BUILDINGS & CITIES

Wellbeing fostered by design: a framework for evaluating indoor environment performance

COLLECTION:
SOCIAL VALUE OF THE BUILT ENVIRONMENT

RESEARCH

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ABSTRACT

High-rise urban development has been controversial for its inability to foster cohesive and flourishing neighbourhoods. A social value perspective can help to better understand and evaluate how new developments in dense urban settings affect places and communities. While the link between wellbeing and social value is well-established in the literature, the question of how design can affect wellbeing and thus contribute to the social value of a development still requires further research and clarification. A better understanding of this relationship can assist architects, developers or consultants during the design process. A review is presented of relevant quantifiable aspects of building design that affect wellbeing in relation to the indoor environment and to social value specifically. A framework for fostering wellbeing is developed to test these aspects and evaluate the indoor environment performance. A case study building is used to analyse the relationship between building design and wellbeing. These lessons can be used to inform and evaluate building design during the design phases to complement the assessment of qualitative factors within a social value framework.

PRACTICE RELEVANCE

This study identifies quantifiable aspects of the indoor environment affecting wellbeing in a high-rise development that can form part of a social value framework. This list of identified aspects provides a useful starting point for architects or consultants to assess designs. The indicators relate to quantifiable indoor environment aspects that can be directly controlled by building design and complement the broader concepts of wellbeing within a social value framework. The paper demonstrates how these aspects can be quantified in a case study mixed-use urban development as part of a post-occupancy evaluation. These quantifiable aspects could be integrated within digital tools to evaluate the building at the design stage to ensure that wellbeing is at the forefront of the project considerations.

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1. INTRODUCTION

By the year 2050, more than two-thirds of the world's population is expected to live in cities (United Nations 2015). Denser and increasingly diverse cities require careful consideration of how to create resilient, thriving neighbourhoods and meet the needs of disparate communities. Architecture and design have a significant impact on wellbeing and place-making, and influence social connectedness, healthier lifestyles, a sense of belonging and positive emotions. High-density urban developments, however, have in the past drawn extensive criticism for failing to sustain and foster thriving communities and neighbourhoods (Newman 1972). For an increasingly urban population, developments need to not only achieve short-term profit but also create living environments that are conducive for wellbeing and for sustainable, thriving communities in the long term. A social value perspective can help to better understand and evaluate how new developments in dense urban settings affect places and communities.

In the relevant literature on social value to date, 'wellbeing' has been recognised as an important component, as outlined, for example, in the Public Services (Social Value) Act 2012, Green Book, Social Value in New Development, RIBA Sustainable Outcomes Guide and RIBA Social Value Toolkit. The Social Value Act, for example, starts by emphasising its concern for economic, social and environmental wellbeing (HMSO 2012: 1), while the Green Book, a key UK government guidance on appraisals, highlights the impact of projects on people's wellbeing (HM Treasury 2022). In relation to the built environment more specifically, RIBA's Sustainable Outcomes Guide, for example, states that the goal for development is to create places for people that not only support basic needs but also enhance individual and social wellbeing (RIBA 2019). The RIBA Social Value Toolkit, intended to inform the viability of new developments, proposes a framework of five core dimensions, with 'wellbeing generated by design' being one of these (Samuel 2020).

The social value framework can inform the design of new developments, making qualities such as wellbeing more explicit when they are often overlooked by other metrics and are otherwise difficult to quantify. For such a framework to be credible, established quantifiable wellbeing metrics should become part of it. As a first step, it seems essential to establish what these wellbeing metrics are, through a review of the literature, and to test how they could be used in post-occupancy evaluation (POE) and simulation at the design stage, using a case study. As such, this paper sets out first to outline existing indicators for wellbeing related to aspects of the built environment that could be quantified, potentially even before the building is completed and in use. The specific focus is quantifiable indoor environment aspects that are directly impacted by the design of the building. The quantifiable aspects are those that can be measured, and values can be extracted from a three-dimensional (3D) model through simulations, the calculation of outdoor views percentages, areas and topological analysis of spaces.

This study sets a framework to investigate the correlation between each of the comfort and delight variables and satisfaction with the indoor environment using a case study building. The hypothesis is that with comfort variables such as temperature, humidity, illuminance, CO_2 levels and noise levels, it is possible to predict how satisfied the occupant will be with the indoor environment in relation to physical comfort. Similarly, having 'delight' variables, such as views, connection to nature and living space size, would enable one to predict how satisfied the occupant will be with the indoor environment in relation to positive stimuli factors. The amount and distribution of social spaces as well as the connection to green areas can predict the satisfaction with the whole building.

This specific focus is not intended to replace a broader understanding of wellbeing that has been explored by others, for example, by Samuel (2022). Instead, this study is intended to be complementary by limiting the scope to a series of indicators that can feasibly be measured. These are then tested in a case study of a high-rise, mixed-use building. Lessons from this case study will be used to refine a framework of quantifiable aspects that will in the future be integrated into a 3D model analysis tool for the design stage, as well as to compare results with actual in-use monitoring.

Recognising the complex nature of wellbeing and the limitations of the built environment on generating it, this paper is limited to discussing the aspects of the built environment that can impact people's wellbeing in high-rise, mixed-use buildings and only those that are within the designers'

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responsibility. The aim is to investigate how high-rise, mixed-use building design can promote positive factors (and reduce negative ones) for the people who reside in or use the building.

This study is intended as a step towards developing a metric that encompasses quantifiable aspects affecting wellbeing. The metric will be based on the data collected and analysed with a statistical approach to understand how the different aspects impact the overall satisfaction with the environment and wellbeing. The eventual intention is to integrate the metric into a computational tool that will use simulation and analysis results to provide a detailed evaluation during the design process. The envisioned tool would enable architects and building designers to visualise a highly detailed map that identifies the weaknesses and strengths of a design regarding the 'wellbeing generated by design' dimension from the Social Value Tool. This will enable designers to anticipate the design performance and test solutions, exploring multiple alternatives to optimise design outcomes to enhance the social value.

