientation of buildings for optimum L.V.T. measure was selected by 89% of respondents as a very effective factor. 78% of the respondents reported using the nearby landforms and structures for wind protection and summer shading as effective factors. The building form measure was chosen by 78% of the respondents as necessary for optimum V. However, in the space planning design measures, only 66.7% of architects selected the PD strategies of using central atriums, lobbies and courtyards as optimum for providing vertical air, locating central exhaust paths, organising rooms, providing a solar-oriented interior zone and linking the exterior and interior airflows for optimum V as effective factors. The roof sub-attribute is composed of several factors. 66.7% of respondents selected "Use solar roof collectors on the south-oriented surfaces" as an effective measure. Some of the facade factors, such as "Provide shading strategies doe optimum V and Use Trombe wall or double façade to collect solar gain", are also selected by 66.7% of the architects as effective.

Passive Design Performance:

In terms of the site performance, 66.7% of the designers chose "utilising views and orientation" as very effective for performance from the point of view of E-Us. The space performance factors, i.e., the adequacy of PD space available for functions/activities, were selected by 77.8 % of the respondents as effective. The thermal performance factor - "the temperature controls provide for the needs of different occupants" - is indicated as effective by 66.7% of designers. The proportion of respondents who choose "air quality in space enhances or interferes with wellbeing of occupants" was 77.8%. in terms of passive lighting factor, while "the visual comfort of the lighting" was chosen as an effective factor by 77.8% of respondents. The measure of "the horizontal utility systems are configured to serve multi-user needs" is the highest proportion of effective factors among adequacy consumption and strategies.

Passive Design Usability:

The operability factors that are deemed effective by architects include "optimum position of service and passive element or equipment for operability, design passive space (PS) that is well-suited for multi-user activities and capabilities as well as space to provide multi-user comfort (light, fresh air, optimal temperature)". 66.7% of the architects supported the selection of these factors for measuring PD usability.

Passive Design Flexibility:

The future adaptability factors of "design the PS to cope with changes in flow of E-Us, design PS based on future use scenarios" were selected by 66.7% of the respondents as an effective measure for design flexibility.

Passive Design Reliability:

The two durability design factors [Design PD service life to match E-U needs and Consider PD details that are reliable for rainfall, humidity, heavy snowfall, flooding and intense sun degradation] were selected as effective factors by 77.8% of architects. Two measures of material quality factors - "use high quality material with long service life to handle PD functions and (2) use standardisation of PD elements and materials respectively" were selected by 77.8% of respondents as very effective and effective factors. The factor of the adaptability sub-attribute of "Specify PS strategies for E-U behaviour usage (such as accidental impact)" was deemed as effective by 88.9% of respondents.

Passive Design Maintainability:

A high percentage of architects thought that "Provide L,V in expected maintenance areas, Design for ease to remove or replace L.V.T elements, Design for ease to adjust L,V,T physical element features" were the most effective factors within the standardization sub-attributes. 66.7% of respondents selected "Minimise use of unique materials of PDs" as an effective factor from the material measures sub-attributes. Finally, 66.7% of the designers highlighted the majority of accessibility design factors as effective factors.

DISCUSSION

The ISO standards that are used in software design have been proven valuable in integrating E-U needs into all software products that exist in the market nowadays. Similarly, if such a system as proposed in this work is adopted in the design of passive buildings, it will revolutionize the building design sustainability agenda. PD is one of the approaches that are used to mitigate environmental impacts. It is through the optimum linkage between functionality, performance and E-Us' needs in building assets design that environmental impacts can be reduced. The UCD process proposed in this work can maximise the level of E-U satisfaction and comfort, leading to an increase in building service life. Dealing with the perceptions and psychological needs of the building E-Us and how they interact with the facility in a systematic way as proposed in this study will certainly enhance the chance of delivering highly performing buildings. We have demonstrated in this work how the socio-techno-economic drivers ought to be considered in PD of buildings in order to meet E-U requirements. For this reason, we extracted tens of drivers. These drivers will be subjected in the future work to further reduction to concentrate only on the most effective measures that will make a huge difference to the E-U experience. The preliminary results so far indicate that architects selected around 40 factors out of 132 as being the most effective. The next stage of the research will try to interpret and explain the importance of the selected measures.

CONCLUSION

UCPBD process and PD human attributes make up the core of the proposed conceptual model. This work has considered E-U aspirations from physical, economic and psychological aspects. The proposed model will add knowledge to the existing methods for helping designers to meet E-U needs in the design of passive buildings. Hopefully this will contribute to the satisfaction of the E-Us and lead to designing highly performing building assets. This study may go a long way to build up capacity and knowledge in this vital area of practice and research. Further work will consolidate the validation of the selected E-U factors, and develop a tool to assess the building design for the inclusion of the E-Us' design measures

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