Unlocking Human Factors for More Resilient and Sustainable Built Environments: Human Centric Solutions

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Abstract. Sustainable buildings are designed to provide a better built environment that reduces environmental impacts, supports communities for social needs, and preserves economic gains. Despite a growing interest in sustainable development over the past few decades, there has been surprisingly little research focusing on the implications of human factors to a sustainable built environment. Sustainable building solutions shall be informed by the needs of building occupants and made in adaptive response to environmental, economic and socio-cultural changes. Interactions between users and buildings are of great importance to determine how successful a sustainable building is. Literature revealed that a failure of putting users at the pinnacle of designing sustainable solutions could be one of the main underlying reasons of underperformance of sustainable buildings. This paper presents a conceptual framework to demonstrate how human centric solutions contribute to improving user-environment interactions in sustainable buildings. By considering human centric solutions, sustainable building performance can be optimised by integrating users' needs and aspirations into the design and development process. This paper helps increase the understanding of the roles of human factors in sustainable buildings, hence supporting the development of social sustainability which has been greatly overlooked in the pursuit of sustainable development.

1. Introduction

The 2030 Agenda for Sustainable Development has been put forth in the development agenda of the building and construction sector worldwide, with the launch of various national and international net zero carbon policies and frameworks. Making built environments more sustainable, in both new and existing building stocks, has become a key in the sustainability transformation of the construction industry. Sustainable buildings are a paradigmatic science that integrates the key tenets of environment, economy, functionality, utility, durability, health and wellbeing, and comfort. Sustainable building solutions are designed to provide a better environment that reduces environmental impacts, support communities for social needs and preserve economic gains.

Despite a growing interest in sustainable development over the past few decades, there is no consistent success evidenced by sustainable building projects. Past research has given great emphases to promoting environmental sustainability where extensive works are carried out to develop more innovations and advanced technologies in the areas of carbon emissions, renewable energy, energy efficiency, building envelopes, and recycled materials. Nonetheless, the technological advancement does not necessarily bring improved sustainability performance throughout the building life span, as anticipated by the project design teams and long awaited by the public. Apart from being over-optimistic in interpreting simulated laboratory results in the real settings, one of the underlying main

reasons of the sustainability performance gaps could arise from the overlook of human factors in determining the quality performance of sustainable buildings throughout its lifetime.

2. Human Factors in the Context of Sustainable Buildings

The purpose of sustainable buildings is to provide improvement in quality of life and promote health and wellbeing. The design and development involve complex and innovative technologies for improved sustainability performance in buildings. Although human and social aspects are a key to the delivery of sustainable development goals, sustainable building practices have been focusing on improving environmental performance due to substantial environmental impacts brought by the construction industry.

Previous research found that there has been inconsistent performance of sustainable buildings across all three key aspects of environmental, social and economic sustainability. Evidence of environmental benefits of sustainable buildings such as energy consumption reduction and carbon emissions are well documented but there are not many studies documenting the benefits of sustainable building design in relation to social aspects such as user needs, health and wellbeing [1, 2, 3]. Little research focuses on the contribution of human factors to building design requirements although the social dimension is proven to contribute to the delivery of sustainable development goals in global value creation [2]. Social benefits of sustainable building design such as user needs, health and wellbeing are not widely investigated [2]. Social values of sustainable buildings are often less immediately visible and harder to quantity. Uncertainties associated with quantifying the social dimension also exacerbates the challenges of delivering social sustainability within sustainable buildings. To deliver innovative and effective ways of sustainable buildings, it is important not to ignore the interconnections of human factors in the built environment and examine how human interacts with various functions in the built environment [4].