2. SOCIAL VALUE AND WELLBEING

Several key public and private initiatives have prompted and supported emerging methods for evaluating projects, in terms of not only immediate financial returns but also their longer term social impact. The Social Value Act of 2012 mandated that individuals responsible for procuring public services are required to consider the potential for generating additional social, economic and environmental benefits. This legislation aims to maximise the social value and encourage innovative solutions to complex issues that improve social, environmental and economic wellbeing. The Green Book supports the implementation of the Social Value Act as a guidance for government projects in the UK on how to appraise policies, programmes and projects. This approach shifts the focus from solely short-term financial viability to a consideration of the overall long-term social welfare. Consequently, costs and benefits that affect the welfare and wellbeing of the population need to be considered when assessing social or public value (HM Treasury 2022).

To measure or estimate social value, a range of methods is employed. The two most widespread are cost–benefit analysis (CBA) and social return on investment (SROI). CBA is a method of understanding the social benefit of a particular action by weighing the costs and benefits associated with it and then calculating the ratio of cost versus benefit. The changes in people's wellbeing are measured and statistical methods are employed to determine the causality of the results (Australian Social Value Bank 2017). SROI combines elements of CBA and social accounting principles. It aims to decrease inequality and environmental degradation and improve wellbeing. This approach analyses how social values are created by measuring social, environmental and economic results to then assign a monetary value to them (Australian Social Value Bank 2017).

These approaches recognise wellbeing as a central component of social value and encourage or require it to be included as a criterion for evaluations. Therefore, when employing the concept of social value in a built environment context, it is necessary to investigate how buildings can impact people's wellbeing, what design aspects play a role in generating or supporting wellbeing, and how these aspects can be evaluated and measured.

2.1 SOCIAL VALUE IN THE BUILT ENVIRONMENT

While the Social Value Act 2012 and the Green Book appraisal guide were not created specifically for the built environment, their principles are still influential for architects (Samuel 2020). Methods such as the CBA and SROI can indeed be employed to assess social value in the built environment. However, the SROI method does not directly investigate or focus on building design aspects nor does it reflect on the value of the design, which makes it difficult to apply to future developments (Watson & Whitley 2017). Aiming to capture how good design can enhance social value outcomes, the Social Value in New Development (UKGBC 2018) has been created to help local authorities and stakeholders better understand the influence of the built environment in this area. The guide identifies a range of positive outcomes that a new development should have for a community and makes recommendations on how to maximise its benefits. The guide also organises these outcomes into three broad themes: jobs and economic growth; health, wellbeing and the environment; and strengthening of community.

As a framework specifically for the built environment, the RIBA Social Value Toolkit has been created to inform the potential social value of new developments and to demonstrate the impact of building design on people and communities (Samuel 2020). The toolkit compiles a series of questions for POE and argues that social value in architecture is created by fostering positive emotions that can be achieved through views and connections with nature, providing conducive spaces for an active lifestyle and for connecting people and the environment. According to the toolkit, the social value of the built environment can be evaluated by using five different dimensions: (1) generating jobs and apprenticeships; (2) wellbeing generated by design; (3) learning through construction; (4) designing with the community; and (5) building with local materials. The dimension of 'wellbeing generated by design', in particular, has a long-term impact on those using and living in the building and is a dimension where the building design has a high impact. Therefore, this study focuses on investigating this dimension by unpacking its meaning and correlation to the indoor environment.

2.2 WELLBEING FOSTERED BY DESIGN

The built environment impacts people's wellbeing through a multitude of factors. Form, aesthetics, urban design and amenities, for example, may affect people's wellbeing, impacting social life in a neighbourhood and people's perception of their surroundings (Gehl 2013; Lynch 1964). From an indoor environment perspective, the building design can, for example, influence how residents use the communal spaces and how residents interact (Abu-Ghazzeh 1999; Bee & Im 2016). The indoor environment can also impact residents' comfort and health, and has the potential to promote positive emotions through good views, daylight and contact with nature (Rohde *et al.* 2020; Altomonte *et al.* 2020).

In order to understand how the built environment can support wellbeing in high-rise buildings, it is necessary to clarify the definition and relevant approaches. Wellbeing is a complex concept that comprises optimal experience and functioning. Psychological research broadly distinguishes two different approaches to fostering wellbeing: hedonic or subjective wellbeing, and eudaimonic or social wellbeing. The hedonic approach focuses on happiness and defines wellbeing in terms of pleasure obtainment and pain avoidance, while the eudaimonic approach focuses on meaning and self-realisation, and defines wellbeing in terms of the degree to which a person is fully functioning (Ryan & Deci 2001). Diener & Michalos (2009) suggest that while hedonic or subjective wellbeing relates to the experience of the individual, the absence of negative factors alone is insufficient and positive factors also need to be included.

In the built environment, wellbeing can encompass several dimensions such as physical, physiological, social, economic and psychological, combining hedonic and eudaimonic approaches (Altomonte *et al.* 2020). Wellbeing in buildings depends on many factors beyond the architectural designer's competence or control, such as people's behaviour, state of mind, economic and cultural context.

Acknowledging the limitation of 'wellbeing generated by design' (Samuel 2020), 'generated' will be substituted in this study by 'fostered' or 'supported'. The term 'generate' could be understood to imply that wellbeing can be created by the built environment alone as an assured outcome for all building users, independent of their circumstances and context. The focus of this investigation is 'wellbeing fostered by design' from the perspective of the user's experience of the building. Promoting wellbeing in this context requires creating an indoor environment that is not only comfortable and healthy, or lacking negative stimuli, but also fosters positive stimuli and is a delight to be in and look at (Altomonte *et al.* 2020; Rohde *et al.* 2020). Therefore, for this paper, it is crucial to identify the building design aspects that impact wellbeing, indicating elements that influence physical comfort and elements that promote delight.

