Occupant-Adaptive Façade Interaction: Relationships and Conflicts

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Adaptive or Intelligent façades are those that can interact with users and dynamically vary their performance or properties (controlling thermal or solar energy, air flow and/or daylight) in response to changing external conditions and indoor demands. Consequently, adaptive façades could help to ensure occupant comfort, health, well-being and satisfaction, while allowing resource-efficient building operation. However, effective adaptive façade solutions that provide an optimal balance between user comfort, satisfaction and energy efficiency cannot be achieved without knowledge of the multidisciplinary complexity of the user-façade interaction. The main objective of this paper is to preliminary review and analyse the existing literature on user interaction with intelligent buildings, especially with façades, and to propose a conceptual framework to capture the multi-disciplinary and multi-domain complexity of user interaction with adaptive façades. The interaction between adaptive façades and occupants is then modelled as a closed loop of information and action exchange. This paper concludes indicating which are the future research needs to be addressed in order to define what is a satisfactory interaction strategy between occupants and façades.

Keywords: adaptive façade, user interaction, dynamic control, occupant satisfaction

1 Introduction

Adaptive façades are smart and responsive systems where an IT control strategy can vary façades performance to increase buildings resource-efficiency (Favoino et al., 2013), but also to interact with occupants in order to tailor environmental conditions to dynamic demands for comfort and well-being (Konis & Selkowitz, 2017). The interaction between occupants and façades is a multidisciplinary and complex relationship with multi-domain effects and conflicts (Loonen et al., 2013). However, the nature and the effects of these mutual interrelationships between occupants and façades is yet to be completely defined (Attia 2018) and also their impact on other building components, such as building management systems (BMS), needs to be investigated. The clear definition of which are the potential interactive relationships between occupants, façades and, additionally, BMS systems is a crucial step towards satisfactory adaptive and smart buildings in both design and operational stages.

The aim of this paper is to review the existing literature on this topic and to initially define which are the potential interactive relationships between occupant, adaptive façades and other building systems and, consequently, identify potential conflicts in the level, mode, frequency of those interactions. Section 2 presents the methodology applied to develop this preliminary review. Section 3 discusses the main conflicts in selected interactive relationships. Section 4 proposes then a conceptual model to frame the interactive relationships between occupant and adaptive façades as a closed loop. Finally, Section 5 indicated the future research efforts to be made on this topic and concludes with the main finding from this review.

2 Methodology

This paper is the result of a literature review on the interactive relationships between occupants and adaptive façades, which was developed within the COST TU 1403 "Adaptive network" participants. For the purpose of this study, adaptive façades are considered as composed by both a hardware (the façade) and a software (the ensemble of embedded IT - information technologies). The literature review has been structured then according the overlapping conceptual areas within Façades, IT systems and Occupants in the Vern diagram in Figure 1: 1) Relationships and conflicts within IT systems and Occupants, which includes the interaction of occupants with the control logic of the façade either requiring action and information or providing feedback; 2) Relationships and conflicts within IT systems and Façades, which includes the logic control actions towards the facades and potential information exchange on its performance; 3) Relationships and conflicts between Occupant and façades, which includes any direct interaction of occupants with facades, similarly to occupant interaction with traditional facades. In addition, the interaction within BMS systems and Façade control strategies was also preliminary included (Figure 1, number 4). This literature review was considered by the authors as a preliminary attempt to investigate the mutual relationships between IT systems or control strategies, occupants and façades and with the full-awareness that this is an initial work and it could serve as basis for a more comprehensive understanding of the multidisciplinary complexity of the interaction between occupants and façades.

