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RESEARCH ARTICLE

A user-centric analysis and survey-based approach for early design decision-making criteria of the 'Symbiotic Data Platform': Integration of BIM with IoT for occupants' thermal comfort

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Abstract

This study aims to create the Symbiotic Data Platform, focusing on the intricate relationship between humans and the environment to optimize occupant thermal comfort and energy efficiency. The paper outlines early design decisions based on a validation survey, seeking to define user-centric demands and identify supply gaps. The Symbiotic Data Platform integrates Building Information Modeling data with real-time information, emphasizing user thermal perception, preferences, and demands. An online validation survey with 475 participants was conducted in the early design stages to gather essential insights. The study underscores the crucial role of user feedback in shaping early design decisions, emphasizing the need to incorporate user requirements for an effective system. The majority of participants expressed a demand for a personalized system to optimize residential thermal comfort and reduce energy consumption while including the building material data together with the occupants' real-time comfort information. Therefore, to be able to analyze the applicability and usability of this study, user-centric analysis was essential. Acknowledging the limitations of relying solely on user feedback, the study emphasizes a comprehensive approach considering various factors affecting occupant comfort and energy efficiency, with these limitations reconsidered during platform design. Practically, the findings stress the importance of real-time consideration of occupant preferences in decision-making processes, contributing to energy optimization and enhanced occupant comfort within buildings. The survey's participantbased demands were implemented as requested during the platform's design.

1. Introduction

Addressing the emerging energy requirement requires a strategic emphasis on energy efficiency within urban planning and infrastructure development. The proactive integration sustainable practices, technological advancements, and renewable energy sources can mitigate the environmental impact associated with the heightened energy demand. Furthermore. promoting responsible resource management and fostering a culture of energy conservation among urban inhabitants are integral aspects of a comprehensive approach to ensure the sustainable growth of cities. Accordingly, our planet faces crucial climatic concerns and there is a current risk The related to energy consumption. built

environment has a remarkable amount of impact on climate change. The HVAC systems typically account for a substantial portion of the total energy usage in a building, averaging around 40% [1]. Moreover, approximately 40% of the world's total energy consumption is attributed to buildings, with projections suggesting that energy conservation potential in this sector could range from 20% to 40% [2]. The global energy system faces the risk of not meeting the expected forthcoming developments in technology [3].

The interaction between individuals and their surroundings is intricate and dynamic, encompassing elements such as time, climate, architectural structure. societal influences. economic considerations, and various other factors, in addition to the immediate physical setting [4]. Several valuable energy-efficient technologies have emerged to address the pressing issue of extensive energy consumption. Consequently, global energy production, distribution, and utilization have become more efficient through various regular measures. These initiatives, supported by an intensified global policy emphasizing energy efficiency, contribute to curbing the escalation of global energy demand. Energy-saving tools and systems effectively diminish the necessity for additional investments in energy supply, combat environmental apprehensions, and sustain economic development. Therefore, innovative technologies offer enhanced efficiency. Notably, fostering a heightened awareness of sustainability and environmental resilience among the new generation can make a significant positive impact. The relationship between humans and the environment is multifaceted, encompassing various aspects such as the physical environment, climate, building characteristics, and individual preferences. Excessive use of HVAC systems and high energy consumption significantly impact global energy sustainability and the climate crisis. Consequently, changes in global trends, the transition toward more conscientious consumer behavior, and collaboration between academic research and industry are expected to yield more advanced tools and sophisticated platforms for addressing global

concerns. With a focus on the intricate relationship between energy consumption and the current thermal management infrastructure, this study delves into exploring a more integrated link between the occupant and the constructed environment. In the realm of energy-efficient technologies, the prevailing focus has predominantly centered on optimizing design and development processes to enhance the overall sustainability of projects. However, a significant research gap exists, notably in the integration of occupants into the efficiency equation. Recognizing the pivotal role that occupants play in the energy consumption of buildings, this research endeavors to bridge this gap by incorporating the human element into the broader framework of energy efficiency. The objective is to create a holistic approach that not only considers technological advancements but also incorporates the behavior and preferences of building occupants. This research aims to redefine the conventional understanding of energy efficiency by blending it with the innovative concept of the 'Symbiotic Data Platform'. By intertwining technological solutions with occupant engagement, this approach seeks to create a harmonious synergy that maximizes energy efficiency while ensuring optimal comfort and functionality for those utilizing the space, not only by developing a sustainability conscience but also offering automation technology. Correspondingly, the research emphasizes the early design phases of a platform aimed at proposing an occupant-centered alternative solution optimizing thermal comfort alongside energy efficiency. This paper provides a brief introduction to the Symbiotic Data Platform and presents the findings of a validation survey conducted during the platform's early design stages.

2. Hypothesis and Research Objectives

In the realm of building design and construction, technological advancements have been consistently reshaping how professionals work and think. Two of the major game-changers in recent years have been Building Information Modeling (BIM) and the Internet of Things (IoT). Independently, they've

transformed their respective domains; however, when blended, they hold the potential to redefine the very fabric of smart buildings. The objective of the Symbiotic Data Platform (SDP) project is to prove the feasibility of using BIM data by the occupants to maximize comfort, as this issue has not been considered in the literature in detail yet. This research develops a new branch that includes both BIM with intelligent environments and responsive structures to have a contemporary, conscious, and environmentally responsible approach to architecture, engineering, and design in the occupation phase. Therefore, the research gap emerges: Since BIM is a platform that holds nearly all the data of the building, why does it not interact with the occupant of the buildings' real-time and personalized input, providing a better comfort level and user comfort maximization, as well as addressing energy efficiency? BIM serves as the virtual counterpart of an actual building, encompassing all physical details in digital form. In the digital age, occupants, who actively utilize the building, should have access to comprehensive information about their constructed surroundings. The Network Society [5] demands more intelligent systems from the built environment. Modern technology and existing software, devices, and tools can capture, process, analyze, integrate, and interact with extensive datasets and real-time information concurrently. As a result, the accessible real-time data and information can be leveraged to enhance the well-being of inhabitants, ensuring optimized comfort and increased energy efficiency. The produced data challenges the smart systems to be used as an incubation medium or as a decisionmaking gear. In this regard, this paper presents the validation survey results that have been conducted at the early stages of the design-thinking process of SDP. The validation survey addressed the potential users of the platform.