Sustainable buildings are considered as an interconnected system of various constituents. Users, as a part of building systems have a key role to creating a conducive built environment for living and working. The design of sustainable buildings shall be outcome-oriented, system-based and user-centered to create well leveraged solutions for sustainability [4]. The concept of sustainable development embraces a multidimensional socio-technical aspect to support environmentally friendly consumption patterns, healthy lifestyles and resilient social behaviours for transformation. Sustainable solutions in buildings should be informed by the needs of occupants and made in adaptive response to environmental, economic and socio-cultural changes or context [1]. Sustainable buildings shall be considered as a product of interdependencies between users and environment (both internal and external), rather than an idealistic and deterministic perspective. Optimal sustainable building performance is beyond advanced technologies, sophisticated green methodologies or a high achievement of sustainable building certification. Understanding the complexity of human behaviours and built environment would be the key to optimise the performance of sustainable buildings.

3. User Behaviours and Interactions with the Sustainable Built Environment

User-environment interactions have been a long-standing subject which involves complex relationships between social, economic, psychological and physiological perceptions for human comfort. There is a variety of factors affecting user behaviours and interactions within the built environment, such as politics and legislations (rules imposed by public administrators and legislators); culture, local habits, and lifestyles; and capability to control, react to the systems [2]. In the contemporary building design, a profound disjunction between the design team and the end users is found. The designers, who are not building inhabitants, are often driven by cost, constraints and regulations in devising sustainable building solutions without taking the demands and aspirations of building users into account [1]. With a transition to modular construction and 3D printing innovation, contractors or technology suppliers also make decisions of building interfaces on site without much deep thought of user expectations [5]. Sustainable buildings are therefore designed based on the desire and considerations of the design team and contractors.

There has been extensive literature suggesting failures of sustainable buildings to meet the people expectation. While being designed in accordance with sustainable building specifications, sustainable buildings are sometimes found to underperform in the aspects of indoor environmental quality, user comfort, psychological needs, health and wellbeing. A post-occupancy evaluation of thermal efficiency conducted by Macintosh and Steemers [6] revealed that heat recovery balanced ventilation systems recorded higher real carbon emission than the calculated optimum case and the base case with only natural ventilation. Charnofsky [7] also found some sustainable buildings do not give high user satisfactions in terms of privacy and noise insulation, although they are able to minimize environmental impacts.

Failures of sustainable buildings to address social needs could be linked to a lack of consideration of putting users at the pinnacle of the building planning and design. As advocated by Sellers and Fiore [8], sustainable features may be adopted or used in an improper way if human-centric solutions are not integrated since the beginning. Interactions between users and buildings are of great importance to determine how successful a sustainable building is. Le, Almeida and Tam [9] asserted that human behaviour variability is a key contributor to the gaps between the predicted energy in the design stage and the actual energy usage in building operation stage, in which it can cause a difference up to 72% energy consumption between aware and unaware energy users. User behaviours can influence the effectiveness of sustainable building solutions significantly because the minimisation of environmental impacts could be counteracted when occupants behave differently from the original intention of the sustainable design solutions [10]. It is therefore paramount to ensure users understand the design and operation of given building interfaces to prevent unintended outcomes to user comfort or energy efficiency.

User behaviours are influenced by intrinsic and extrinsic motivators. Intrinsic motivators include biological factors (age, body composition, etc.) and socio-psychological factors (personal preferences, habits, social norms, level of clothing, etc.) [5]. Extrinsic motivators consider wider economic or technical contexts such as electricity cost, diffusion of smart technologies, etc. [5]. Users interact with the building systems in the aspects of perception, cognition, action and evaluation of outcomes, where the built environment acts as a stimulus triggering response mechanisms from users [10].

In the presence of a trigger and an adequate ability to control or change, users can react, respond and adapt to the ambient environment. Users interact with building interfaces of: a) building services; b) energy consumption; and c) indoor environmental quality and users would make adjustments to these settings to meet their needs. The extent to which building interfaces provide information and control to users, in a great extent, affects the user behaviours greatly. In the context of sustainable built environments, natural forms of energy and resources are employed to reduce the energy dependency, manage resources effectively and safeguard the health and wellbeing of users. With active and passive sustainable strategies, sustainable buildings shall create more opportunities to engage and empower users to harness the environment effectively and efficiently. The user-environment interaction can be affected by the design, functionalities and effects of the systems [10]. To create a sustainable built environment for human habitats, user demands in terms of physical comfort, physiological and psychological wellbeing, and satisfaction should be taken into account.