A significant body of research has investigated the relationships between indoor environment and wellbeing through different approaches. Many of these relate wellbeing to indoor environment quality (IEQ) (Al horr *et al.* 2016; Bourikas *et al.* 2021; Vladoiu *et al.* 2021), focusing on the comfort parameters such as thermal comfort, visual comfort, acoustic comfort and air quality. Comfort parameters can, indeed, impact wellbeing, health and performance. The impact of thermal comfort on health and wellbeing, for example, is well established in the literature, with some studies suggesting that extreme temperatures, for both cold and heat, can increase mortality (Diaz *et al.* 2005; Nicholls *et al.*

2008; Hansen & Soebarto 2019). Visual comfort can impact wellbeing in many ways: it can affect the performance and stress levels of workers in offices (Boyce *et al.* 2003; Heschong & Mahone 2003), impact sleep patterns (Chang & Chen 2005) and influence health and mood (Denissen *et al.* 2008; Borisuit *et al.* 2015). Several studies have demonstrated the negative effects of acoustic discomfort on occupants' health and wellbeing, impacting mental health (Laird 1933), mood (Thompson *et al.* 2001) and life satisfaction (Urban & Máca 2013). Studies show, for example, the direct relationship between acoustic comfort and occupant productivity in commercial buildings (Sundstrom *et al.* 1994; Martellotta 2011), where environmental noise can cause stress and loss of concentration, contributing to dissatisfaction and increased workplace conflicts (Leather *et al.* 2003; Mak & Lui 2012).

In addition to acoustic comfort, indoor air quality is another important factor for occupant wellbeing. The lack of appropriate ventilation rates and subsequently a high CO_2 concentrations can lead to sick building syndrome (SBS) (Carrer *et al.* 2015; Maddalena *et al.* 2015) and increase exposure to microbial pollutants, which is often associated with respiratory diseases, allergies, asthma and immunological reactions (Myatt *et al.* 2004; Heseltine & Rosen 2009). Other studies also point to the impact of indoor air quality on performance and learning (Federspiel *et al.* 2004; Bakó-Biró *et al.* 2012). Further research focuses on wellbeing at the workplace, going beyond physical comfort parameters. These studies investigate factors such as biophilic design, daylight, views, multisensory experiences and aesthetics, for example, by using POE questionnaires to investigate the relationships between indoor building conditions and the wellbeing of workers (Bluyssen *et al.* 2011; Clements-Croome 2018).

A body of recent studies has sought to define new ways to contribute and improve the lives of individuals in the built environment by advancing positive stimuli to enhance people's experiences that affect human flourishing and thriving (Gifford & McCunn 2018; Stevens *et al.* 2019; Altomonte *et al.* 2020; Rohde *et al.* 2020). Rohde *et al.* (2020) propose a framework where the IEQ should be measured with a holistic approach that suggests three domains: comfort, health and wellbeing. The third domain, wellbeing, can be fomented by positive stimuli in the environment, such as pleasant views, visual daylight cycle and views to natural sceneries. In reference to the well-known Vitruvian triad of *firmitas, utilitas, venustas*, Rohde *et al.* see wellbeing as an element of the IEQ that is separated from comfort and health, equating wellbeing with pleasure or positive stimuli (Figure 1).

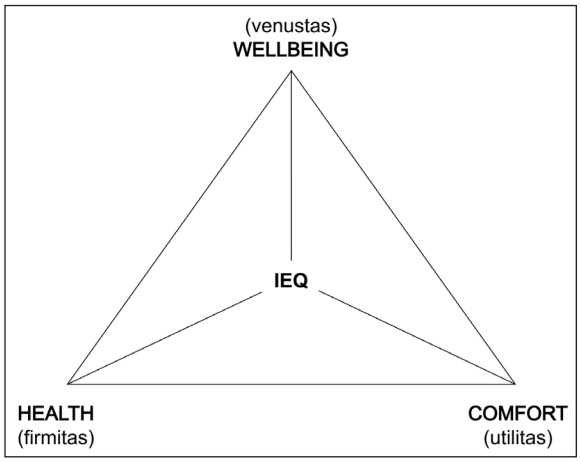

Figure 1: Suggested framework inspired by the Vitruvian triad of *firmitas, utilitas, venustas*.

Note: IEQ = indoor environment quality.

Source: Rohde *et al.* (2020).

For Altomonte *et al.* (2020), creating an indoor environment beyond mere 'comfort' requires consideration of the preferences and adaptation for physical comfort as well as their changes over time. These considerations also include providing good daylight with distant views through windows and connections to nature. Their framework proposes that to achieve pleasure and wellbeing, comfort must be assured first, relating it to Maslow's (1954) 'hierarchy of needs' pyramid where pleasure and wellbeing are at the top of the hierarchy.

Different from visual comfort that seeks to design luminous environments in order to support tasks and avoid glare discomfort, daylight stimulus and views to the outdoors will enhance inhabitants' connection with the circadian rhythm, influencing sleep cycles, memory formation, immune

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response, growth, development and metabolic health (Boyce *et al.* 2003; Aries *et al.* 2015). Daylight affects melatonin secretion, which is a hormone that regulates our sleeplessness and alertness periods (Aries *et al.* 2015). Many studies also reveal that inhabitants prefer views to natural scenes (greenery, mountains, bodies of water) over predominantly urban scenes (Ulrich 1981; Kaplan 1993; Grinde & Patil 2009). Access to views of the outdoors may also enhance cognitive function, simultaneously providing information, stimulation and relaxation (Ulrich 1984). According to Ulrich (1981), visual contact with nature reduces stress and speeds up patient recovery, particularly in urban environments, while others suggest that it enhances the recovery of the capacity to focus one's attention (Kaplan & Talbot 1983; Kaplan 1993).

Samuel (2022: 19–21) examines the correlation between wellbeing and the built environment in relation to housing. Related to the frameworks and standards outlined above, Samuel emphasises the necessity to create a comfortable environment with access to daylight, views and nature. The author places particular emphasis on the connection between eudaimonic wellbeing and social value, highlighting the importance of factors such as people's physical health, self-actualisation and community identity. Samuel supports the inclusion of quality spaces that allow social interactions to happen, such as community centres, green spaces, community gardens, cafés and restaurants. Another study also points to the importance of considering the intangible outcomes of the design and disposition of these social spaces, such as prompting people to stay physically active, offering people ways to experience different intensities of social interaction, experiencing seasonal changes and the weather conditions (Stevens *et al.* 2019).