3. The Symbiotic Data Platform Research

The Symbiotic Data Platform [6] is a research initiative focused on creating an adaptive tool to optimize the comfort of occupants and improve energy efficiency with real-time information. By

utilizing the Building Information Modeling (BIM) data of the occupants' structure as an input, the platform continually monitors the occupants' body temperature and analyzes the surrounding thermal conditions. The scientific contribution of this research project lies in its ability to automatically compute the ideal comfort level and sustain it in real time while consuming the bare minimum of energy. Functioning as an interactive tool, the Symbiotic Data Platform operates through the automatic capture of real-time data. It owes its development to advancement of existing information technologies and supportive tools. By implementing this platform, the notion of intelligent homes can be propelled to a more advanced and interactive stage, linking these smart homes to an accessible network and utilizing the acquired data to its advantage. It aspires not just to be an upgraded, digitally controlled home or building, but a comprehensive platform that engages with users and processes data to elevate living standards and productivity. In this project, the continuous flow of real-time data holds utmost importance, as it serves not only as a monitoring mechanism but also as an interactive data platform that is managed by the end-user, who happens to be the building occupant. The backbone of this platform is the Building Information Modeling (BIM), while real-time data serves as the interactive input, facilitated by the Internet of Things (IoT) system. This platform operates as a responsive tool designed to tailor the optimization of thermal comfort to individual preferences. The research is primarily focused on exploring novel avenues for enhancing interactivity the of the methodology, utilizing existing BIM data during the building's occupancy phase, and investigating the potential for simultaneously boosting energy efficiency and maximizing comfort by harnessing the capabilities of BIM. Similarly, emphasizing the significance of BIM data within the Symbiotic Data Platform, particularly about thermal comfort, employing the prototype as a regular daily tool for the private spaces of residents could yield precise feedback concerning both energy efficiency and personalized comfort standards (Fig. 1).

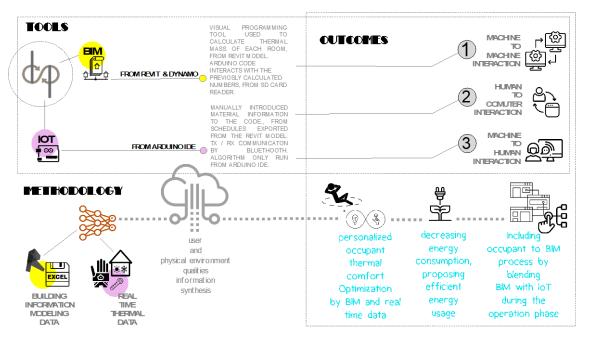


Fig. 1. Symbiotic data platform project flowchart (tools, methodology and outcomes)

The platform is designed to monitor the user's body temperature in real-time and assess the thermal conditions of their surroundings. It also provides up-to-date information on external weather conditions and internal thermal data. This comprehensive approach aims to ensure optimal thermal comfort for each user. Users can set their preferred comfort levels during setup, and these settings can be adjusted as needed. The platform considers various variables, including the user's current body temperature, thermal characteristics of materials drawn from the BIM database, and realtime environmental conditions such as outdoor weather and indoor ambient temperature. The interaction begins when users touch the data collection device, also known as the transmitter. This device can be linked to the user's mobile phone, as it operates location tagging and other control mechanisms through a mobile app. Once users confirm their indoor location via the app, the system verifies the "room thermal value" against predefined thresholds. After this initial interaction, the system gathers open-source local weather information and specific case data, including interior temperature, user location, and body temperature. This data is then transmitted to the

algorithm, which integrates real-time weather and thermal information. To ensure accurate and personalized thermal comfort, corresponding thresholds are set within the mobile app. The platform's custom algorithm blends these variables to generate personalized thermal comfort analyses. It can subsequently adjust for optimal comfort and achieve energy savings by regulating the HVAC system.

The literature review by Birgonul [6] shows that when BIM technologies are integrated with sensor networks, it opens up a new horizon with promising capabilities to monitor building operation & maintenance, and therefore preventing energy waste during the life-cycle of the building. Lately, such projects as Nguyen [7]; Wu and Liu [8]; Lin and Cheung [9]; Baiardi and Ferreira [10]; Mataloto et al. [11] and Kameli et al. [12] indicate the feasibility and feasibility of integrating controls using Building Information Modeling (BIM) and the Internet of Things (IoT) during the occupancy period. While the significance of occupants' roles and influence during this phase is recognized, there is still an unaddressed research gap regarding the utilization of user-operated enabling technologies, systems, or platforms. This gap particularly concerns the effective utilization of existing BIM data and real-time data during the operational stage of buildings.