4. Human-Centric Solutions

Human centric solutions emphasise the understanding of human factors and their interactions with building systems to optimise human wellbeing and overall system performance in sustainable buildings. In response to a dynamically changing environment, users tend to maintain the surrounding environment in a homeostatic condition to provide a good level of comfort, wellbeing and health. As defined by ISO-9241-11:2018 [11], human centred design is an “approach to system design and development that aims to make interactive systems more usable by focusing on the use of the system; applying human factors, ergonomics and usability knowledge and techniques”. Giacomin [12] described human centred design as a hierarchy that is based on the scientific facts about human physical, perceptual, cognitive and emotional characteristics, followed by progressively more

complex, interactive and sociological considerations. In the meanwhile, Vezzoli et al. [13] considered human centric design as an approach emphasising the needs, expectations, and interests of users to ensure that the products, services and systems create useful, usable, engaging, pleasurable and desirable experience.

By reviewing the principles of human centric concept, it can be deduced that a human centric solution gives attention to human needs, capabilities, behaviours by recognising physical, physiological and psychological needs of people. Human centric solutions are critical to realising innovative investments in creating buildings of the future [14]. By adopting human centred solutions in sustainable buildings, building functions can be made to adapt contextually appropriate operational strategies that integrate passive, hybrid and active techniques with site, functions and occupants' requirements (Altomonte, et el., 2015). This helps increase active and passive user participation within sustainable built environments, following growing user interests in improving quality control for their environment.

5. A Conceptual Framework of Human-Environment Interactions in Sustainable Buildings

Figure 1 presents a conceptual framework to demonstrate how human centric solutions contribute to improved user-environment interactions within sustainable buildings. Evidence from scholarly articles revealed a missing link to connect human factors in existing sustainable building approaches, hence leading to performance gaps and failures of sustainable buildings to live up the people expectations towards the sustainable development goals. By putting human centric solutions a priority in developing sustainable buildings, the sustainability performance can be optimised with increased engagement of building users and occupants. It is however critical to note that human centric solutions should not be restricted to ergonomic features of devices or systems in sustainable buildings.

The heart of sustainable development is to develop the three pillars of sustainability - environmental sustainability, social sustainability and economic sustainability in a balanced and integrated manner, without deprioritising either one of the pillars in action. It is vital to reconcile the disconnection of social sustainability in the existing pursuit of sustainable built environments. The social dimension is inseparable from the other two dimensions since dynamic changing needs and lifestyle of people can have direct and indirect impacts on the environmental and economic performance of sustainable buildings. In the domain of environmental performance, operational carbon and energy consumption are produced the most during the building operational and maintenance stage, where end users and occupants play a critical role in this stage. As for economic performance, operational and maintenance cost is known to be a determinant of life cycle cost in which proactive commitments from end users are required to perform administrative and control routines with the same sustainability goals in mind. A clear understanding of the sustainable design techniques and strategies shall be demonstrated by building occupants in efforts to meet sustainability targets. There is a distinct interdependency between social sustainability and the two sustainability pillars, and human centric solutions can bridge the gap by reconciling social sustainability to sustainability strategies in buildings.

Human centric solutions support dynamic relationships between users and the built environment. The respect of human variability leads to overcoming the whole stereotyped behaviours and standard reference that represents the design starting point [2]. Human centric solutions offer a systematic method in designing sustainable built environments with a shift of attention from an exclusively function-oriented to user-oriented approach. Human needs and expectations are taken into consideration at the very beginning of sustainable building projects with early stakeholder engagement. End users are involved in the front-end stage of sustainable buildings to determining the building system qualities. As such, users are empowered and in control of what they want and need of their buildings to live and work.

