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Towards a Human Centred Approach for Adaptive Façades

An Overview of User Experiences in Work Environments

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Abstract

Adaptive façades are multifunctional systems that are able to change their functions, features, or behaviour over time in response to changing boundary conditions or performance requirements. As one of the significant developments in the façade industry over the last decade, the adaptive façade offers an intelligent solution that can decrease energy consumption and potentially increase users' comfort in a building. From an engineering perspective, these advanced technologies aim to improve the overall performance of the building while generating a better indoor environment for the users, but unfortunately, investigations show that this goal is not always achieved. This is why, to bridge this performance gap, we embark on a change of perspective in façade design, from a technology-centred to a human-centred one. This research emphasizes that, with their changeability aspects, adaptive façade technologies offer unique potential, although the design of such façades requires a deeper understanding of users. With this as its focus, this paper aims to identify the factors affecting the user experience in a working environment, considering the interactions of the user with building services and façade systems from a holistic point of view, in which façade-user relationships are to be distinguished, towards the larger aim of developing a human-centred approach for adaptive façade design.

Keywords

human centred design, user experience, adaptive behaviour, adaptive façade, façade design, changeability, interaction

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1 INTRODUCTION

The complex multifunctional aspects of façade design hold an inherent duality between optimizing the energy performance of a building and providing comfort for its users (Klein, 2013). Although these two sides are inseparable and highly intertwined, as a result of their conflicting nature one could be easily overlooked in favour of the other, which unfortunately would result in poor design on both sides.

Worldwide, there have been several research projects that have searched for new ways and developed new technologies to design more energy efficient buildings for a more sustainable future (Aelenei et al., 2018). The belief that "technology will save us" has been a clear trend in building engineering, but there has been a general disregard for the people who will use it. Even with the use of high technology solutions, in practice we may end up with the following scenarios: a building may be highly energy efficient but its users could be dissatisfied or because of users' interference the building may not achieve the predicted levels of energy performance and we may end up with dissatisfied users anyway (Lazarova-Molnar & Mohamed, 2017).

Since the façade is the *mediator* between the exterior and interior environments, it could be said that its design is the key to shaping the whole performance of the building (Knaack et al., 2014). However, implementing high technology solutions to reduce energy consumption should not turn the façade into a *barrier* between the indoor and outdoor, which would create hermetically sealed spaces in which every physical aspect is regulated through HVAC systems (Addington, 2009). Instead, the façade needs to be carefully designed and integrated with the service systems, where smart technologies would be used as the tools to provide desired indoor environmental conditions in harmony with the users and to find an optimal energy efficient balance. In order to achieve that goal, a human-centred approach in façade design, rather than a technology centred focus, needs to be embraced.

The current applications of high performance buildings with smart building automation systems stress even further the need for such human-centred approach (Capeluto & Ochoa, 2017). These so-called intelligent systems are creating new pathways for user interactions, where user expectations and user experiences are changing along with it (Kaasinen et al., 2013). *Wigginton and Harris* used the analogy of the human body's neural system to explain their user-centred perspective on the topic, in which the *somatic* system that is responsible for the voluntary actions of the muscles that create movement is likened to the actions of the users in the building. Conversely, the *autonomic* system refers to the building's intrinsic responsive envelope (Wigginton & Harris, 2002). This approach highlights the co-existent nature of users' adaptive behaviours and the automated dynamic responses of the building systems.

A paradigm shift from occupants being *passive* subjects in a building to being *active* participants has begun by acknowledging the effects of occupant behaviour on the energy performance of the building (Yan & Hong, 2018). Although significant efforts are being made to better understand and simulate the adaptive behaviours of the users, the influencing factors behind these interactions and how these affect the user experience in the first place, are still quite theoretical (Heydarian et al., 2020). There needs to be further interdisciplinary studies investigating multi-domain exposure situations on users' satisfaction and behaviour, humans' perception of the built environment, and user-oriented design of the control interfaces, in order to achieve an occupant-centric building design approach (O'Brien et al., 2020).

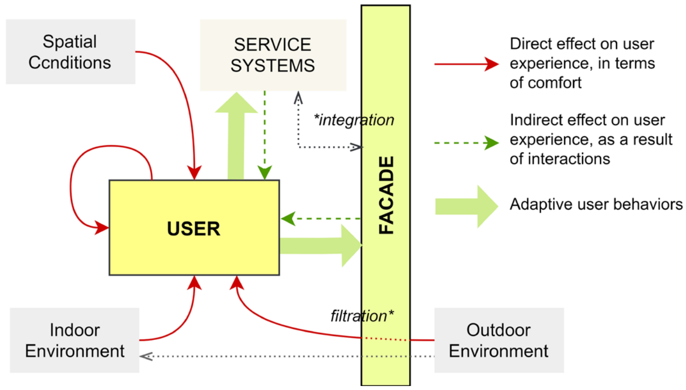

FIG. 1 Façade – User – Building relationships

There are many factors affecting and shaping users' experience in a building (Figure 1). The feeling of comfort (or discomfort) brought about by the effects of the factors related to the indoor and/or outdoor environment, spatial conditions, as well as the individual parameters related to the user itself are the main elements that could be listed. It is not just the comfort-related satisfaction, but also the overall user sensation and perception that results in interactions with the building façade and/or service systems, that are important parts of the user experience in the indoor environment (Law et al., 2009). Considering the amount of time we spend inside, especially in work environments, several studies highlight the importance of users' comfort and wellbeing on their health and productivity (Bluyssen, 2019; Fisk, 2000; Humphreys, 2005).

Even though the façade is highly significant in shaping the indoor environment, there seems to be a lack of understanding about its effects on the overall user experience (Alavi et al., 2017). Even in low technology buildings, the façade is a system that users commonly engage with, by opening the windows, closing the window blinds, or simply by looking outside. It does not seem far-fetched to state that these interactions have a crucial effect on users' experience, while they also create a gap between the predicted and achieved performance of the building (Masoso & Grobler, 2010). Such adaptive behaviours of users are one of the key factors that influences a building's design, performance optimization, and energy simulation (Yan & Hong, 2018). In the case of adaptive façades, with their smart and dynamic automation systems, it could be said that interactions between the façade and the user become even more significant. From an engineering perspective, being able to change façade properties would enhance their performance –by providing dynamic responses to ever-changing external stimuli–, but this dynamic character may also enhance the effect of the façade on the user experience, hence, it may also potentially deepen the aforementioned performance gap.

There is a limited number of studies focusing on adaptive façades, investigating the comfort and well-being of the users as they relate to their interactions. In a recent study, *Luna-Navarro* presents a classification scheme for different pathways in occupant façade interaction, which offers a deeper understanding of the conflicts and relationships between the user and intelligent control strategies in adaptive façades (Luna-Navarro et al., 2020). Another study on occupant-centric control strategies for adaptive façades discusses the implementations of adaptive comfort models and personalized control strategies to improve user satisfaction (Tabadkani et al., 2021). In addition, there are a few other research studies on post-occupancy evaluations and real-time occupant feedback in buildings with adaptive façades, demonstrating the influences of different physical factors on the feeling of comfort in users (Alavi et al., 2017; Attia et al., 2018; Bakker et al., 2014; Lassen et al., 2021; Luna-Navarro et al., 2021).