4. Methodology

In this study, the research is conducted initially with a profound literature review on the possibilities of integrating BIM and real-time information (IoT) technologies. The outcomes from the existing literature are implemented in the design and development of the Symbiotic Data Platform. Relatively, this paper documents a brief introduction to the Symbiotic Data Platform and focuses on the survey results, shedding light on the early design decisions shaped by user feedback. This project was conceived with a focus on the preferences and expectations of building occupants, initiating the decision-making process through an online survey. The research yielded a positive validation of the hypothesis, demonstrating the utilization of real-time data in the Building Information Modelling framework during the occupancy phase, catering to the daily comfort and energy efficiency needs of the occupants. By leveraging BIM as an established data repository and integrating it with other platforms, the system facilitates sophisticated data processing techniques to optimize energy efficiency and enhance occupant comfort in practical settings.

5. Validation Survey Results

In the pursuit of this project, the primary focus has been directed towards exploring thermal comfort. Aiming to demonstrate the practical application of the Symbiotic Data Platform, an online survey involving 500 participants was undertaken. During one week, 475 participants completed the survey. The participants were informed at the beginning of the online survey, and they only proceeded to the questionnaire by giving consent for their participation. No personal information is asked or used during the study, all answers are kept anonymous.

In this validation survey, questions related to the needs and desired occupancy qualities are asked.

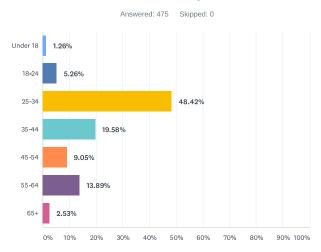
There were 27 questions in total, and most of them had multiple-choice formats. The last question was in written answer format since the personal feedback was highly appreciated questionnaire. Participants' age and gender are depicted in Fig. 2. Nearly half of the respondents (48.42%) fall between the ages of 25 to 34, with the second-largest cohort (19.58%) comprising individuals aged 35 to 44. The remaining participants are distributed across other age groups. Gender information was collected solely to illustrate respondent distribution but was not utilized as a decision-making factor in the study, as it did not significantly impact the analysis.

The user profile is selected by the education level, and the survey link is shared with universities and companies. Participant selection is done by asking about their education level and their profession. Participants' profession and specialization is shown in Fig. 3. The majority of the respondents are from the Architecture and construction industry profession (34.11%). This fact is important due to the occupants' knowledge of BIM and physical environment awareness is valuable, (but not essential) for the study.

The survey findings highlight the widespread preference for thermal comfort as the paramount physical consideration in both residential and public buildings. Additionally, the participants responded to inquiries regarding energy-efficient practices within the same survey. The project's feasibility and contextual validation are established based on the participants' quantitative responses and an extensive review of pertinent literature. The survey was conducted to comprehend societal norms concerning thermal comfort and energy efficiency, ultimately validating the viability and pertinence of the Symbiotic Data Platform, given the participants' expressed interest in incorporating such services into their daily lives.

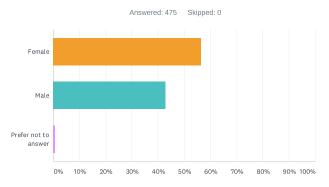
There is evident enthusiasm among users for the adoption of enabling technologies and applications to enhance both comfort optimization and energy efficiency, whether independently or through integrated means.

Q1 How old are you?



ANSWER CHOICES	RESPONSES	
Under 18	1.26%	6
18-24	5.26%	25
25-34	48.42%	230
35-44	19.58%	93
45-54	9.05%	43
55-64	13.89%	66
65+	2.53%	12
TOTAL		475

Q2 What is your gender?



ANSWER CHOICES	RESPONSES	
Female	56.42%	268
Male	42.95%	204
Prefer not to answer	0.63%	3
TOTAL		475

Fig. 2. Survey participants' profile (age and gender)

Q5 What is your profession category? (if applicable)

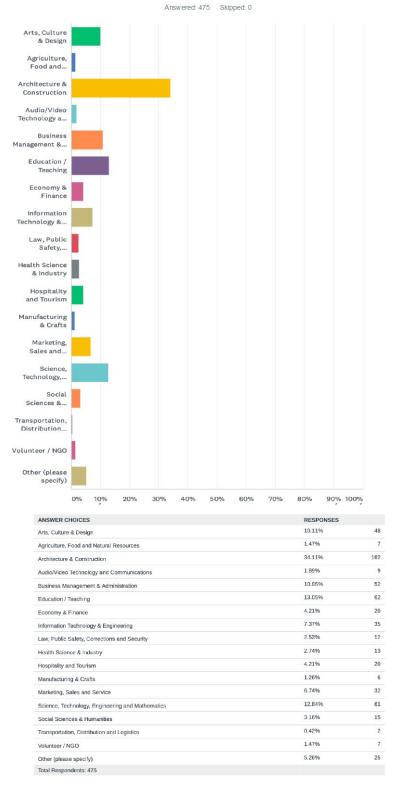


Fig. 3. Survey participants' profile (profession and specialization)

Initial eleven questions were designed to detect the participant's profile while keeping the identities anonymous. The first questions addressed the participant's age, gender, location, profession, type of housing, and type of convivence.

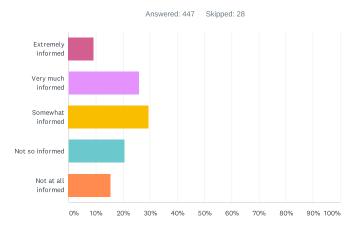
In Questions 12 and 13; the knowledge and awareness of their physical environment is questioned. For Question 12: 'Are you informed about your houses' structure and material qualities?'; participants answered as follows; Extremely informed 9.17%, Very much informed 25.95%, Somewhat informed 29.53%, Not so informed 20.58%, Not at all informed 15.44%. This information represents the occupant's perception and their prior knowledge of the physical quality of the space that they occupy. Eventually, 65.55% of the participants do not have a clear idea of the material, insulation, and thermal qualities of their house, which may cause inconvenient acts for thermal comfort and energy efficiency. For Question 13: 'Are you satisfied by the physical conditions of your house?', participants reacted as; 14.77% Very satisfied, 36.91% Satisfied, 23.94% Somewhat satisfied, 11.86% Neither satisfied nor dissatisfied, 9.40% Somewhat dissatisfied, 3.80% Dissatisfied and 0.45% Very dissatisfied. As a result, 49.45% of all, which is almost half; are not completely satisfied with the physical conditions of their home. This information represents the necessity of the betterment methodologies and is also considered as a research gap in the existing literature, that should be examined more profoundly (Fig. 4).