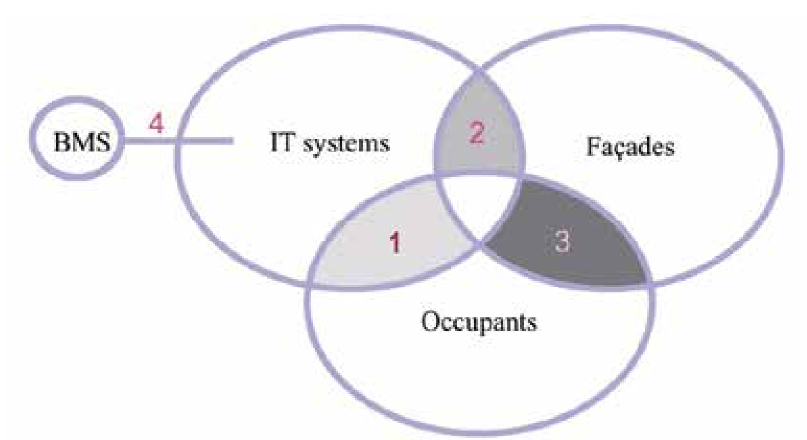

Figure 1 Vern diagram of the literature review topics addressed in this work

3 Literature review on Occupant-Adaptive Façade Interaction

3.1. Relationships and conflicts between occupants and adaptive façades IT systems or control strategies

Due to the multisensorial effects of façades and the highly-individual response of occupants, designing for user interaction with dynamic envelopes is a challenging task and conflicts and inconsistencies often arise (Day & Heschong, 2016). In the literature review, two different types of conflicts have been identified when occupants interact with intelligent façades: 1) Conflicts among users in relation to their personal control; 2) Conflicts between users and automatic control strategies.

Conflicts among users often arise in shared office spaces (Galasiu & Veitch, 2006), since comfort expectations tend to be highly individual and, hence, ensuring appropriate environmental conditions and control for all users can be burdensome. The wealth of research on individual based environmental services in modern office environments is a response to this challenge. However, façade are usually considered as a shared components and, consequently, just designed to avoid severe discomfort scenarios (Fabi et al., 2014). Moreover, their effect on users strongly depends on occupant location. Defining a control strategy that can satisfy all users demands is then a challenging task and a question arises as whether the level of control required for user satisfaction is dependent on the occupant position (Cohen et al, 1998). For instance, the occurrence of fully raised lower blinds was found to be dependent on the distance between occupants desktop and the external façade by Haldi and Robinson (2010). However, several studies have also shown that users in open space offices can be either active or passive independently from their location in the space. Active users tendency to take responsibility of controlling the environment on behalf of others co-workers, depends more on personality features than occupants position among the space. Hence, providing different interfaces and degree of control according to the position to the façade might not be the most appropriate solution for a satisfactory interaction.

Identifying which is the appropriate balance between personal control and automatic strategies is one crucial aspects, as shown from the literature review. Occupants inclusion in the "control loop" is widely recognized as being paramount to occupant satisfaction (Heerwagen & Diamond, 1992; Norman, 1994) and when their environmental control is denied users tend to become "infuriated" with automatic control strategies (Cole & Brown, 2009). The appropriate balance between personal and automatic strategy is not, however, easily generalised, since it depends on several factors. Day and Heschong (2016) report that there is no clear universal tendency for user preferences between manual and automatic controls. Nonetheless, there are two valid principles identified in literature (Day et Heschong, 2016): a) automated controls are more accepted if users can override them; b) automatic controls are highly accepted if they meet user preference, otherwise they are perceived as strongly uncomfortable.

The type of control is also influencing user acceptance of automatic strategies (Day & Heschong, 2016). For example, several studies have shown that people are more likely to accept blinds being raised rather than lowered (Galasiu & Veitch, 2006; Venkatesh et al., 2003; Reinhart & Voss, 2003). The balance between personal and automatic control can also be adjusted at different stages of the building life. Levels of automatic control could gradually increase together, and in parallel, with their users acceptance. In this sense, Matthew and Vic (2012) reported a user evaluation of an "adjustable autonomy system" (Matthew & Vic, 2012), whose levels of control were gradually increased, as the user gained confidence with the interactive system. Consequently, allowing for the most appropriate personal control is important for a satisfactory interaction of active users in intelligent buildings. Users preferences on personal control modalities are also influenced by the type of intelligent façades and the frequency with they would like to interact and override automatic systems. Meerbeek (Meerbeek et al., 2014) showed that users can be classified according "different usage patterns and attitudes", namely: minimal users control, regular user control, active user control and system control with manual override. Several factors can influence usage patterns and attitudes. For instance, Bakker underlined the importance of the distance from the façade in defining the desired interaction frequency (Bakker et al., 2014). The effect of the distance from the façade on occupants' level of perceived control was identified, as well, by Boestra (2016). The influence of space typology on user behaviour (O'Brien et al., 2013) or acceptance of automatic controls has also been widely reported in literature (Attia 2015 and 2016ab). Occupant behaviour has also been shown to depend on orientation (Fabi et al., 2012).