Acknowledging the contributions of such research towards reaching a human-centred adaptive façade, the influence of human factors on user behaviours and the indirect effects of interactions on the user experience still requires further investigation. Therefore, this paper (1) investigates how different factors affect the user experience in a working environment, (2) presents an overview of adaptive user behaviours with a human-centred approach, (3) distinguishes the façade - user relationship within the larger context, and (4) identifies the missing links towards reaching the full potential of adaptive façades.

A holistic perspective is embraced in this study and the presented overview is built over the user experience concept, which covers all human senses, emotions, behaviours, and interactions with the façade and/or environment. With this focus, this paper aims to bring the scattered information in the literature from different fields of expertise like engineering, architecture and social sciences together, ensuring that not just the effects of the environmental factors but also the human factors on user experience are investigated. As a broader aim, the information provided in this paper offers a starting point towards developing a human-centred approach for adaptive façades.

2 SCOPE AND METHOD OF RESEARCH

Research presented in this paper starts with an initial exploration of literature, which draws the context for further investigation. Exploratory research is conducted using Science Direct, Google Scholar, ITU and TU Delft Libraries, with the keywords: *human-centred design, adaptive façade, user experience.* Because of the lack of literature specifically focused on the façade and user relationship, the scope of the overview later widens to involve: *human-centred design in various fields, façade technologies and applications (traditional or advanced), façade properties and performances in general (physical and energy related), user comfort, satisfaction, well-being, and related studies to improve indoor environment quality.* After reading the titles, abstracts, keywords, and highlights of the papers collected in the initial exploration, the context of the detailed investigation is formulated. Figure 2 below portrays the research boundaries around respective keywords and concepts, presents an outline of this paper, and draws the relationship of its sections.

The users or the occupants are the main *subjects* of this overview. The *scope* of the study evolves around the user experience concept, which embraces a holistic approach to cover the users' comfort, satisfaction, and well-being, as well as users' emotions, behaviours, and interactions. The relationship between these concepts and their relevance to user experience are examined through studies of human-centred design, from different fields (social sciences, industrial design, environmental psychology, etc.). Although the main *focus* is on the adaptive façades and distinguishing its dynamic relationship with the users, since there is a scarcity of literature with this specific focus, studies related to user experience in indoor environments are investigated in general. Workplaces are chosen as the main *domain* of the research. In order to define a whole list of influencing factors, several *agents* of the indoor environment and adaptive façades are searched within the context of user experience. Thus, various studies evaluating users' comfort during the occupancy stage, theoretical studies investigating different parameters affecting user's satisfaction, studies regarding users' adaptive behaviours and the motivations behind that, users' effects on the energy performance of the building, studies investigating occupant-centric design and automation of the adaptive façade, and other relevant studies within its broader reach, formed part of the review process.

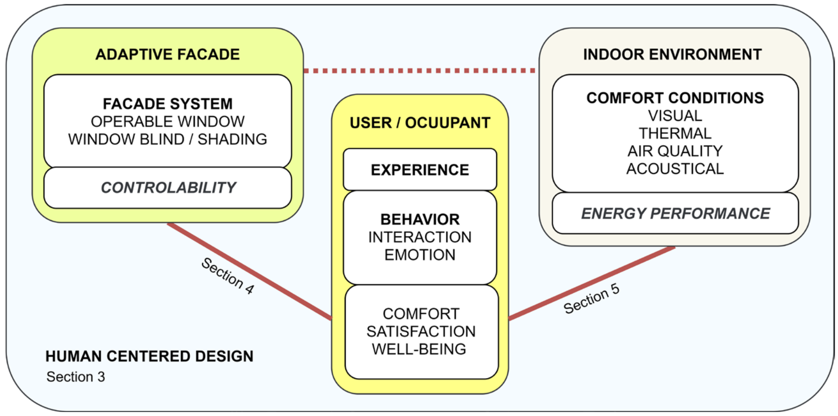

FIG. 2 Scope and boundaries of the research

As for the structure of the paper, Section 3 presents background information on different approaches of *human-centred design* to establish the point of view of this research, and to describe the relationship between adaptive behaviour and user experience. Section 4 introduces the potentials of adaptive façades, presents a brief overview of their relationship with the users, identifying the missing links, demonstrating the perspective of the authors and relevance of the research. Section 5 is the main body of the paper, where the findings of the review process are presented in a systematic way and different factors affecting user experience in working environments are identified, through a mechanism of change. Lastly, Section 6 presents an overall discussion and highlights relevant issues that require further investigation for a human-centred approach for adaptive façades.

3 HUMAN-CENTRED DESIGN

Human-centred (or centric) design is a concept which, over the years, has found application in various different fields, mainly in industrial design and software engineering (Hoffman et al., 2002). Different approaches to the concept in architecture and related behavioural theories that highlight a deeper understanding of the user experience are overviewed in this section.

3.1 HUMAN-CENTRED DESIGN APPROACHES

Norman describes human centred design as *the process which ensures that the designs match the needs and capabilities of the people for whom they are intended* (Norman, 1988). In other words, it is a philosophy that starts with understanding humans, to support the design of a useful, usable, pleasurable, and meaningful product/system (IDEO.org, 2015; Norman, 2013).

Designing *for* the users has been a part of design thinking since early ages. The evolution of the concept has started with the consideration of the physical *ergonomics* of the users while engaging with the product/system (Verbeek & Slob, 2006). Later, this concept evolved into *usability,* which covers the effectiveness, efficiency, and satisfaction in a specified context of use (ISO 9241-210, 2010). Then, the consideration of *emotions, behaviours,* and users' *experiences* became part of the approach, often referred to as *interaction design* in the literature (T. Zhang & Dong, 2008). Recent approaches aim to cover not just the present experiences but also the *needs and aspirations* of the future (van der Bijl-Brouwer & Dorst, 2017). Designing *with* the users on the other hand, by means of involving them in the design process (participatory design and generative techniques) or asking for feedback regarding the design (human-computer interaction), could be traced back to the 1970s – 1980s (Damodaran, 1996; Maguire, 2001; Visser et al., 2005; Zoltowski et al., 2012).

Sanders maps the different human-centred approaches in design practice and defines the designer's mindset as two categories; *expert* or *participatory* (Sanders, 2008). Expert mindset refers to the case where users are seen as *subjects* and the design aims to achieve the best possible usability for them. Participatory mindset, on the other hand, refers to the case when users are seen as *partners* and are actively involved in the design process from the beginning (Abras et al., 2004). Involvement of the users in the design phase is a way of ensuring that the design would match their needs, but unfortunately, there are operational barriers (Chammas et al., 2015). Consequently, in the case of building design, engagement of the users mostly occurs only at the occupancy phase, in the form of post-occupancy evaluations with real-time occupant sensing and/or feedback technologies (Wagner et al., 2018).

A collective perspective of the different approaches is offered by ISO 9241-210, where the human-centred design is defined as *an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques* (ISO 9241-210, 2010). Feedback and communication between the stakeholders (users and designers) are highlighted as the key to this approach. By acknowledging ISO's definition of human-centred design and embracing an *expert* mindset, we are taking the user as the subject of this research. Hence, we start by investigating how users interact with and experience their surroundings, thereby aiming to translate and transfer the information learned from users to the designers.