For question 14: 'Which indoor physical condition is more important for your comfort?', participants answered in the majority' Thermal Quality' at 60.85%, where 'Light Quality' takes 55.03%, 'Air Quality' at 46.76%, 'Acoustics' 19.69%, 'Spatial Organization' 28.19%, and others 2.68%. For this question, respondents were allowed to choose more than one option, so as not to force them to only one possibility. Even in that case, the thermal conditions are selected as the most essential quality for comfort. Also, in question 15, 'Which ones from the options below do you consider that

are important for users' comfort level?', they answered, Location & Surrounding Environment 84.12%, Material Qualities of the Building 53.24%, Habits & Cultural Aspects 25.50%, Real-time Conditions 20.18, Biologic Factors 12.30%, and others 2.91%. This information shows the importance of the location and the surrounding environments' effect on audiences' perception, as well as the cognition of the importance of the material qualities of the building. The extensive evaluation of participant responses underscores the paramount importance of examining interdependent relationship between 'Location & Surrounding Environment' 'Thermal Quality' and 'Material Qualities of the Building'. These findings underscore the critical role of both factors in shaping occupants' comfort perception, highlighting the intricate interplay between indoor environmental conditions and the structural elements of the building, thereby emphasizing their collective significance in ensuring an optimal comfort experience for building occupants (Fig. 5). This substantial majority underscores the crucial importance of focusing on comfort optimization within residential settings. The remarkable percentage of respondents emphasizing the significance of this aspect validates the relevance and necessity of this research from the perspective of the occupants, solidifying the significance of the study's objectives in addressing key concerns related to occupant comfort in their homes, but not at other public spaces in the first position.

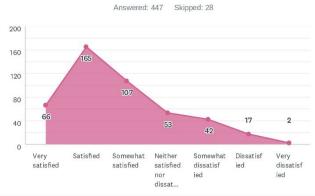
For questions 16 and 17; 'Would you like to have a smart control system for your comfort optimization?' and 'If yes, which concern you would like it to address in the first position?', participants answered; 31.99% said Very Likely, and 40.72% answered Likely. In total, 72.71% of all answered positively to this question. By extension, 36.02% chose 'Thermal Comfort Optimization' as a majority. This fact shows and validates the importance of thermal qualities and thermal comfort in residential spaces once again (Fig. 6).

Q12 Are you informed about your houses' structure and material qualities?



ANSWER CHOICES	RESPONSES	
Extremely informed (1)	9.17%	41
Very much informed (2)	25.95% 1	.16
Somewhat informed (3)	29.53% 1	.32
Not so informed (4)	20.58%	92
Not at all informed (5)	15.44%	69
Total Respondents: 447		

Q13 Are you satisfied by the physical conditions of your house?



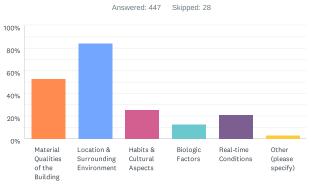
ANSWER CHOICES	RESPONSES	
Very satisfied	14.77%	66
Satisfied	36.91%	165
Somewhat satisfied	23.94%	107
Neither satisfied nor dissatisfied	11.86%	53
Somewhat dissatisfied	9.40%	42
Dissatisfied	3.80%	17
Very dissatisfied	0.45%	2
Total Respondents: 447		

Fig. 4. Online survey – Questions 12 and 13

Q14 Which indoor physical condition is more important for your comfort?



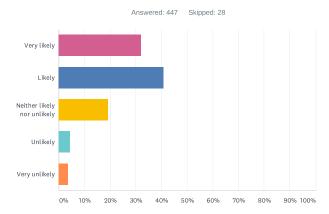
Q15 Which ones from the options below you consider that are important for users comfort level?



ANSWER CHOICES	RESPONSES	
Material Qualities of the Building	53.24%	238
Location & Surrounding Environment	84.12%	376
Habits & Cultural Aspects	25.50%	114
Biologic Factors	12.30%	55
Real-time Conditions	20.81%	93
Other (please specify)	2.91%	13
Total Respondents: 447		

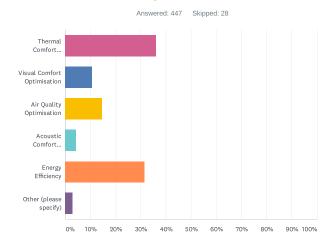
Fig. 5. Online survey - Questions 14 and 15

Q16 Would you like to have a smart control system for your comfort optimisation?



ANSWER CHOICES	RESPONSES	
Very likely	31.99%	143
Likely	40.72%	182
Neither likely nor unlikely	19.24%	86
Unlikely	4.47%	20
Very unlikely	3.58%	16
TOTAL		447

Q17 If 'Yes', which concern you would like it to address in the first position?