The conceptual framework shown in Figure 1 incorporates human centric solutions to improve the sustainability performance in aspects of a) accessibility and availability; and b) functionality, serviceability and flexibility. User needs and aspirations are integrated into the design and

development of sustainable buildings to clarify the objectives, assess the performance targets, facilitate decision making and finetune responses in the programmes for promoting sustainability performance.

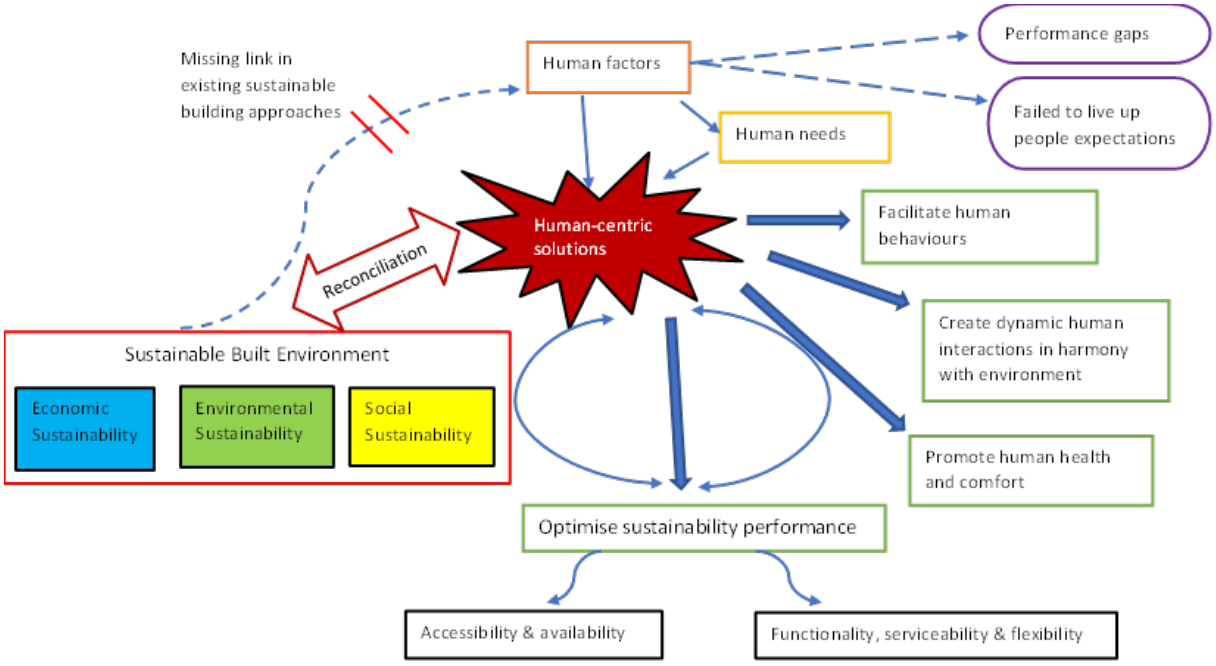

Figure 1. A conceptual framework of human-centric solutions for dynamic human-environment interactions in a sustainable built environment

5.1. Functionality, serviceability and flexibility

Functionality is a measure which focuses on the accomplishment of intended tasks and goals of a product or system. There are various aspects of functionality such as technical functionality (operational functionality – a property that make the artefact do the job itself), structural functionality (a property to make an artefact work as a part of a larger whole), interactive functionality (a property to communicate with users of artefacts) [15]. Functionality depends on the situation in which an artefact is used, as well as the context it is designed and used in the values of designers and users. Functionality should consider the technical and physical properties and also their theoretical potentials to deliver the required practical effects. Serviceability is a broader term that considers the capability of a building or facility to support the function for which it is designed, used or required for use and performance [16]. Flexibility can be thought of an ability to be changed or modified to make suitable for a particular use. By large, functionality, serviceability and flexibility are the nexus of artefact design for delivering good values.