3.2. Relationships and conflicts between façades and occupants

The existing wealth of research on occupant interaction with windows or façades has already largely investigated the relationships between occupant and window or façade operation. For instance, Wymelenberg reported an extensive review of the patterns of occupant interaction with window blinds (Wymelenberg, 2017) or Fabi et al. (2012) for occupant window opening behaviours. Conflicts are usually related to: a) user misunderstanding of window and façade operation or means for their personal control; b) the simultaneous and multi-domain effects of façades on occupants; c) conflicts within multiple users in shared spaces (Stazi et al., 2017).

Occupant misunderstanding of personal control modes can often generate frustration and strong environmental dissatisfaction, while also undermining passive energy-efficiency strategies (Janda, 2011). In this sense, occupants training on building operational strategies plays a crucial factor, as shown by Day and Gunderson (2015), who reported that occupants with effective training were significantly more satisfied with their office environment. Window signalling systems are also one example of new communication modes between façades and users that can better inform user on optimal window operation (Ackerly & Brager, 2013).

Since any change in façade operation and performance can potentially affect more than one environmental domain, discrepancies with conflictive occupant demands often arise when an optimal balance in façade environmental performance is not achieved. Conflicts between acoustic comfort and natural ventilation are an example of these discrepancies. Successful façades should allow satisfactory operational modes, ensuring for instance outside view while preventing glare discomfort and maintaining energy efficient building operation (Loonen et al., 2013). Studies on the motivation behind user behaviour driven by discomfort (Fabi et al., 2012; Zhang & Barrett, 2012; Stazi et al., 2017) are in this sense useful to inform automatic control strategy about which control employ, even in conflictive scenarios.

As already mentioned for the conflicts within occupant and façade control strategies, the social dynamics of shared office space can also have strong impact on user operation of façades (Fabi et al., 2012). For instance, Cohen et al. (1998) reported that all manual controls in open-plan offices tend to follow operational pattern that minimise conflicts among users but do not optimise building performance.

3.3. Relationships and conflicts between BMS systems and façades IT systems

BMS and façade control strategies are strongly related since façades are the primary origin of heat losses and the principal building component in modulating solar radiation intake and natural ventilation strategies. Consequently, BMS are designed in response and completion to façade performance to ensure acceptable indoor conditions. Optimal façade control strategies can minimise peaks in cooling and heating loads and reducing over-lighting due to control of direct solar penetration (Halawa et al., 2018). Pervasive Sensing (Kumar et al., 2016) and Building Automation (Merz et al., 2009) allow to develop reactive and even predictive integrated control strategies where BMS and façades IT systems can communicate to mutually adapt their performances and potentially predict future control patterns. Integrated lighting and façade control strategies are an example of these adaptive integrated building controls.

Discrepancies between BMS and façade control strategies often arise when the granularity of communication between both logics is not sufficient either in space or in time. For instance, there is a need for a sufficient number of façade sensors in space and for them to communicate with

BMS in order to correctly align both control strategies. BMS systems or façade automatic controls are often only relating on central weather stations, which are not sufficient to read significant changes on façade performance according to the distance from or the orientation of the façade. The role and location of façade and BMS sensors and actuators need also to be update in time in order to ensure scalable and flexible exchange of information and feedback between both logics (Comminges & Dugué, 2015). For example, this happens when occupancy pattern changes or either presence of new obstruction on the façade are not recorded by BMS system or, alternatively, when open and flexible spaces are commonly designed in office buildings. Conflicts arise when inconsistencies in the flexibility of the layout and the adaptability of the façade exist (Juaristi & Monge-Barrio, 2016), and in addition, BMS system are not consistent with this relation. Therefore, façade and BMS should also be compatible enough with the re-design of the open space, providing as much flexibility as possible. To conclude, there is a need for connecting both façade and BMS intelligences from early design stages (Puglisi & Ciaramella, 2016), in order to ensure their smooth interaction through a flexible and scalable exchange of data.