ANSWER CHOICES	RESPONSES	
Thermal Comfort Optimisation	36.02%	161
Visual Comfort Optimisation	10.74%	48
Air Quality Optimisation	14.54%	65
Acoustic Comfort Optimisation	4.25%	19
Energy Efficiency	31.54%	141
Other (please specify)	2.91%	13
TOTAL		447

Fig. 6. Online survey – Questions 16 and 17

Moreover. the notable response rate underscores the relevance of addressing occupants' specific needs and preferences within their living spaces. By focusing on comfort optimization in residential settings, the research demonstrates a profound understanding of the crucial interplay between environmental conditions and individual satisfaction, thereby aligning the study's objectives with the immediate concerns of the target users. Additionally, the clear indication of the importance of comfort optimization in residential environments serves as a vital guideline for policymakers, architects, and building designers, directing attention toward the significance of incorporating user-centric design principles in the development of future residential structures. This result not only underscores the urgency of addressing comfortrelated challenges in residential buildings but also underscores the potential societal impact and practical implications of implementing effective strategies to enhance comfort and well-being for occupants.

For question 18; 'In which cases comfort optimization is more important for you?', the

majority of the participants responded with 'Residential' usage 71.6% which is a remarkable percentage, therefore this result shows the validation and the importance of this research for the occupant's point of view (Fig. 7).

The dominance of the 'Residential' category in respondents' prioritization of comfort optimization emphasizes the critical role of enhancing living conditions and well-being within personal spaces. As individuals spend a significant portion of their time in residential settings, the high percentage of participants prioritizing comfort optimization in this context highlights the direct impact on their quality of life and daily experiences. The remarkable 71.6% majority of participants prioritizing comfort optimization in residential settings underscores the significance and relevance environment from the occupant's perspective. The decision to concentrate on residential spaces is justified by recognizing the critical role these environments play in individuals' lives.

Q18 In which cases comfort optimisation is more important for you?



Fig. 7. Online survey – Questions 18

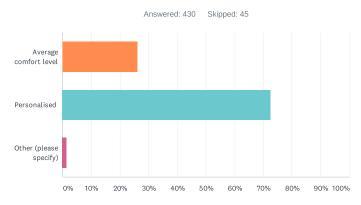
Given that people spend a substantial amount of their time in their homes, the high percentage of respondents expressing a need for comfort optimization in residential settings indicates a direct impact on their overall quality of life and daily experiences. The study acknowledges immediate and tangible benefits associated with improved comfort in personal spaces, as evidenced by the dominant preference for 'Residential' in respondents' prioritization. By choosing residential spaces as the main area of focus, the study aligns with the priorities and preferences of the participants. It acknowledges the importance of enhancing living conditions within personal spaces, emphasizing the potential to make a meaningful impact on occupants' well-being and satisfaction. In essence, the selection of residential spaces as the primary area for investigation is grounded in the recognition of their central role in individuals' lives and the compelling need, as expressed by participants, for optimizing comfort in these environments.

For question 19; 'Do you think comfort optimization should take reference from average

values or users' personal input?', the majority of 72.56% answered 'Personalized' comfort optimization over 'Average' comfort level references. This information is a validation for the project, on the way of proposing customized and personalized thermal comfort by real-time values and current, material information (Fig. 8). For Question 21; 'Do you know about smart home technologies?', participants answered in the majority with 84.88% positive.

For question 25, 'If there will be a platform that does comfort optimization and improves energy efficiency together, how likely would you be using that service?', 53.26% responded 'Probably would' and 40.47% responded 'Definitely would'. In total, 6.28% of all answers are negative, whereas the majority is 93.73% positive. This result validates the feasibility and relevance of the Symbiotic Data Platform since the audience is willing to receive such a service in their daily life. The user is enthusiastic about enabling technologies and applications for comfort optimization and energy efficiency accelerants both in separate technologies and blended means (Fig. 9).

Q19 Do you think comfort optimisation should take reference from average values or users' personal input?



ANSWER CHOICES	RESPONSES	
Average comfort level	26.05%	112
Personalised	72.56%	312
Other (please specify)	1.40%	6
TOTAL		430

Fig. 8. Online survey – Questions 19

Q25 If there will be a platform that does comfort optimisation and improves energy efficiency together, how likely would you be using that service?

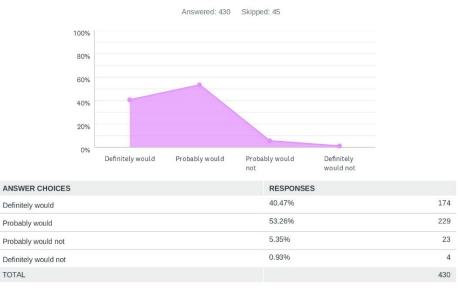


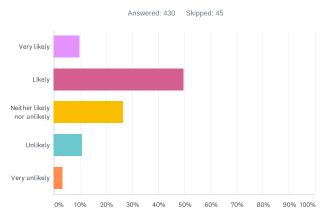
Fig. 9. Online survey – Questions 25

For question 26, 'How likely would you be to pay for such a service'; the majority of 59.3% responded positively, 26.51% were unsure or neutral, and 14.19% responded negative or unlikely. This fact shows the validation of the applicability of the project to the professional industry, regarding the users' will to pay for such services as digital applications or other mediums (Fig. 10).

In response to this question, which inquired about the likelihood of paying for the proposed service, an impressive 59.3% of participants resounding enthusiasm. expressed overwhelming vote of confidence not only signals a strong market demand but also underscores the unwavering support for the service within the professional landscape. Such an overwhelmingly positive response serves as a resounding endorsement, highlighting a clear and compelling need for the integration of this innovative solution within the digital ecosystem and other related mediums. Moreover, this result shows the potential of the SDP as a sustainable digital product that could be developed as an everyday tool that might be available in the market.