3.2 ADAPTIVE BEHAVIOUR AND USER EXPERIENCE RELATIONSHIP

The term experience is used to define the encounter of an event or occurrence and the *takeaways* from it. It could be a piece of knowledge, a skill or an impression, a feeling. In other words, experience defines *how people remember their interactions* (Norman, 2013). From a human centred point of view, any system that interacts in some way with its users should be designed with consideration given to users' needs and capabilities. Therefore, in order to achieve the *best* user experience, it is crucial to understand the factors that shape the nature of such interactions and how these may differ from one individual to another.

According to the *stages of action* model (Norman, 2013), an action (or behaviour) like opening a window is a *goal-driven* activity that could be triggered by various different physiological, psychological, or sociological factors. The activity starts by making the decision to take action, which is defined as the *planning* stage, followed by *specifying* the action and *performing* it by engaging with the window. The effects of the action will begin to show themselves, like creating changes in the air quality and temperature of the room. Then the user will *perceive* the new condition, *interpret* the reason behind it, *compare* it with the previous situation and make a decision to either close the window or keep it open. In this instance a *data/event-driven* activity occurs, which has surfaced as a result of the user's emotions in the initial condition (Naqvi et al., 2006). In other words, the perception of the environment triggered the interaction with the surroundings, while at the same time the interaction created a change in the perception.

Even though *Norman's* model defines a certain loop between perception and behaviour, it does not explain what exactly drives the behaviour itself. There are several other cognitive behaviour theories used in explaining occupant interactions with different building systems. From these theories, five commonly acknowledged models could be listed as: Theory of Reasoned Action - TRA, Theory of Planned Behaviour - TPB, Theory of Interpersonal Behaviour -TIB, Norm Activation Model – NAM and Value, Belief, Norm Theory – VBNT (Ajzen, 1991; Heydarian et al., 2020; Triandis, 1977), in which *affect, attitude, social norms, perceived control,* and *habits* are referred to as the main elements that create the *intention* of taking an action. *Affect* refers to what the organism feels, and defines the value, in other words, the quality of the experience. Interpretation of such feelings could be referred to as emotions that shape preferences for the future or moods for the present situation (Ortony et al., 2005). Along with the affect, different *personal or social norms* and individual *beliefs are* also related to the *intention* of a behaviour (Pee et al., 2008). The *perceived control* and individual's *attitude* towards taking an action are other elements that generate behavioural motivations (Heydarian et al., 2020). In addition to these conscious behaviours, *habit* refers to a sequence of behaviour that has become an automatic response to specific cues in the environment (Verplanken & Aarts, 1999), which can be defined as an unconscious behaviour or an intentional one.

All in all, a behaviour could surface because of a poor affect, with the intention to make it better and as a result, it will create an interaction to change the values of the experience. This phenomenon could also be explained with the concept of adaptive behaviour which is often referred to in the literature as follows: *if a change occurs such as to produce discomfort, people react in ways that tend to restore their comfort* (Nicol & Humphreys, 2002). Such comfort-driven behaviours are an important part of the user experience and simultaneously affect the overall energy performance of the building by creating unforeseen energy consumptions (Jia et al., 2017; Stern, 1992)

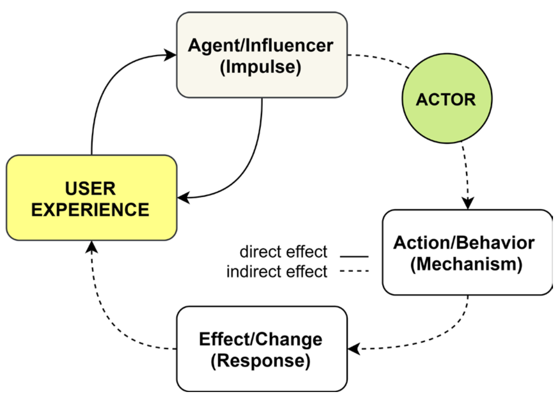

FIG. 3 The dynamic cycle of the user experience: the mechanism of change

Within the context of the built environment, users' behaviours, in terms of interactions with the building's service systems or façades, are significant elements of the user experience, which either (1) shape or (2) reflect upon the experience itself (Alavi et al., 2017). These behaviours may differ for each individual, due to their different physiological, psychological, or sociological conditions/backgrounds (Khalid, 2006). Therefore, understanding the mechanism of change is considered to be an important step towards defining how different factors affect the user experience in work environments.

4 POTENTIALS OF ADAPTIVE FAÇADES

The previous section introduced the dynamic cycle of user experience over a mechanism of change (Figure 3). In the case of adaptive behaviours, users are the actors that trigger the mechanism of change. Influencers that affect the users' behaviours may be related to human or environmental factors, which will be overviewed in the following section in relation to the user experience. Triggered by those factors in a case of discomfort, to achieve a more desired comfort condition, users can either choose to alter themselves, like changing their clothing level or the occupancy conditions, or they can alter their environmental conditions by interacting with the building's façade and/or service systems (O'Brien & Gunay, 2014) (Figure 4). Adaptive façades with their smart automation systems have a similar mechanism of change, by creating an artificial response to certain impulses, which results in a change in the indoor environmental conditions.

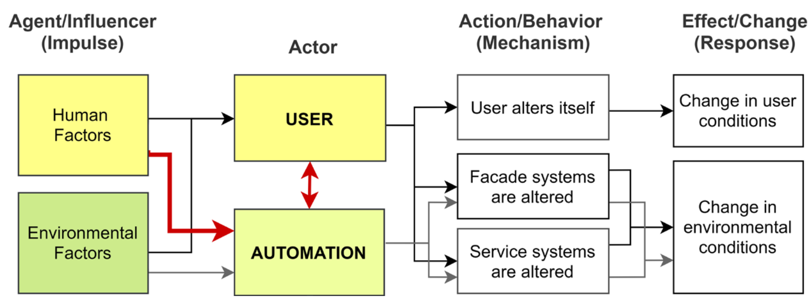

FIG. 4 Relationship of factors indirectly affecting user experience

If we take a holistic approach to façade design, it could be said that today's challenge is to find an energy efficient façade solution that would also create a positive user experience. To deal with that complexity, and with their changeability aspect, adaptive façades offer a unique opportunity. This research explores the hypothesis that there is a missing link (shown in red lines on Figure 4) between the human factor and the adaptive façade. The operation of the adaptive façade by means of automation should regard the human factors as agents, along with the environmental factors. Moreover, automation systems should be designed to co-exist with and learn from the users' adaptive behaviours, and to consider the indirect effects on the user experience. If these gaps could be bridged, only then would adaptive façades reach their full potential.

Adaptive technologies have the potential to significantly reduce the energy use of the buildings (Perino & Serra, 2015) along with having a profound influence on user satisfaction (Attia, 2017). The performance of the adaptive façade – in terms of comfort and energy – is highly dependent on its dynamic operation strategies (Favoino et al., 2018). The automation system is another actor like the user, which is used to manipulate the change in indoor environmental conditions, thus directly and/or indirectly altering the user experience. Therefore, design consideration of an adaptive façade system should consider the implementation of occupant-centric automation and integration with the operation of other building services systems, along with the functional requirements of the façade.

Each adaptive façade technology (such as movable solar shading, switchable glazing, phase change materials, dynamic insulation, multifunctional façades ...etc.) requires a unique consideration since they offer different ways of interaction with the user and may have different effects on users satisfaction and well-being (Attia et al., 2019). In terms of a human-centred design approach to adaptive technologies, existing studies and performance modelling approaches are limited to considering environmental factors as the main agent of change, thus missing the relationship with the human factors and user experience.