Amenities for social interaction between neighbours are particularly important in high-density urban developments, with studies suggesting that this typology can result in a lower sense of community, less contact with neighbours and social support when compared with low-density urban settings (Wilson & Baldassare 1996; Williams 2005). Other research also reported a higher prevalence of mental health issues in high-rise buildings, such as depression, suggesting social isolation as a contributing factor (Evans *et al.* 2003; Gifford 2007). Others concluded that mental health may be negatively affected by a lack of contact with natural elements (Wener & Carmalt 2006). Additionally, the size of living spaces, particularly in high-density developments where space is often limited, has been found to have a significant impact on occupants' wellbeing and can potentially contribute to mental health issues (Baum & Valins 1974; Evans *et al.* 2003; Williams 2005; Gifford 2007), affecting family dynamics, privacy and educational performance (Roberts-Hughes 2011).

Research on the relationship between wellbeing and the built environment has been integrated into relevant standards and certifications, *e.g.* those developed by the WELL Building Institute and the UK Green Building Council (UKGBC). The WELL Building Standard is a comprehensive framework that focuses on enhancing the health and wellbeing of building occupants (Delos Living 2016). The standard regards the built environment as a means to foster human health, wellness and comfort, helping to improve the nutrition, fitness, mood, sleep, comfort and performance of their inhabitants. In order to be certified, a project must satisfy a certain number of features, such as good thermal performance, air quality, acoustic comfort, daylight design, health and wellness, and nourishment, also promoting good mental health.

According to the UKGBC (2018), the strategies for the theme 'health, wellbeing and the environment' include: resilient buildings and infrastructure, opportunities for blue and green infrastructure, good mental health fostered by incorporating biophilic elements and natural materials, good ventilation and natural light, good physical health through thermal comfort, acoustic and visual comfort, as well as healthy local air quality through materials that absorb pollutants and minimise exposure to pollutants.

The Social Value Tool model suggests assessing the impact of design on wellbeing through POE surveys that focus on the relationship between design and positive emotions, such as feelings of pride and delight, opportunities for social interaction, flexibility, adaptability and community involvement. According to the studies outlined above, other important indoor environmental factors impact occupants' wellbeing in the indoor environment. Identifying the quantifiable aspects of the building design that affect occupants' satisfaction with the indoor environment would allow the evaluation and quantification of a case study. Together with the POE, this can enhance the understanding of

how the building design contributed to the wellbeing outcomes. This correlation can be analysed through statistical analysis to elaborate metrics to evaluate building design. A metric based on quantifiable indicators allows designers to better understand the potential 'wellbeing fostered by design' outcome through simulations and 3D model analysis already during the design process, and therefore enhance the social value of the development through their design decisions.

3. METHODS

3.1 IDENTIFYING THE QUANTIFIABLE ASPECTS

To structure the framework for assessing the wellbeing fostered by design in indoor environments, this study relies on a literature review to identify the aspects of the building design impacting satisfaction with the indoor environment and wellbeing that could be quantified and evaluated in a 3D model in the early design stages. These quantifiable aspects are those that can be measured, and values can be extracted from a 3D model through simulations, views percentages calculation, areas and topological analysis of spaces.

A Scopus search found the relevant and the most updated frameworks regarding wellbeing in the indoor environment. The search used the keywords 'building design' OR 'build environment' OR 'indoor environment' AND 'wellbeing' OR 'well being', and it was limited to journal papers in English, excluding papers related to urban design, to learning environments such as schools and universities, as well as healthcare facilities such as hospitals and clinics since this study is focused on high-rise, mixed-use developments. As result, a pool of 531 publications was selected and the abstracts were scanned to identify the most relevant frameworks in relation to a broad selection of quantifiable aspects of the indoor environment affecting wellbeing. Two main frameworks were identified that respond to the criteria: (1) 'Framing holistic indoor environment: Definitions of comfort, health and well-being' by Rohde *et al.* (2020); and (2) 'Ten questions concerning well-being in the built environment' by Altomonte *et al.* (2020).

From the pool of publications, the keywords were categorised thematically in order to identify the most frequently occurring terms in conjunction with the primary search terms, namely 'building design' and 'wellbeing'. Figure 2 indicates that over 60% of the publications encompassed air quality-related terminology, *e.g.* air pollution, volatile organic compounds and particulate matter, among others. The IEQ category (more than 20%) encompassed studies addressing all the four physical comfort parameters. Other categories were thermal comfort (20%) and visual comfort (15%). The inclusion of acoustic comfort-related terms constitutes less than 10% of the publications, which is surprisingly low given that studies indicate noise-related issues as a prevalent source of complaints in office environments (Sundstrom *et al.* 1994). More than 10% mentioned physical activities alongside wellbeing in the built environment, and more than 10% included biophilic design-related terms. Fewer than 5% of the studies mentioned views in their keywords, indicating a potentially underexplored area within the context of building design and wellbeing.