In this section, the results of the validation survey are reported. In general, the potential user desires corresponded to the hypothesis and the research question. Therefore, the survey results are used as validation outcomes for the design decisions for the Symbiotic Data Platform. To conclude; this comprehensive analysis of the results from the validation survey has affirmed the alignment between the anticipated requirements and the initial research hypotheses. The congruence observed between the desires expressed by potential users and the underlying research questions not only validates effectiveness of the survey design but also reinforces the user-centric approach adopted in the development of the platform.

By utilizing the survey results as validation outcomes, the design decisions for the platform are substantiated, ensuring that the final product is tailored to effectively meet the needs and expectations of its prospective users.



Q26 How likely would you be for paying such a service?

ANSWER CHOICES	RESPONSES	
Very likely	9.77%	42
Likely	49.53%	213
Neither likely nor unlikely	26.51%	114
Unlikely	10.93%	47
Very unlikely	3.26%	14
TOTAL		430

Fig. 10. Online survey – Questions 26

Moreover, this positive correlation between user preferences and the platform's design parameters indicates a promising trajectory for the successful implementation and adoption of the Symbiotic Data Platform. The integration of user feedback into the platform's development process not only enhances its functionality but also fosters a sense of ownership and engagement among potential users. By prioritizing user comfort and preferences, the platform can effectively serve as an instrumental promoting energy efficiency sustainability within the built environment. This proactive approach, grounded in the insights gleaned from the validation survey, underscores the potential of the Symbiotic Data Platform to create a more harmonious and symbiotic relationship between occupants and their built environment, ultimately contributing to a more sustainable and comfortable living and working environment for all stakeholders involved.

6. Discussion of Results

The study presented in this chapter offers valuable insights into the development of the Symbiotic Data Platform, a novel approach aimed at improving both energy efficiency and occupant thermal comfort. The interconnectedness of human behavior, the built environment, and climate change underscores the need for innovative solutions to tackle global energy sustainability and the pressing climate crisis. By integrating Building Information Modeling data with real-time information, the Symbiotic Data Platform represents a promising tool to address these challenges. Of particular significance is the user-centric approach taken in this study, prioritizing the thermal comfort and preferences of building occupants as the primary drivers of real-time decision-making within the platform. This approach recognizes the pivotal role of occupants in shaping the effectiveness of building systems and ensuring their satisfaction. To construct such a system effectively, the authors conducted a validation survey in the early stages of

the platform's development. The engagement of potential users and their feedback provided crucial insights that guided the platform's design and functionalities. The results of the survey illuminate the pivotal role of user requirements in shaping the Symbiotic Data Platform. By aligning the platform's features with user expectations, this approach not only ensures better thermal comfort but also actively engages occupants in the pursuit of energy efficiency. As a result, the platform represents a promising solution to reduce the excessive use of HVAC systems, minimize energy consumption, and ultimately contribute to more sustainable and climate-resilient building environments.

According to the survey results, the most important physical condition according respondents in the order of most important to least important thermal comfort, with the following percentages: Thermal Quality' with 60.85%, where 'Light Quality' takes 55.03%, 'Air Quality' 46.76%, 'Spatial 'Acoustics' 19.69%, Organization' 28.19%, and others 2.68% (Table 1). For this question, respondents were allowed to choose more than one option, so as not to force them to only one possibility. Even in that case, the thermal conditions are selected as the most essential quality for comfort.

Concerning the factors that affect users' comfort level, respondents choose the most important consideration as; 'Location & Surrounding Environment' with 84.12%, and 'Material Qualities of the Building' with 53.24%, among 'Habits & Cultural Aspects', 'Biological Factors', 'Real-time Conditions' and 'Others'.

Table 1. Survey results for question: "Which indoor physical condition is more important for your comfort?"

Physical conditions	Percentages
Thermal Quality	60.85 %
Light Quality	55.03 %
Air Quality	46.76 %
Acoustics	19.69 %
Spatial Organization	28.19 %
Other	2.68 %

The argument you presented highlights the critical role of various factors in influencing users' comfort levels, with particular emphasis on the importance of 'Location and surrounding Environment' and 'Material Qualities of the Building' (Table 2). These two aspects are crucial in determining the overall user experience and satisfaction within a built environment. Furthermore, the integration of Building Information Modeling (BIM) is proposed as a significant tool in addressing these concerns effectively. The dominance of 'Location & Environment' a Surrounding as primary consideration reflects the growing recognition of the impact of external surroundings on the overall comfort and well-being of individuals within a built space. Factors such as accessibility, proximity to amenities, natural lighting, noise levels, and overall ambiance contribute significantly to the users' perception of comfort. Understanding these aspects during the design and construction phases can significantly enhance the user experience and satisfaction, thereby contributing to the overall success of a project. Similarly, the emphasis on the 'Material Qualities of the Building' underscores the importance of selecting appropriate building materials that not only enhance the aesthetic appeal but also contribute to the comfort, durability, and sustainability of the built environment. Factors such as thermal performance, acoustics, indoor air quality, and sustainability of materials play a crucial role in ensuring the overall comfort and well-being of the occupants.

Table 2. Survey results for question: "Which ones from the options below do you consider that be important for users' comfort level?"

Factors affecting users' comfort level	Percentages
Location & Surrounding Environment	84.12 %
Material Qualities of the Building	53.24 %
Habits & Cultural Aspects	25.50 %
Real-time Conditions	20.81 %
Biologic Factors	12.30 %
Other	2.91 %

The comprehensive analysis of participant responses not only highlights the clear precedence of 'Thermal Quality' as the foremost contributor to indoor comfort but also underscores the crucial significance of 'Location & Surrounding Environment' and 'Material Qualities of the Building'. These findings emphasize the intricate between the environmental interdependence context and the physical attributes of the built environment. Understanding the collective impact of these factors is crucial in fostering an in-depth comprehension of the multifaceted nature of occupant comfort, thereby guiding the development of sustainable and human-centric design strategies aimed at creating harmonious, comfortable, and conducive indoor spaces that cater to the holistic needs of the occupants. Therefore, Symbiotic Data Platforms' early design decision-making criteria are defined to address various factors in a melting pot.