Along this path, one of the key issues that needs to be investigated is the balance between automation and user control. Adaptive façades controlled by an intelligent automation system could be designed to predict a possible result of discomfort and act on behalf of the users to alter the indoor environmental conditions (Böke et al., 2020). However, there are also studies indicating that users are more satisfied, happier, and more productive when they are given at least a certain degree of control (Samani, 2015). This opens up the discussion on how much control should be left to the users considering the building's energy performance. Educating the users and improving the response feedback mechanism would be the highlighted ways to deal with a possible performance gap between the predicted and actual energy consumption of the building (Al-Obaidi et al., 2017).

Another issue is the diversity of each user's needs and preferences. There have been several studies aiming to model the reasoning behind users' behaviours and simulate them in order to demonstrate the actual energy performance (Yan et al., 2015). However, it is quite impossible to predict how each user would react to a certain situation. From another perspective, despite the variety of each human factor and its endless combinations, by observing user's behaviour under certain conditions, it could be possible to identify some user types (Ortiz, 2019), which requires a deeper understanding of the human factor and an interdisciplinary study that incorporates architecture, engineering, and social science. From an expert point of view, by identifying what are the key factors that affect the experience and how they show diversity, the level and type of adaptation that is needed for certain user types could be defined. Thus, this would be used as a starting point towards a human-centred adaptive façade design approach.

From this perspective, which aims towards a human centred design approach, we are looking from the users' point of view to understand what experiences that they expect from their façades. Identifying the complex and dynamic mechanisms of the user experience in an indoor environment (workspaces in the context of this paper) would be the first step. To that end, this research investigates how each factor affects the mechanism of change and portrays a better understanding of the triggers that make users take action. From there, it would be possible to (1) identify certain patterns in users' adaptive behaviours that could be mimicked with the adaptive façades, (2) determine the effects of human factors and define certain expectancies of different user groups, (3) distinguish certain aspects of the façades that need to be variable in order to satisfy individual adaptive comfort needs.

5 USER EXPERIENCE IN WORK ENVIRONMENTS

User experience is defined as *a person's perceptions and responses that result from the use or anticipated use of a product, system, or service* (ISO 9241-210, 2010; Law et al., 2009). It is a concept that not only covers the past and present experiences but also those *anticipated* for the future. In the context of this paper, experience is used as a holistic term to cover all human senses and refers to any kind of emotion, perception, sensation over interaction, and any feeling of comfort, satisfaction, or well-being.

Although the façade is one of the main systems that shapes the indoor environment, there has been only a limited number of studies exploring how it affects users' experiences. The ways in which users engage with their façade and experience it could be defined in two ways: *active or passive*. (1) Passive experience refers to the perception, for instance, of feeling the sunlight coming through the glazing or looking outside the window. (2) Active experience refers to interaction, for instance, opening the window because of feeling warm, closing the window blind to prevent glare. In other words, passive experience indicates a path for the direct effect of an influencer, while active experience draws an indirect path where certain behaviour is triggered.

Based on the review of the existing literature, the effects of different factors on the user experience, in a working environment, are identified. Figure 5 shows the relationship of the parameters from the findings of the review, which are systematically organized in a way to demonstrate the dynamics between the influencing factor, the mechanism that is triggered by it, the response that results in a change of the initial state, and how this whole cycle affects related user experiences (Figure 3).

Referring to the aforementioned mechanism of change, we classify the influencing factors under two main groups: *human* and *environment*. According to occupant behaviour studies, it could be said that it is not only physical factors of the environment, but also the individual factors for each user, that influence the experience in an indoor environment (Frontczak & Wargocki, 2011). As the elements that could be easily manipulated by the building design, the general tendency in the related research projects is to focus on the environmental factors. There are only a few studies that investigate the diversity of individual factors and their relationship with users' adaptive behaviours (Hong et al., 2017). Taking the human as the centre of focus, first of all, *personal descriptors and needs* that are different for each individual and which affect the experience are outlined. Environmental factors, on the other hand, are related to the surroundings of the user. On a building scale, these would be divided into three subcategories: *external, internal,* and *spatial* factors.

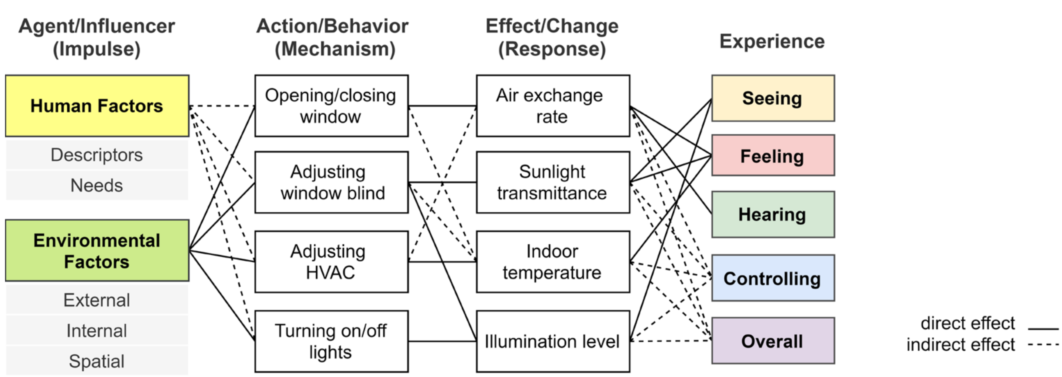

FIG. 5 Relationship between the parameters within the mechanism of change

The main adaptive behaviours that users would take to alter their indoor environment, based on the common mentions within the existing literature as potential causes of unpredicted energy consumptions, could be listed as *(1) opening/closing windows, (2) adjusting window blinds (shading elements), (3) adjusting HVAC systems (heating, cooling, ventilation units), (4) turning on/off lighting* (Boerstra, 2016; Delzendeh et al., 2017; Nicol & Humphreys, 2002). In addition to these, in cases of discomfort, users may also choose to *(5) adjust their clothing* or upon arriving/departing the space *(6) change their presence* without engaging with their surroundings (Haldi & Robinson, 2008;

Zhang et al., 2018). The main focus of this paper is on the experiences of the users that resulted from their comfort-driven interactions with their façade and integrated service systems, thus the first four behaviours that require engagement with the windows, shading, HVAC, or lighting systems are investigated, in the context of a working environment. Each of these actions creates a reaction and alters at least one of the properties of the façade and/or the indoor environment. These could be respectively defined as the changes at *(1) air exchange rate*, level of *(2) sunlight transmittance*, value of *(3) indoor temperature*, *(4) illumination level* (Frontczak & Wargocki, 2011; Wagner et al., 2018). The changed conditions that resulted from the adaptive behaviours indirectly affect the user experience, and thereby become an influencer once again.