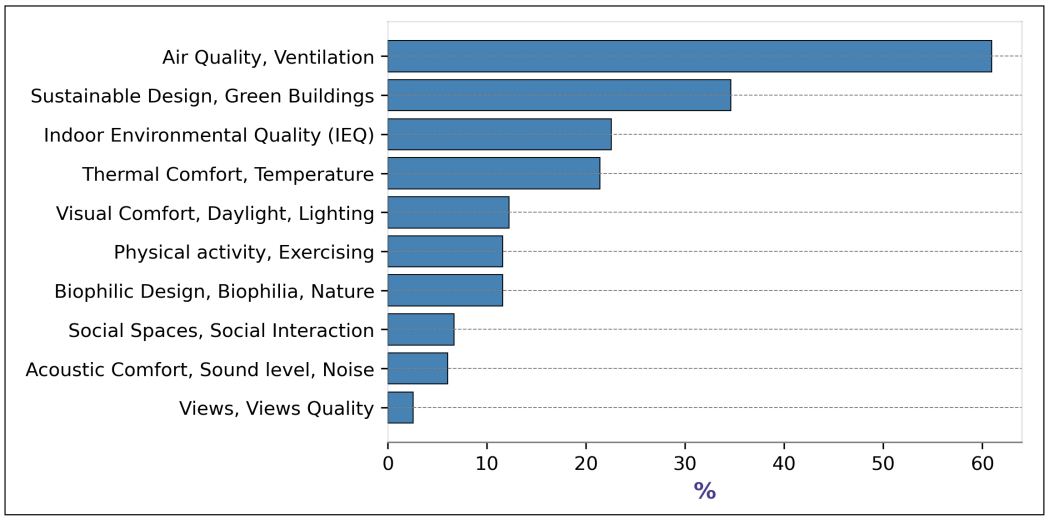

Figure 2: Percentage of papers mentioning the related themes keyword groups.

To gain a comprehensive understanding of the factors influencing wellbeing, each individual aspect was thoroughly examined in conjunction with the concept of wellbeing. This approach enabled a detailed exploration of the specific effects of these aspects on health and satisfaction. In addition to the conceptual frameworks, established building standards such as WELL and the UKGBC were incorporated into the analysis. These standards were chosen due to their comprehensive guidelines and recommendations specifically tailored to enhance wellbeing within built environments, encompassing a broader range of factors and strategies related to wellbeing in building design.

3.2 QUANTIFYING ASPECTS AFFECTING WELLBEING

As identified in the literature review, the satisfaction with the indoor environment constitutes an important part of the wellbeing fostered by design. Therefore, to create the framework for building design analysis, the aspects mentioned above must be evaluated in relation to occupants' satisfaction with the indoor environment and then its correlation and significance to their wellbeing analysed.

Through a POE, it is possible to extract and analyse numerical values derived from occupants' responses regarding their satisfaction with each of the identified aspects. Such an analysis allows for the prediction of the overall satisfaction level experienced within the indoor environment. These predictions can be done through data analysis and machine-learning methods such as multilinear regression or multinomial classification, where multiple independent variables are used as predictors of the target variable. The framework will provide guidance on the correlation between the data obtained from the POE for assessing the wellbeing fostered by design. Furthermore, the framework can provide a foundation for training a machine-learning model incorporated into a 3D model analysis tool, enabling the prediction of indoor environment satisfaction and wellbeing fostered by design based on simulation outcomes.

3.3 CASE STUDY BUILDING

The case study is the U City building, a 19-storey 'extreme' mixed-use urban development in Adelaide Central Business District, South Australia (Figure 3). U City was built in 2019 and is owned by Uniting Communities, a not-for-profit organisation providing social and community services. This mixed-use building is labelled as 'extreme' because, unlike most mixed-use buildings or developments in central business districts (CBDs) that normally consist of offices, residential apartments, or hotels and retail spaces, U City consists of independent living retirement apartments on the top five floors, short- and long-term accommodation for people with disabilities on the middle floors, social and community services for a wide variety of marginalised community groups, commercial office spaces on the lower levels, as well as art studios, commercial and retail spaces that can be accessed by the general public on the ground floor (Figure 4). Four floors have dedicated public and semi-public spaces for community gathering: one for the retirement apartments' residents on the 13th floor, one communal balcony space for the occupants and guests of the disability accommodation, a space on the third floor for office workers and the general public, and finally a large lobby space.

U City operates as a carbon-neutral, 6-Star-rated building (according to the Green Star environmental rating assessment by the Australian Green Building Council) and has recently been awarded the 2020 Good Design Australia Award in the category of Social Impact (Good Design Australia 2020). Importantly, U City aspires to be a socially sustainable building that improves the wellbeing of residents and users. The building has been designed and operated in ways that aim to bring together different types of building occupants and users to create a vertical living community, making it an ideal case study to explore the social value of architecture. Relevant to the particular focus here are the aspects of the building design that impact satisfaction with the indoor environment and the wellbeing of its occupants. For example, each apartment unit has been designed to include a wide balcony that provides occupants a directly accessible outdoor area which allows them to create their own green spaces. The design has also been based on the objectives to minimise the use of heating and cooling appliances to achieve thermal comfort (which is one of the basic requirements to achieve a 6-Star Green Star-rated building), to allow natural light to enter as much as possible, and to minimise noise that will disturb the occupants through the use of certain building construction and materials for the building envelope and internal partitions and floors.

Figure 3: U City building in Adelaide Central Business District, South Australia.

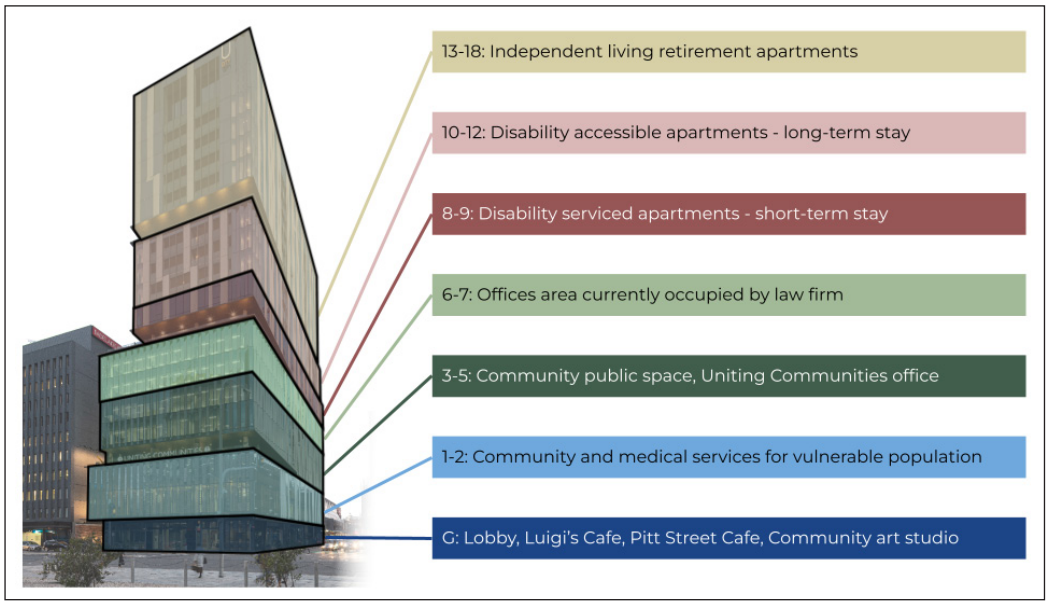

Figure 4: U City floors use.