Utilizing BIM as a comprehensive tool to integrate and analyze various material options can aid in making informed decisions that align with the desired comfort and sustainability goals. The statement recognizing BIM as a valuable tool with an efficient database for addressing material and environmental concerns aligns with the growing trend of utilizing advanced technologies in the construction industry. BIM facilitates the creation of virtual models that enable architects, engineers, and construction professionals to visualize, analyze, and optimize various aspects of a building project, including material selection, energy performance, and environmental impact. By integrating BIM into the design and construction processes. stakeholders can make informed decisions that prioritize user comfort. sustainability, and overall building performance. In conclusion, the provided data and argument underscore the importance of considering both the environment and internal building external materials in enhancing users' comfort levels within a built environment. The integration of BIM as a powerful tool can significantly aid in addressing these concerns efficiently, leading to

development of sustainable, comfortable, and usercentric built spaces.

Respondents answered 72.71% positively to the question "Would you like to have a smart control system for your comfort optimization?" By extension, 36.02% of all respondents choose 'Thermal Comfort Optimization' as a majority of the concern to be addressed by such smart control tool, followed by 'Energy Efficiency' with 31.54%. This fact shows and validates the importance of thermal comfort and energy efficiency in residential spaces from the occupant's perspective. Moreover, the presented data underscores the growing demand interest among respondents implementation of smart control systems aimed at optimizing comfort within residential spaces. The high positive response rate of 72.71% indicates a strong inclination towards incorporating advanced technological solutions to enhance the overall comfort and livability of built environments. This trend reflects the increasing recognition of the potential benefits that smart control systems can offer in terms of creating more user-friendly, energy-efficient, and sustainable living spaces. Furthermore, the fact that 36.02% of the respondents prioritize Comfort 'Thermal Optimization' and 31.54% prioritize 'Energy Efficiency' highlights the key areas of concern for the occupants when it comes to the implementation of smart control systems. Thermal comfort optimization is crucial for ensuring that the indoor environment remains within desirable temperature range, thereby promoting comfortable living or working environment throughout the year. By integrating smart control systems that can regulate heating, ventilation, and air conditioning (HVAC) systems based on realtime data and user preferences, it becomes possible to maintain optimal thermal conditions while minimizing energy consumption. Similarly, the emphasis on 'Energy Efficiency' underscores the growing awareness of the environmental impact associated with energy consumption within residential spaces. By utilizing smart control systems, occupants can effectively manage and monitor their energy usage, leading to reduced

energy wastage and lower utility bills. These systems can incorporate features such as automated lighting controls, smart appliances, and energyefficient HVAC systems, thereby enabling users to make informed decisions that align with their comfort preferences and sustainability goals. This data serves to validate the significance of prioritizing thermal comfort and energy efficiency residential spaces from the occupant's perspective. It highlights the importance of integrating smart control systems that can effectively address these concerns while also enhancing the overall living experience. By leveraging advanced technologies and data-driven solutions, occupants can enjoy a more comfortable, energy-efficient, and sustainable living environment that aligns with their specific preferences and requirements. In summary, the data presented reinforces the importance of incorporating smart control systems within residential spaces, with a specific focus on optimizing thermal comfort and energy efficiency. By addressing these priorities, stakeholders can create living environments that are not only technologically advanced but also promote the well-being of occupants and contribute to a more sustainable and energy-conscious future.

Additionally, regarding the question 'Do you think comfort optimization should take reference from average values or users' input?', the majority of 72.56% answered 'personalized' comfort optimization over 'average' comfort level references. This information is a validation for the project from the user's perspective, by proposing a platform for customized and personalized thermal comfort assisted with real-time values and current material information. This fact reinforces the platform's commitment to tailoring its services to individual user needs.

Regarding the previous knowledge of smart home technologies, participants answered in the majority with 84.88% positive. Concerning the will of the prospective user of the platform, the question: "If there will be a platform that does comfort optimization and improves energy efficiency together, how likely would you be to use that

service?', 53.26% responded 'Probably would,' and 40.47% responded 'Definitely would.' In total, 6.28% of all the answers are negative, whereas the majority is 93.73% positive. As a result of this survey, the user in prospect is enthusiastic about enabling technologies and applications for comfort optimization and energy efficiency accelerants, both in separate technologies and blended means. Those results validate the feasibility and relevance of the Symbiotic Data Platform since the audience is willing to receive such a service in their daily life, and they believe this would be a practical tool for daily life. The survey's findings also underscore the respondents' familiarity and openness to smart home technologies, with an impressive 84.88% expressing prior knowledge and engagement with such innovations. This high level of technological literacy further bolsters the prospects for the successful adoption and integration of the Symbiotic Data Platform, suggesting a receptive and tech-savvy user base ready to embrace and leverage its advanced functionalities.