As mentioned before, within the context of this research, the *user experience* concept is issued from a holistic point of view that covers all human senses, emotions, behaviours and interactions with the façade and/or environment. It not only refers to a state of comfort or discomfort, but it is about the overall sense of satisfaction that occurs before, during, and after use (ISO 9241-210, 2010; Law et al., 2009). Therefore, from a human-centred point of view, this paper takes the human senses to its centre and classifies user experiences as *seeing, feeling, hearing, and controlling*. The aim is to broaden the commonly used visual, thermal, air quality, and acoustical comfort titles, and to investigate the indirect effects of comfort-driven adaptive behaviours on the user experience. With that perspective, *seeing* refers to any experience related to sight, issues regarding visual comfort and aesthetics are covered under this title. *Feeling* is used to cover the experiences related to the haptic and olfactory senses of the human. The factors that are mentioned in relation to the experience of feeling show a similar mechanism of change and are related to the thermal comfort and indoor air quality collectively, and therefore could not be separated. *Hearing* refers to the audial experiences and is related to acoustical comfort. *Controlling* is added since the main focus of this study is adaptive façades and it refers to the anticipation of control during user interaction and its psychological effect on user experience. In addition to these, the *overall* experience title is also used, referring to the factors that may not have a direct effect on a specific sense, but still found to be in relation to a general positive sensation of the human being.

Based on the above-mentioned classification, collected and interpreted information from the literature on how each human or environmental factor triggers each comfort-driven adaptive behaviour, which in turn creates a change in the environment that affects user experience, (Figure 5), are systematically presented in this section over the defined mechanism of change.

5.1 HUMAN FACTORS

Each person by nature has their own unique traits. These are not just physiological factors, but also psychological, social, cultural, economic, or other contextual factors that show diversity among each individual. These different characteristics alter a person's needs, habits, aspirations and influence his/her experience (Khalid, 2006). These human factors are grouped as *personal descriptors* and *needs*. A holistic approach to how each human factor triggers an adaptive behaviour and alters the experience in a working environment is found to be lacking in the literature. Therefore, an attempt to gather the existing but scattered information from the literature is made and presented in detail in this section. Table 1 below presents the relationship of each factor with each adaptive behaviour and user experience

TABLE 1 The human factors that affect user experience in a mechanism of change

IMPULSE (Influencer / Agent)		MECHANISM (Action / Behaviour)				RESPONSE (Effect / Change)				RELATED EXPERIENCE				
HUMAN FACTORS		Opening / Closing window	Adjusting window blind	Adjusting HVAC	Turning on/off lights	Air exchange rate	Sunlight transmittance	Indoor temperature	Illumination level	Seeing	Feeling	Hearing	Controlling	Overall
Personal Descriptors	Age	+	-	+	-	+	-	+	-	+	+	-	+	o
	Gender	+	-	o	-	+	-	+	-	+	+	-	o	+
	Country of Origin	-	-	o	o	-	-	o	o	o	+	+	o	+
	EducationLevel	o	-	o	o	o	-	o	o	o	+	-	+	+
	Type of Job	+	+	+	+	+	+	+	+	+	+	o	+	+
	Socio-personal traits	+	+	+	o	+	+	+	+	+	+	o	+	o
Personal Needs	Security	+	o	-	-	o	o	o	o	o	o	-	+	+
	Privacy	-	+	-	-	-	o	-	o	+	o	+	o	o
	Hygiene	o	-	-	-	o	-	o	-	o	o	-	-	+
	View	-	+	-	o	-	+	-	+	+	o	-	o	+

(+) Direct mention in the literature, (o) Interpreted from the literature, (-) Not mentioned in the literature

5.1.1 Personal Descriptors

The factors mentioned in this category refer to the characteristic features of an individual, which may be quantifiable tangible conditions or identifiable intangible aspects of the users.

Age

Age is mentioned as one of the physiological factors that have an impact on the users' comfort requirements and mainly on the thermal comfort perceived by the occupants (Al horr et al., 2016; D'Oca et al., 2016; Fanger, 1970). *Frontczak & Wargocki*, in their research, portray how individual characteristics influence satisfaction with indoor environmental quality, and age is associated with subjective air quality, visual satisfaction, and adverse perception (Frontczak & Wargocki, 2011).
In another study that identifies the influencing factors on occupants' energy related behaviours, age is listed as one of the social and personal parameters (Delzendeh et al., 2017). In terms of adaptive behaviours, window opening behaviour (Fabi et al. 2012; Zhang et al. 2018), heating thermostat adjustment (Deme Belafi et al., 2018), and in general the need for personal control (Boerstra, 2016) are affected by the age factor.

Gender

Another frequently mentioned physiological factor that influences thermal satisfaction and the overall comfort perception of the users is gender (Al horr et al., 2016; Boerstra, 2016; D'Oca et al., 2016; Day & Gunderson, 2015). It is an acknowledged fact in the field that in general, due to different body compositions, thermal preference and satisfactory set temperature for a female and a male differ from each other (Delzendeh et al., 2017; Fanger, 1970; Huizenga et al., 2006). In the case of discomfort, altering clothing (Holopainen et al., 2014) could be the initial act followed by heating thermostat adjustment (Deme Belafi et al., 2018), opening or closing the windows (Fabi et al., 2012; Zhang et al., 2018) or interfering with the HVAC system to alter the intensity of airflow (Fountain et al., 1996). Along with thermal sensation, *Frontczak & Wargocki* also mention gender as influencing the satisfaction with air quality and the visual satisfaction along with general preference on indoor environmental conditions (Frontczak & Wargocki, 2011).

Country of Origin

Country of origin is listed as another human factor that has both physical and socio-economic aspects. First of all, due to racial features and/or accustomed climatic conditions, users may have different means of thermal comfort (Al horr et al., 2016). In addition, the expectation of thermal conditions would also vary from country to country due to cultural differences and defined local standards, which would result in different experiences in terms of feeling (Day & Gunderson, 2015). As a result of various customs and habits, individuals' acoustical dissatisfaction and any overall adverse perceptions would also show diversity (Frontczak & Wargocki, 2011). Lastly, in terms of adaptive behaviour, cultural norms are mentioned as an influence on the use of electrical systems (O'Brien & Gunay, 2014).

Education Level

The level of education is mentioned in relation to the user's knowledge and awareness. As a socio-personal factor, education affects users' attitudes, motivations, and behaviours in their working environment (Delzendeh et al., 2017). Although it is not possible to define a direct correlation, users with different levels of education have a different perception of thermal comfort, air quality, and overall satisfaction (Frontczak & Wargocki, 2011). *Day & Gunderson* states that to minimize energy consumption, especially in high-performance buildings, training and education have a crucial effect (Day & Gunderson, 2015). Informing users on how to control the façade and service systems, and in which way their actions would affect the energy performance of the , greatly influence adaptive behaviours such as opening/closing windows, adjusting HVAC units, and turning on/off lighting (Yan & Hong, 2018).