3.4 OCCUPANT AND CASUAL USER SURVEYS

Data were collected not only on the specific quantifiable aspects of the building design but also on how generally the occupants and users experience the building and neighbourhood, using several methods: (1) occupant and casual user surveys; (2) monthly focus group discussions; (3) monitoring and measuring indoor environmental quality parameters; (4) occupant audits of building and neighbourhood activity; and (5) observations of public space use in the building. These are in addition to gathering the background and demographic information about the participants. Data collection commenced in August 2022 and is scheduled to continue until December 2023.

To date, a total of 45 occupants or building users have actively participated in the study. The participant demographics revealed that 55% of the participants identified as female, 42% as male and 3% as non-binary. The dominant age group in the case study is the 75–79-year-old group (Figure 5), which can be attributed to the residential area being a retirement vertical village.

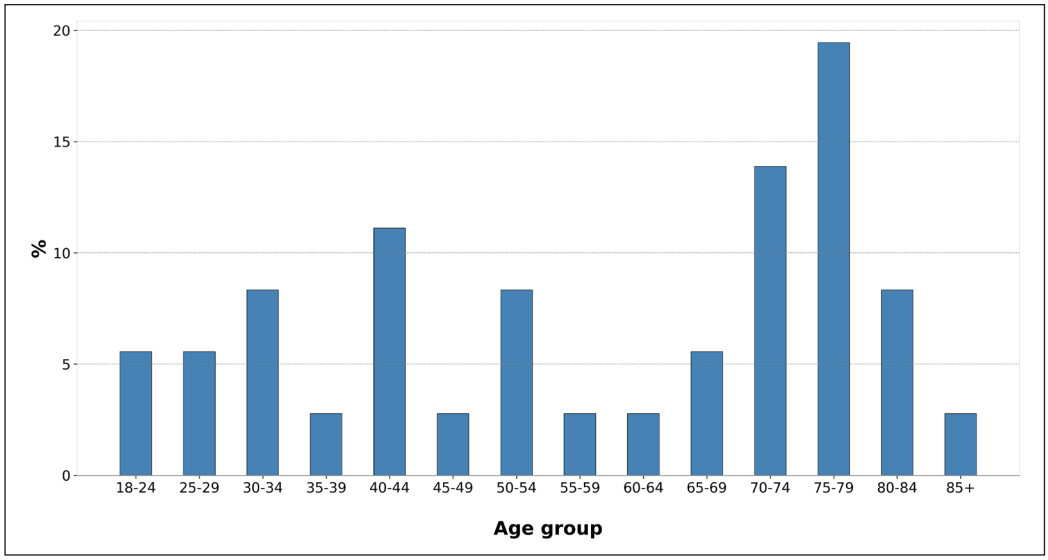

Figure 5: Participants' age groups' distribution.

To test the hypothesis and gather the required data for analysis, the POE was designed to include two primary surveys: (1) regular indoor comfort surveys (see Table S1 in the supplemental data online); and (2) one-off indoor delight survey (see Table S2 online). These surveys aimed to capture the occupants' satisfaction with various aspects of the indoor environment, as well as their overall satisfaction and wellbeing. Both occupants and casual users were given the opportunity to self-assess their level of satisfaction with each identified aspect. The social dimension aspects of spaces for social interaction and building connection to nature will impact the building as a whole and are investigated with questions in another survey (see Table S3 online), as well as focus group discussions (see Table S4 online). Besides the surveys, the residents, office workers and other building users are asked to 'audit' the spaces they use and reflect on their perceptions about those spaces by using an 'audit tool' on their smart devices.

In the (1) regular indoor comfort surveys (see Table S1 in the supplemental data online), also on smart devices, the occupants and office workers respond to a series of indoor environmental quality questionnaires developed mainly using a Likert scale to reflect on their perceptions of thermal, visual and acoustic comforts, indoor air quality, and their wellbeing at the time. They also provide information about their adaptive behaviours to respond to their present indoor environmental condition, such as their clothing layers, activity types, window operations and indoor lighting operation. During an introductory visit, the participants received comprehensive instructions on how to respond to the survey, which included a detailed explanation of all the questions and an opportunity to address any queries or concerns they had. Each participant is expected to respond to the survey at least twice a week at different times of the day, for 12–18 months, so that their experiences in different seasons throughout the year can be captured. The participants are free to answer the survey at their convenience and availability. However, they are specifically instructed to, if possible, provide a balanced mix of responses between moments of satisfaction and moments of dissatisfaction with the indoor environment in relation to physical comfort. To encourage participation, local café vouchers are distributed to participants who answer a minimum of 10 surveys per month. In June 2023, there were a total of 559 survey answers from residents and 343 from office workers.

The one-off indoor delight survey (see Table S2 in the supplemental data online) involves participants responding to questions regarding specific aspects of the indoor environment that enhance positive stimuli, focusing on evaluating the impact of views, connection to nature, and space size on occupant satisfaction and wellbeing. As this survey is only completed once, it is

expected to generate a lower number of responses compared with the physical comfort survey. In order to increase the response rate, the survey is also available to all individuals within the building, irrespective of their participation in this research. This approach aims to gather a larger and more diverse set of responses, contributing to a comprehensive understanding of the relationship between these specific environmental factors and occupant satisfaction and wellbeing.