Additionally, the overwhelmingly positive response to the hypothetical scenario presented in the survey, with 93.73% expressing a willingness to utilize a platform combining comfort optimization and energy efficiency, underscores the user base's enthusiasm for innovative solutions that promise to enhance their daily living experiences. This resounding endorsement of the platform's concept and objectives serves as a powerful validation of its viability and relevance in addressing contemporary environmental and comfort-related challenges. In summary, the survey findings not only reaffirm the pressing need for user-centric, technologically driven solutions in the realm of sustainable building design but also fortify the rationale behind the development of the Symbiotic Data Platform. As the project moves forward, the survey's insights will undoubtedly serve as a guiding beacon, ensuring that the platform remains attuned to the evolving needs and expectations of its prospective users, thereby fostering a more symbiotic relationship between people, technology, and the built environment. The survey findings serve as a compelling testament to the growing recognition and acceptance of smart technologies aimed at enhancing both comfort optimization and energy efficiency in residential spaces. The resoundingly positive response of the participants expressing a desire for a smart control system for comfort optimization underscores the burgeoning demand for integrated solutions that prioritize user comfort while concurrently promoting energy-saving measures. By endorsing a personalized approach over generic average values, the survey highlights the intrinsic value placed on user agency and the acknowledgment of the diverse and subjective nature of comfort preferences. This user-driven approach forms the cornerstone of the platform's design philosophy, emphasizing its commitment to fostering a highly customized and responsive user experience.

7. Conclusion

The relationship between people and the environment is complex and active, involving concerns such as the physical environment, climate, building qualities, and personal factors. Excess use of HVAC systems and relatively extravagant energy consumption have substantial effects on global energy concerns and the climate crisis. Due to this concern, the Symbiotic Data Platform is developed as a receptive-responsive tool for maximizing the occupant's thermal comfort while enhancing energy efficiency by blending Building Information Modelling data with real-time information. For this occupant-centric comfort study with interactive responsivity, the user's thermal perception, preference, and demand were the main databases for the platform's real-time decision-making. To be able to construct such a system, the requisition must be analyzed. Therefore, in the early design stages of the Symbiotic Data Platform; a user survey was conducted to validate its usability and its functional demand. This survey addressed the potential users of the platform; which are the people that eventually identified essential consideration points towards the evolution of the platform. The evolution of the Symbiotic Data Platform marks a paradigm shift in the realm of sustainable building design, underscoring a transformative approach that transcends conventional energy management systems. In its seamless amalgamation of BIM data and real-time information, the platform redefines environmental responsiveness parameters and sets a precedent for a more symbiotic relationship between technology, architecture, and human well-being. A pivotal aspect of the Symbiotic Data Platform is its profound emphasis on occupant-centric comfort.

By prioritizing the thermal perception, preferences, and demands of the individuals within the built environment, the platform recognizes the inherently subjective nature of comfort and seeks to transcend the limitations of standardized temperature control systems. This holistic approach engenders a heightened sense of well-being and productivity among occupants, fostering a more harmonious and conducive living or working environment. Furthermore, the integration of the platform's real-time decision-making capabilities not only optimizes energy efficiency but also fosters a deeper level of engagement and empowerment among users and the built environment. By affording occupants a degree of control over their immediate surroundings, the platform cultivates a sense of environmental responsibility, thereby instilling a collective consciousness regarding energy conservation and sustainability.

The critical role played by the validation survey in the early stages of the platform's development cannot be overstated. By soliciting input from prospective users, the survey not only facilitated a comprehensive understanding of their diverse needs and expectations but also catalyzed the platform's user-centered design ethos. The insights gleaned from the survey served as a compass guiding the development team toward a more nuanced and inclusive approach, one that was attuned to the intricacies of human experience and behavior within the built environment. As the discussion unfolds, it becomes apparent that the Symbiotic Data Platform represents more than just a technological innovation; it embodies a holistic philosophy that underscores the inseparable link

between environmental sustainability, user wellbeing, and technological advancement. By fostering a deeper understanding of the complex interplay between people and their built environment, the platform offers a compelling vision for a future where technology serves as a facilitator of enhanced human experience while simultaneously contributing to the preservation of our planet's resources.

The main limitation of the study is the variety of existing HVAC systems and the diversity of the constructed infrastructure. However, how the platform can maintain its sustainability and ensure consistent results, especially if the participant (occupant) profiles. technological infrastructural features, environmental factors, and geographical conditions might change is considered during the development of the Symbiotic Data Platform. To ensure sustainability, the platform needs suitable infrastructure, regular updates, and the ability to adapt to new trends and technologies. It must remain useful and relevant over time. Therefore, this survey underscores the need for clear methods, thorough analysis, and careful documentation of participant demands from the built environment and physical control mechanisms in order to optimize comfort levels. By doing so, the platform can keep providing valuable insights while adjusting to changes in who uses it.

The integration of technology with environmental concerns has become paramount in

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contemporary society, particularly in the context of the escalating climate crisis. In response to the significant impact of energy consumption on environmental sustainability, the development of the Symbiotic Data Platform represents a crucial step towards reconciling human comfort needs with energy efficiency goals in the built environment. The key premise of the Symbiotic Data Platform lies in its ability to synergize Building Information Modelling data with real-time information, thereby facilitating a dynamic balance between maximizing occupants' thermal comfort and minimizing energy consumption while including the occupant in the operational stage. By harnessing the power of realtime data, the platform can make informed and instantaneous decisions, enhancing the overall sustainability of buildings and their operations.

Its user-centric approach is central to the platform's functionality, which prioritizes the occupants' thermal perception, preferences, and demands. By leveraging this rich database of occupant feedback, the platform tailors its responses to create an environment that optimally suits the needs and expectations of the building's inhabitants. This personalized approach not only ensures heightened comfort levels but also fosters a sense of engagement and control among the occupants, thereby fostering a more sustainable and harmonious relationship between people and the built environment.

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Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

The author(s) acquired ethics committee permission for surveys implemented in this paper from the CER Research Ethics Committee of the Universitat Internacional de Catalunya (Date. 27.01.2024).

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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