Type of Job

Type of job is one of the most comprehensive factors that covers dress codes and activity levels, working hours, time pressure and stress levels, relationship with colleagues, relationship with employees/employers, and overall contentment with the job. According to *Frontczak & Wargocki* different factors related to different professions, defining a variety of needs and influencing the perception of thermal comfort, visual comfort, and air quality, as well as overall satisfaction (Frontczak & Wargocki, 2011). Job satisfaction in general is shown to have a significant effect on work performance, productivity, and psychological well-being (Samani, 2015). Depending on the job description, the required level of activity would define a metabolic rate and clearly have an influence on the thermal comfort parameters (Delzendeh et al., 2017; Haldi & Robinson, 2008; Holopainen et al., 2014; Nicol & Humphreys, 2002). Another influencing factor in terms of thermal satisfaction is clothing (Al horr et al., 2016; Day & Gunderson, 2015). The level of clothing could be defined by a dress code for certain professions or it could be a parameter that is for users to alter and adapt (Fanger, 1970; Huizenga et al., 2006). In any case, clothing could be mentioned as one of the factors that influences users to take adaptive actions in order to control the indoor temperature (Fountain et al., 1996). In addition to these, working routine and arrival and departure patterns are found to be important motivational factors for adaptive behaviours (D'Oca et al., 2016). Opening the windows on arrival to the office and closing them upon departure is a common habit (O'Brien & Gunay, 2014). Adjusting the window blinds, turning on/off heating and lighting are other actions that are consistent with the working schedule (Deme Belafi et al., 2018; Wagner et al., 2018). Moreover, these could be listed as some of the main occupant behaviours that create the gap in the predicted and actual energy performance of the buildings (Masoso & Grobler, 2010).

Socio-Personal Traits

The main intangible factors that show diversity among the users and influence behaviours in various different ways are grouped under the title socio-personal traits. There are several behavioural models that try to portray the intentions and motivations of users' adaptive behaviours based on their personal and social properties (Deme Belafi et al., 2018). Personal factors could be listed as individual traits, beliefs, and attitudes which are the reflections of one's character (Fabi et al., 2012). A study investigating the influence of personality traits on occupant behaviour shows how the *Big Five Personality Traits* influence the behaviours associated with window opening, adjusting blinds, fans, or clothing, in addition to how thermal sensation and preference are affected (Schweiker et al., 2016; Wagner et al., 2018). Briefly, it states that people with high *neuroticism* traits tend to stick to the actions that they know and are able to control more, like clothing adjustments or operating windows. On the other hand, the *extraversion* trait could define a person who may very likely act quickly against any discomfort. Similarly, people with a high degree of openness to experience would be more open to changes, and hence feel less need to engage in adaptive behaviour. In other words, depending on their level of willingness to take action, a person could be defined as more active or passive (D'Oca et al., 2016). Apart from the personal profiles, social parameters could also be highly influential as a behavioural motivation (Zhang et al., 2018). Social constraints, norms, and pressure in a shared office are some of the most effective factors in terms of energy awareness and influence the adaptive behaviours related to energy usage (Day & Gunderson, 2015; Wagner et al., 2018). Besides, one's cultural belonging or certain lifestyle is another factor that affects human cognition and would alter the user behaviour (Delzendeh et al., 2017). All in all, perception and preference of comfort are highly interrelated with the socio-personal traits, thus these factors are significant influencers on the user experience.

5.1.2 Personal Needs

The factors mentioned in this category cover the main psychological elements in terms of users' needs and stressors that affect users in positive or negative ways.

Security

The need for security is a factor that influences the experience both directly and indirectly. According to *Vischer*, health and safety are part of the physical comfort parameters that are the first step of the habitability pyramid (Vischer, 2007). Additionally, the feeling of safety and security is a significant psychological factor that affects the indoor environmental satisfaction of the users (Russell et al., 2013; Zagreus et al., 2004). In terms of adaptive behaviours, in residential or working places, the act of window opening and closing is influenced by the means of providing security (O'Brien & Gunay, 2014; Roulet et al., 2006). To indicate whether someone is outside, adjusting window blinds could also be another adaptive behaviour that is influenced by the feeling of security (Deme Belafi et al., 2018).

Privacy

The need for privacy is another psychological factor (like security) that both directly and indirectly affects users' experience in a working environment (Vischer, 2007). The need for privacy applies to both visual and acoustical environments (Kim & de Dear, 2012). Especially for open-plan offices, communication privacy is an important parameter that affects the level of satisfaction and productivity in the physical work environment (Al horr et al., 2016; Samani, 2015). For visual privacy, controlling the shading elements could be listed as the main influenced adaptive user behaviour, which applies to homes as well as offices (Deme Belafi et al., 2018; Lee et al., 2013).

Hygiene

The need for hygiene is one of the basic human needs as a part of physical comfort (Vischer, 2007). Cleanliness of the working space and maintenance of the building directly influence occupants' level of satisfaction and productivity in the work environment (Huizenga et al., 2006; Kim & de Dear, 2012; Roulet et al., 2006; Samani, 2015; Zagreus et al., 2004). Although there is no mention in the literature about it triggering an adaptive behaviour, by means of protecting the indoor environment it may be interpreted that there is an indirect effect on the window closing action.

View

The need for a view is mentioned in relation to outside view, visual quality, and aesthetic appearance, which would influence the level of satisfaction with the working environment (Samani, 2015). Architectural features of the space, colours, textures, materials, and components affect the sense of aesthetics and positively influence the seeing experience (Delzendeh et al., 2017). In addition, view out is one of the significant factors that affects visual comfort. Lack of view to outside may cause eye tiredness (Day & Gunderson, 2015), but having a pleasant view like a green landscape positively influences the overall satisfaction (Kim & de Dear, 2012). After sunlight levels, quality of view is the next main factor that triggers the window blind controls (Bakker et al., 2014; Kwon et al., 2019; O'Brien & Gunay, 2014; Vischer, 2007; Wagner et al., 2018).

5.2 ENVIRONMENTAL FACTORS

Apart from the human factors, the conditions of the environment surrounding the users directly affect their comfort, both physically and psychologically (Vischer, 2007). As the barrier between the exterior and interior environments, façades undertake multiple functions with the main goal of providing a comfortable indoor environment (Klein, 2013). Therefore, its design is surfaced with regard to external conditions and it is the main element that shapes the internal conditions. Besides, other design characteristics related to the functionality of the building, referred to as spatial conditions, would also be factors that affect users' comfort in their environment. Effects of environmental factors on users' comfort and behaviours are a more commonly studied aspect, therefore the information presented in this section is a brief mention within the context of the mechanism of change. Table 2 below represents the relationship of each factor with each adaptive behaviour and user experience.

5.2.1 External Factors

The factors mentioned in this category are the main climate-related factors that depend on the geographic location and show variety for each season, time of year, or time of day.

Outdoor Temperature

Outdoor temperature is one of the main factors that affects thermal comfort. In different seasons, it influences the window opening/closing behaviours of the users, as well as the adjustment of window blinds and heating/cooling units (Al horr et al., 2016; Bakker et al., 2014; Brager et al., 2004; Buso et al., 2015; Day & Gunderson, 2015; Delzendeh et al., 2017; Fabi et al., 2012; Frontczak & Wargocki, 2011; Haldi & Robinson, 2008; Wagner et al., 2018; Zhang et al., 2018)

Solar Access

Solar access, depending on the orientation of the building, is one of the main factors that affects visual comfort. Along with the time of the day, the intensity of the daylight and sky conditions are mainly effective on the shading elements opening/closing behaviours of the users and turning on/off artificial lighting. Besides, the effect of sunlight may cause overheating which is related to thermal comfort. In terms of temperature adjustment, closing window blinds or altering the HVAC systems could also be listed as other influenced adaptive actions (Day & Gunderson, 2015; Delzendeh et al., 2017; Fabi et al., 2012; Huizenga et al., 2006; Wagner et al., 2018; Zhang et al., 2018).