3.5 FOCUS GROUP DISCUSSION

A series of focus group discussions with U City residents and office workers in the building are held to gather qualitative data relating to the experience of the building users. They are held every month in the third-floor public communal space. These focus groups are based on the different parameters of RIBA's Social Values Framework and provide in-depth, qualitative data about different themes of importance to the overall project, including factors about living or working at U City that users perceive to influence their sense of wellbeing. Topics are detailed in Table S4 in the supplemental data online.

3.6 INDOOR ENVIRONMENTAL PARAMETERS DATA COLLECTION

Throughout the duration of the study, continuous monitoring and recording of indoor environmental parameters in the spaces where occupants or building users respond to survey questionnaires were conducted at 30-minute intervals using data loggers. Additionally, hand-held measuring devices were employed for regular measurements. These parameters encompassed indoor dry bulb temperature, globe temperature (representing radiant temperature), relative humidity, illumination level, sound or noise level, air velocity and CO_2 levels. The collected data regarding indoor environmental parameters enable an understanding of the comfort conditions in which occupants or building users tend to experience satisfaction and positive wellbeing, as well as the conditions that lead to dissatisfaction and reduced wellbeing. In conjunction with the logger data, a 3D model of the building and its surroundings was developed to extract information and quantify aspects such as views, access to green spaces, living space size, and the quantity and distribution of spaces for social interaction. This information aids in discerning the conditions that trigger greater or lesser satisfaction, contributing to the comprehension of what factors or aspects of the delight dimension contribute to occupant wellbeing.

4. RESULTS

When evaluating high-rise, mixed-use developments, it is important to augment hedonic data with elements related to eudaimonic wellbeing, adding a social dimension that includes spaces for social interaction and building access to green spaces that allow occupants to connect with nature and engage in physical activities. Therefore, the quantifiable aspects that affect satisfaction with the indoor environment and wellbeing have been separated in three different dimensions: comfort, delight and social (Figure 6).

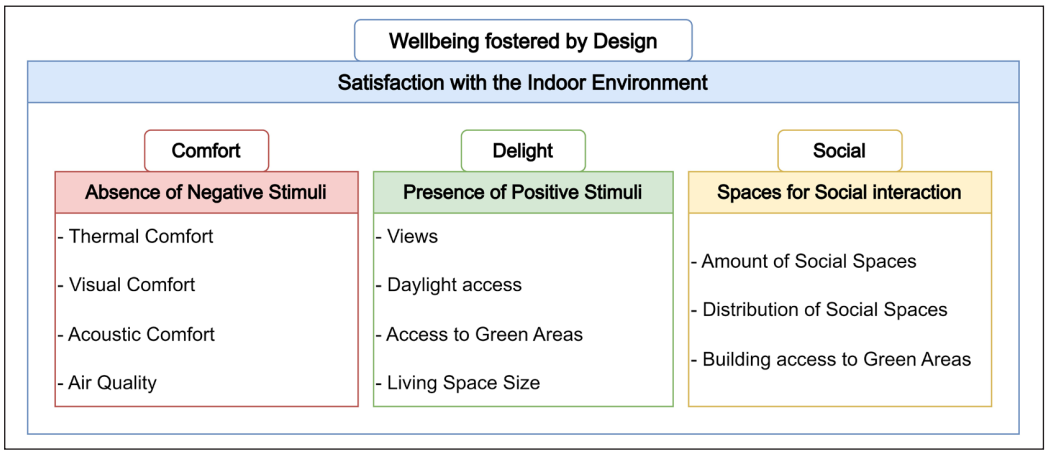

Figure 6: The three dimensions of quantifiable aspects of the building design that affect satisfaction with the indoor environment and wellbeing.

The proposed dimensions informed the development of the framework and the POE to gather and integrate the required data in a way to have a holistic understanding of the wellbeing fostered by design. The framework incorporates data collection from the indoor environment through data loggers along with 3D model information such as view percentages and areas. The responses provided by survey participants will provide a way to quantify their level of satisfaction with these parameters and their overall satisfaction with the environment. The underlying argument stems from the recognition that satisfaction with the indoor environment is an important component of occupants' wellbeing, as highlighted in the literature review. This framework represents an initial step towards the development of a metric for evaluating building design, which can be seamlessly integrated into the analysis tool for the 3D model. The metric aims to provide a quantifiable measure of the level of wellbeing fostered by the design itself, enhancing the assessment process (Figure 7).