The principles of functionality, serviceability and flexibility help determine the suitability of a system to support the specific purpose and activity in sustainable built environment. By deploying human centric solutions, sustainable building features can be leveraged better to serve the human needs and expectations. Insights can be gained by understanding user-environment interactions with an examination of social and behavioural aspects (e.g., user preferences, concept of proximity and boundary, work patterns and the level of exertion), thereby defining task support of sustainable built environment for productivity, quality of outputs and work engagement [17]. Human centric solutions can potentially give users greater jurisdictions over the built environment to regulate requirements of functionality, serviceability and flexibility to improve task performance [17]. For instance, human centered approaches can increase perceived control of users that attributes to improved functionality and serviceability of building ventilation systems.

5.2. Accessibility and availability

In a sustainable built environment, accessibility and availability to building services and systems play a crucial role for managing and administering buildings efficiently. Accessibility refers to "an extent to which products, systems, services and environments and facilities can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve goals in identified contexts of use" [11]. Accessibility can also refer to the ability to enter and use a space or device with ease, subject to users' requirements [16]. Meanwhile, availability is defined as the quality of being able to be used or obtained. Proper user-environment interfaces should always be provided to ensure continuity of operational and maintenance activity for performing the required functions. Lack of visibility and control in the building management systems could prevent users from effective execution or programming of building use.

To enhance efficiency, basic building functions are now moved outside the building spaces. It is not uncommon that the administration of sustainable building services and systems sometimes take place beyond their own building boundaries (e.g., district heating). This has reduced and removed users' real and perceived control over the sustainable building systems, hence widening the gap between users and the built environment. With an absence of proper building interfaces, user behavioural interventions to adapt themselves for better building monitoring and control are also reduced. Despite the move towards centralised building management systems in sustainable buildings, it is important to reserve a degree of human interactions with technical and social systems for increased autonomous and conscious usage of resources to encourage sustainable behaviours [2]. Users should be made aware of their roles and abilities of managing buildings effectively with conscious resource utilisation.

6. Conclusions and Future Research

The paper uncovers the missing link of human factors in existing sustainable building practice. The development of sustainable buildings has predominantly focused on environmental performance such as increasing energy efficiency and reducing carbon emissions. This narrow view of sustainable buildings shall be changed with a shift of attention to human centric solutions. By increasing the understanding of human factors in sustainability practice, human-centric solutions help address socio-cultural issues and increase community development in the built environment, thereby promoting the lagging performance of social sustainability in practice. Human centric solutions can help construction stakeholders to make informed decisions by reducing the deployment of sustainable building strategies that do not serve intended people well, thus saving unnecessary costs and time. This would eventually increase cost effectiveness of sustainable buildings and promote the uptake of sustainable buildings in the construction industry, with improved cost-benefit results.

This paper also presents a conceptual framework that offers new insights into understanding user values, perceptions, and expectations in the pursuit of sustainability goals. The incorporation of human centric solutions helps maximise the performance of sustainable buildings by facilitating human behaviours and creating dynamic human interactions in harmony with the surrounding environment for delivering the sustainability goals. The sustainability performance of a building is influenced, directly and indirectly, by her users. With human centric approaches, users are empowered and in control of what they want and need of their buildings to live and work. This will greatly reduce frustrations, dissatisfactions, and helplessness in managing or administering sustainable buildings, hence promoting the success of sustainable buildings.

Future research should explore how users interact with various interfaces in sustainable buildings by investigating the perceived and real interactions between users and the environment. A range of motivation factors should be taken into account because there could be wide variations of how users react to building interfaces due to individualised needs, cultural factors, regional differences, climate conditions, application purposes, and etc. In addition, it is also important to explore the transparency of building interfaces in translating the performance outcomes and providing feedback for improving engagement between users and the built environment for achieving the sustainability goals.

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Acknowledgement
The work is supported by School of Geoscience, Engineering, Infrastructure and Society (EGIS), Heriot-Watt University Malaysia under the EmGRS 2021/2022 Project "Optimising the Performance of Sustainable Buildings via Human-centric Design".