TABLE 2 The environmental factors that affect user experience in a mechanism of change

IMPULSE (Influencer / Agent)		MECHANISM (Action / Behaviour)				RESPONSE (Effect / Change)				RELATED EXPERIENCE				
ENVIRONMENTAL FACTORS		Opening / Closing window	Adjusting window blind	Adjusting HVAC	Turning on/off lights	Air exchange rate	Sunlight transmittance	Indoor temperature	Illumination level	Seeing	Feeling	Hearing	Controlling	Overall
External Factors	Outdoor Temperature	+	+	o	-	+	+	+	o	o	+	-	+	o
	Solar Access	+	+	o	+	+	+	+	+	+	+	-	+	o
	Wind/Rain	+	-	-	-	+	-	+	-	-	+	-	o	o
	Relative Humidity	+	-	o	-	+	-	+	-	-	+	-	o	o
	Outdoor Noise Level	o	-	-	-	o	-	o	-	-	-	+	o	+
Internal Factors	Indoor Temperature	+	+	+	-	+	+	+	o	o	+	-	+	+
	Lighting Conditions	o	+	-	+	o	+	o	+	+	o	-	+	+
	Air quality	+	-	o	-	+	-	o	-	-	+	-	o	+
	Relative Humidity	+	-	O	-	+	-	o	-	-	+	-	o	+
	Indoor Noise Level	o	o	o	-	o	o	o	o	-	-	+	o	+
Spatial Factors	Building Function	+	+	+	+	+	+	+	+	o	o	o	o	+
	Building Layout	+	+	o	o	+	+	+	+	+	+	+	o	o
	Façade Characteristics	+	+	o	o	+	+	+	+	+	+	o	+	o
	Service Systems	o	o	+	+	o	o	+	+	+	+	o	+	+

(+) Direct mention in the literature, (o) Interpreted from the literature, (-) Not mentioned in the literature

Wind and Rain

Wind and rain conditions are listed together as factors that affect the window opening/closing behaviours of the users. Due to their effect, it results in changes in the indoor air quality and it also affects thermal comfort (Delzendeh et al., 2017; Fabi et al., 2012; Haldi & Robinson, 2008; Zhang et al., 2018).

Relative Humidity

The outdoor relative humidity is linked with thermal comfort and indoor air quality, in relation to the window opening behaviour and if there is an active ventilation system, by means of adjusting its air flow (Al horr et al., 2016; Delzendeh et al., 2017; Deme Belafi et al., 2018; Zhang et al., 2018).

Outdoor Noise Levels

Outdoor noise levels have a direct effect on acoustical comfort, and the resulting hearing experience, and they are also mentioned as one of the factors that influence window closing behaviour (Day & Gunderson, 2015; Haldi & Robinson, 2008; Roulet et al., 2006; Vischer, 2007)

5.2.2 Internal Factors

The factors mentioned in this category are the main quantifiable/measurable conditions of the indoor environment.

Indoor Temperature

Indoor temperature is one of the main factors that affects thermal comfort. Its effects could be investigated under two main sub-categories: mean radiant temperature and temperature variability created by the air movement, in other words, draught (Frontczak & Wargocki, 2011). Due to different needs, it influences the window opening/closing behaviours of the users as well as the adjustment of window blinds and heating/cooling units (Al horr et al., 2016; Bakker et al., 2014; Boerstra et al., 2012; Boerstra, 2016; Bordass et al., 1993; Brager et al., 2004; D'Oca et al., 2016; Day & Gunderson, 2015; Delzendeh et al., 2017; Deme Belafi et al., 2018; Fabi et al., 2012; Fanger, 1970; Frontczak & Wargocki, 2011; Haldi & Robinson, 2008; Holopainen et al., 2014; Huizenga et al., 2006; Kim & de Dear, 2012; Kwon et al., 2019; Nicol & Humphreys, 2002; O'Brien & Gunay, 2014; Roulet et al., 2006; Samani, 2015; Wagner, 2018; Zagreus et al., 2004; Zhang et al., 2018)

Lighting Conditions

Lighting conditions are the primary indicator of visual comfort. It covers the level of illumination within the space, homogeneity of the brightness, and formation of glare. It is affected by the external conditions, mainly solar access, and regulated initially by adjusting the window blinds and later by means of artificial lighting. In relation to the outside view and sunlight's overheating capability, it is linked with the window opening behaviour as well as the adjustment of window blinds (Bakker et al., 2014; Boerstra et al., 2012; Boerstra, 2016; Bordass et al., 1993; D'Oca et al., 2016; Day & Gunderson, 2015; Delzendeh et al., 2017; Deme Belafi et al., 2018; Fabi et al., 2012; Kim & de Dear, 2012; Kwon et al., 2019; O'Brien & Gunay, 2014; Roulet et al., 2006; Samani, 2015; Vischer, 2007; Wagner, 2018).

Air Quality

Indoor air quality refers to the CO_2 concentration of the air, odours, and air composition as in the content of dust/electrical particles/microorganisms. It is related to the feeling experience and affects the window opening/closing behaviours of the users (Bakker et al., 2014; Boerstra et al., 2012; Boerstra, 2016; Bordass et al., 1993; D'Oca et al., 2016; Deme Belafi et al., 2018; Fabi et al., 2012; Fanger, 1970; Haldi & Robinson, 2008; Huizenga et al., 2006; Kim & de Dear, 2012; Kwon et al., 2019; Roulet et al., 2006; Samani, 2015; Zagreus et al., 2004; Zhang et al., 2018).

Relative Humidity

The indoor relative humidity, similarly to the external conditions, influences thermal comfort and indoor air quality, in relation to the window opening behaviour and if there is an active ventilation system, by means of adjusting its air flow (Al horr et al., 2016; Day & Gunderson, 2015; Deme Belafi et al., 2018; Holopainen et al., 2014; Huizenga et al., 2006; Kwon et al., 2019; Roulet et al., 2006; Zhang et al., 2018).

Indoor Noise Levels

Indoor noise levels is one of the main factors that creates discomfort in a working environment. It directly affects acoustical comfort. Depending on the source of the noise - if it is from the outside it impacts window closing behaviour, and if it is an operational sound interfering the window blinds and/or HVAC systems, operations would be influenced (Boerstra, 2016; Day & Gunderson, 2015; Kim & de Dear, 2012; Roulet et al., 2006; Samani, 2015; Vischer, 2007; Zagreus et al., 2004).

5.2.3 Spatial Factors

The factors mentioned in this category are the properties related to the design of the space and its function.

Building Function

The function of the building is one of the main factors that defines the user requirements. It defines the function of the space and its spatial needs for comfortable usage. Therefore, it influences all adaptive behaviours in various ways and could be linked with all the user experiences (Al horr et al., 2016; Boerstra, 2016; Brager et al., 2004; Delzendeh et al., 2017; Frontczak & Wargocki, 2011; Huizenga et al., 2006; Kwon et al., 2019; Nicol & Humphreys, 2002; Roulet et al., 2006; Samani, 2015; Vischer, 2007; Wagner, 2018).