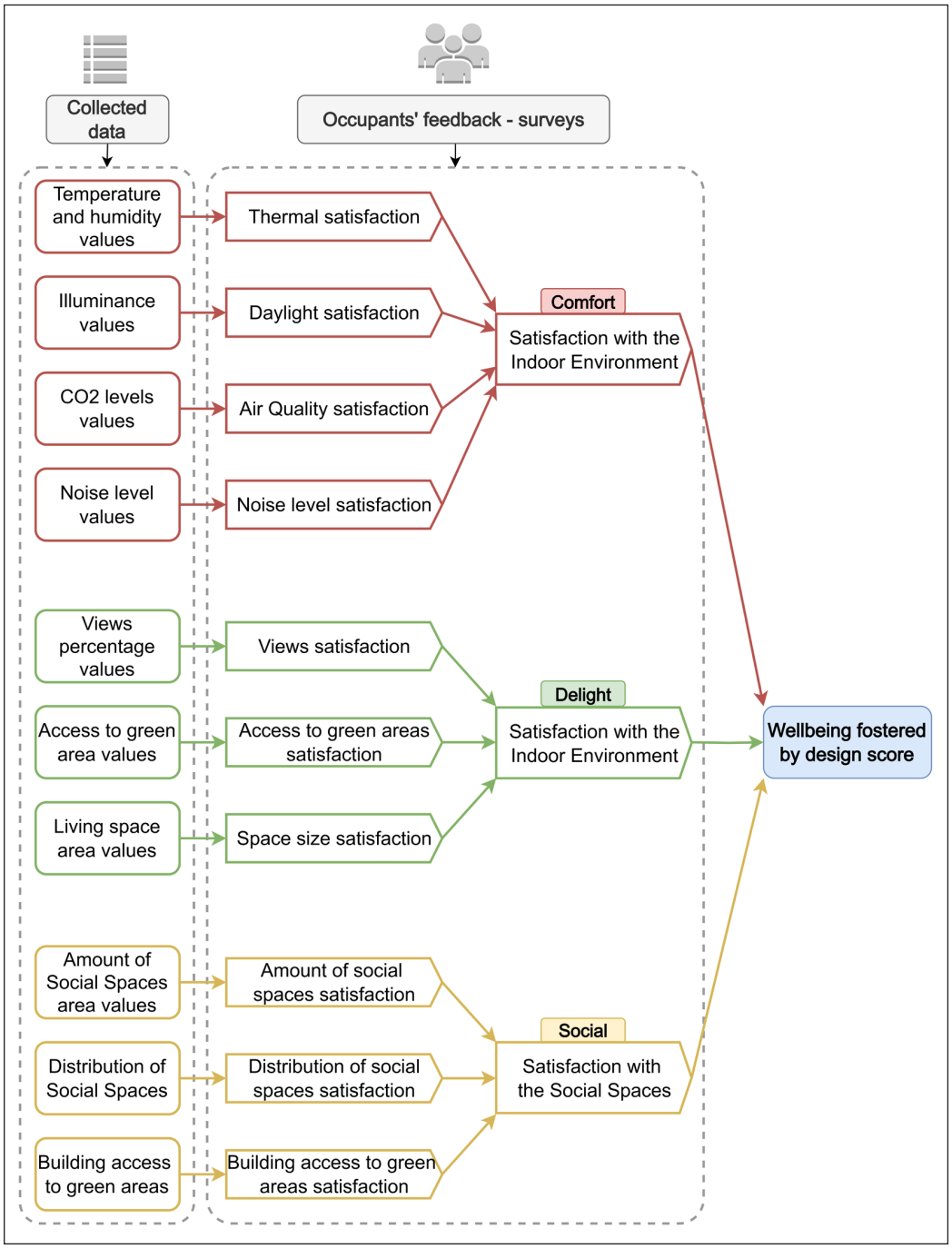

Figure 7: Proposed framework.

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5. DISCUSSION AND LIMITATIONS

As discussed in the literature review, to foster wellbeing in the built environment, the spaces need to provide not only comfort but also positive stimuli that include views, connections with nature, appropriate space size and appropriate spaces to allow social interaction.

Due to insufficient data to present the preliminary results on the 'delight' and 'social' dimensions, the authors decided to exclude such results from this paper and redirect the focus towards the development of the framework. However, the focus group discussions so far have pointed to the need of creating more green spaces and community gardens, and that the spaces for social interaction and activities that bring the occupants together, making the building a community, are important features. These have been mentioned a few times as relevant and important to their wellbeing. Quantifying those spaces and evaluating qualities such as comfort, connections to nature and views, can therefore provide designers with feedback on how well the building performs in fostering wellbeing of its occupants.

Evaluating the wellbeing fostered by the built environment is an important step towards enhancing the social value of new developments as the social value is intrinsically connected to the wellbeing of the building occupants as outlined above in the first part of the literature review. The aspects pointed out by this study are, however, limited to those that can be quantified and evaluated by analysing a 3D model. The aspects identified in this study can also be considered as the more permanent ones, or aspects that cannot be easily changed or retrofitted, and therefore those that need more attention from the early design stages.

Many other intangible aspects relating to the quality of the spaces have been omitted. The qualities relating to interior design such as colours, finish materials, ergonomics, aesthetics, interactive features, furniture and art installations are beyond the scope of this study, and this is a limitation. Some of these other aspects were indeed mentioned in focus group discussions. It is possible to include these as guidelines for designers within a broader social value framework that will be developed by other complementary studies or that could even be a subject of study in future research.

Another limitation is that the POE was conducted solely in a single case study, featuring occupants with a specific profile in terms of age, financial background and education. Consequently, this restricted scope may introduce biases and hinder the generalisability of the findings. However, the proposed framework can serve as a foundation for future multiple case studies. Expanding the study to include diverse settings and occupant profiles would enhance the external validity of the findings and provide a more comprehensive understanding of the relationship between indoor environment, occupant satisfaction and wellbeing.

6. CONCLUSIONS

This paper develops a framework that could quantify the aspects of building design impacting occupants' wellbeing within a high-density development. By establishing a framework that measures inhabitants' perceptions of each aspect in a specific case study, this research initiates the exploration of the relationships between different design elements and provides insights.

The development of this framework and the use of quantifiable aspects offer a means for promoting occupant wellbeing in building design. The lessons learned and data collected serve as the foundation for a prototype machine-learning model that could be integrated into a 3D model evaluation tool to enhance future developments. By integrating these considerations into the design process, designers and stakeholders can make informed decisions that prioritise the creation of environments that foster occupants' satisfaction, social interaction and overall wellbeing.

The proposed approach intends to complement broader social value assessments of buildings, such as the Social Value Tool, by offering quantifiable aspects that can be assessed during the design stage. These aspects could enable predictions regarding how building design can promote positive emotions and encourage social interaction, thereby contributing to the realisation of wellbeing fostered by design. Incorporating quantifiable aspects into computational tools allows

for the evaluation of wellbeing throughout the design process, facilitating evidence-based decision-making. Furthermore, quantifiable aspects that can be measured can provide evidence for financial assessments and funding opportunities. This evidence can be instrumental in advocating for long-term development strategies that prioritise and foster wellbeing.

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COMPETING INTERESTS

The authors have no competing interests to declare.

ETHICAL APPROVAL

Ethical approval was obtained from the Human Research Ethics Committee, University of South Australia (application ID 204505). All participants provided written consent for participating in the research.

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SUPPLEMENTAL DATA

Supplemental data for this paper can be accessed at: https://doi.org/10.5334/bc.336.s1.

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