Building Layout

Building layout is the other factor that covers a wide range of design aspects like private or open-plan working environments, area of workspace per person, and position of each user within the space. It may affect all experiences in terms of seeing, feeling, and hearing. Users' interactions with their façade vary due to their distance from it, hence building layout is listed as one of the influential factors for opening/closing windows and adjusting shading elements behaviours (Kwon et al., 2019; Luna-Navarro et al., 2021). In addition to that, as was also mentioned under the socio-personal traits, being in a private or shared office may alter ones adaptive behaviours by creating social pressure (Bakker et al., 2014; Boerstra, 2016; Brager et al., 2004; Buso et al., 2015; D'Oca et al., 2016; Day & Gunderson, 2015; Delzendeh et al., 2017; Fabi et al., 2012; Huizenga et al., 2006; Kim & de Dear, 2012; O'Brien & Gunay, 2014; Roulet et al., 2006; Samani, 2015; Vischer, 2007; Wagner, 2018; Zagreus et al., 2004; Zhang et al., 2018).

Façade Characteristics

Façade characteristics refer to window size and position, wall to window ratio, mass, robust or dynamic character, and other design aspects of the façade. In the case of adaptive façades, it is clearly a factor that influences the controlling experience of the users (Tabadkani et al., 2021). The level of manual or automated control of the openings and shading units influence the level of user interactions and along with that effect the visual and thermal comfort of the occupant (Bakker et al., 2014; Buso et al., 2015; Fabi et al., 2012; Kwon et al., 2019; Vischer, 2007; Zhang et al., 2018).

Service Systems

Service systems refer to the active, mechanical units of the building, which have a great influence on shaping the indoor environment. Their design is outside the context of this paper; however, their control and feedback mechanisms can be mentioned as one of the factors that influences the controlling experience of the users (O'Brien et al., 2020). Alterations made by engaging with the HVAC systems or lighting element can also affect the visual, thermal, and overall comfort of the occupant (Brager et al., 2004; Buso et al., 2015; Delzendeh et al., 2017; Fountain et al., 1996; Huizenga et al., 2006; Kwon et al., 2019; Nicol & Humphreys, 2002; Wagner, 2018; Zhang et al., 2018).

6 DISCUSSION

In the previous section, an overview of the factors that affect user experience is systematically presented over the mechanism of change. According to the findings, it could be said that the most affected experience by the human factors is *feeling*. There is a direct effect, mainly related to the *perception of thermal comfort,* and an indirect effect as a result of being triggered by users' interactions. Among these, the most commonly investigated adaptive behaviour is found to be *opening/closing windows*, followed by *adjusting HVAC*. Both of these actions are in relation to the changes in the *air exchange rate* and/or *indoor temperature*, hence associated with the feeling experience. Other commonly affected experiences are *seeing* and *controlling*. Related to these experiences, the indirect effect of *adjusting window blind* behaviour needs to be further investigated, in terms of user-façade interactions. From the listed human factors, *type of job* and *socio personal traits* covered a wide range of factors, therefore it was an expected outcome to see that these titles are in relation to all the listed adaptive behaviours and experiences. Even though, with a holistic perspective, it was possible to gather information regarding the influences of human factors on user experience, the number of studies with this focus is limited and research targeted on the experience was found to be especially scarce.

As for the environmental factors, there was more research in the literature investigating direct or indirect effects on user experience. From the listed external factors, *solar access* is found to be the most influential one that could trigger all the issued adaptive behaviours. It directly and indirectly affects the *seeing* and *feeling* experience, and, related to the mechanism of change, could also be associated with the *controlling* experience. It is followed by the *outdoor temperature,* and from the internal factors, *indoor temperature*. From the listed spatial factors, the *function of the building* shows a clear relationship with all the adaptive behaviours and is related with the *overall* experience. However, based on the existing literature, it is difficult to define a direct effect caused by the building's function on each experience. On the other hand, studies show direct and indirect effects of *building layout* on *seeing*, *feeling,* and *hearing* experiences. By looking at the results of the review, studies investigating the effects of the environmental factors in relation to hearing experience seems to be lacking. Considering the fact that outside or inside sound levels are indicated as some of the main causes for discomfort, the indirect effects of these factors in relation to the mechanism of change need to be explored in a deeper way. Besides, *controlling* experience requires a more targeted study, where indirect effects on the experience would be investigated when the façade systems are fully or partially left to the users' control or fully automated. In addition to that, *façade* and *service systems characteristics* needs to be further explored in terms of their direct effects on each user experience. As a final remark on the review, the collective effect of different parameters is another issue that needs to be further investigated in terms of user experience.

The presented overview shows that the adaptive mechanisms related to the façade, like opening/closing windows and adjusting window blinds, are highly influenced by human factors. It could be said that the users' intention behind adaptive behaviours is the reflection of their adaptive comfort needs and adaptive control expectations. A similar outcome could be drawn for the behaviours related to the building service systems. Each adaptive behaviour is performed to overcome a certain discomfort and/or to enhance the user experience. Therefore, users' adaptive actions reflect their way of thinking. With a human centred approach, if the adaptive façades are to be designed in harmony with its users, users' anticipations of their indoor environment, as they relate to their experiences, require further research. Transferring this information from the occupancy to the design stage is crucial for developing occupant-centric control and operation systems, predicting the building's energy consumption, and enhancing users' positive interactions with their surroundings, with the ultimate aim of reaching the full potentials of the adaptive façades.

7 CONCLUSION

An overview of human-centred design and user experience in the context of working environments is presented in this paper. With a holistic perspective, all of the factors affecting users' experience are investigated through a literature review process. A mechanism of change is defined to explain the dynamic cycle of the user experience with respect to users' interactions with the building façade and service systems. According to the findings, factors that trigger a change mechanism by influencing an adaptive user behaviour are identified and categorized under two main groups: *human* and *environmental* factors.

Human factors are divided into two sub-groups: (1) *age, gender, country of origin, education level, type of job*, and *socio-personal traits* as personal descriptors; (2) *security, privacy, hygiene*, and *view* as personal needs. Environmental factors are divided into three sub-groups: (1) *outdoor temperature, solar access, wind/rain, relative humidity*, and *outdoor noise level* as external factors, (2) *indoor temperature, lighting conditions, air quality, relative humidity*, and *indoor noise level* as internal factors, (3) *building function, building layout, façade characteristics*, and *service systems* as spatial factors. The main adaptive behaviours are identified as (1) opening/closing windows, (2) adjusting window blinds (shading elements), (3) adjusting HVAC systems, (4) turning on/off lighting, and the change effects that these actions would result in are listed as (1) air exchange rate, level of (2) light transmittance, value of (3) indoor temperature, and (4) illumination level. Through these impulse, mechanism, and response relationships, the direct or indirect effects of each factor on user experiences are distinguished. Where the *user experiences* are defined as *seeing, feeling, hearing, and controlling*, they are therefore not only focused on the concept of comfort but also cover all human senses, emotions, behaviours, and interactions.

Based on the outcomes, in the simplest terms, it could be said that every user has different needs, perceptions, and thus, different behaviours. With a human-centred point of view, adaptive façades with their changeability feature, offer great potential to deal with these diverse needs and to keep the indoor environment in its preferred condition with a reduced level of energy consumption. An understanding of the users' relationships with the façade is essential in creating an ideal way of interaction, thus improving the user experience. In order to achieve that goal, the relationship between the human factor, as an agent of change, and automation systems of the adaptive façades, as the actor in the mechanism of change, is pointed out as the missing link. Therefore, relevant issues and further research areas towards a human-centred adaptive façade design approach are introduced. The information presented in this paper could serve researchers in the field as a starting point, and show façade designers the adaptive nature of the users, hence transferring the knowledge on the dynamics of occupancy to the design phase.

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