4 Proposed framework of relationships within occupant, adaptive façades and BMS systems

For the purpose of this paper, the interaction between adaptive façades and occupants has then been modelled as a closed loop of mutual relationships amidst the façade, the occupant and the IT control strategy. As shown in Figure 1, the user-façade interaction embraces different type of interchanges between occupants and the intelligent façades. A satisfactory interaction between occupants and intelligent envelopes fulfills all needs of the system for interacting in a closed loop between occupants and the adaptive façades (Konis & Selkowitz, 2017). From the review, the interaction between users and dynamic façades has been divided in (Figure 1): 1. The interaction between users and the IT system, both as capability of the user of overriding and personally control the IT strategy (a) and of the IT system to read user feedback and demands (b); 2. The interaction between the IT system and the façade, both as active capability of IT to control the façade (a) and read data from its performance (b); 3. The interaction between the user and the physical interface of the façade, including the façade opportunity for being an information hub for users (a) or the possibility of occupants for changing the façade properties (b); 4. The interaction between façade control strategies and BMS systems, façade control strategies can read performance data from façades and change the BMS inputs (a) or the BMS can change the façade behaviour to improve energy efficiency strategies (b). Depending on the façade and IT technology, all these features need to be present and characterise in terms of level, mode, frequency and space in order to ensure a satisfactory interaction strategy.

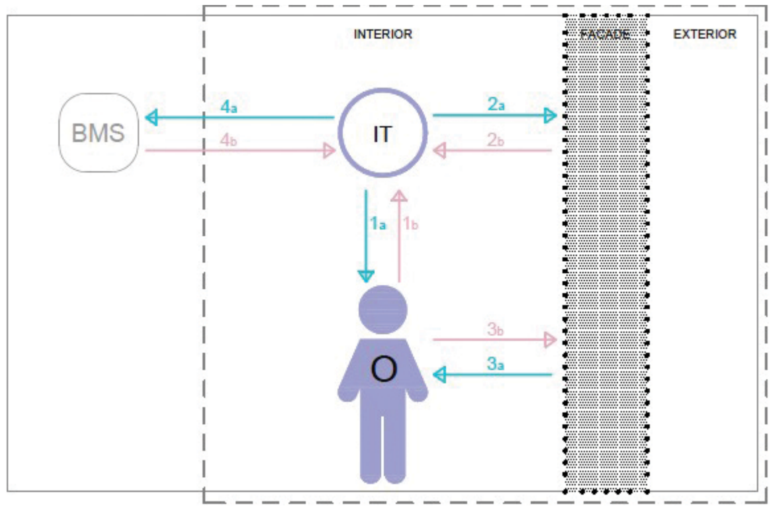

Figure 2 Proposed framework of relationships within occupant, adaptive façades and BMS systems.

In order to minimise the discrepancies and conflicts highlighted in Section 3, whilst maximising occupant satisfaction with the environment and building operation, this conceptual model has been framed as a closed loop of mutual information and controls exchange between users, adaptive façades (considering both the IT central intelligence and the façades components and actuators) and potentially BMS systems. The implementation of this closed loop of interaction strategies is considered fundamental for the delivery of satisfactory intelligent buildings, where alternative intelligences (BMS, occupants and adaptive façades) are connected and communicating with each other. This closed-loop of interactions could allow multiple responsive system to share their real-time sensorial information or stored database and simultaneously inform any responsive or adaptive control strategy within the building, even to predict future occupant demands or energy-efficiency strategies. Nevertheless, this model is still an initial framework and there is a need for its further development in order to include in detail the multi-domain and multi-disciplinary complexity of alternative scenarios and directions of interaction.

5 Conclusion

This paper reports initial findings on the relationships and conflicts generated by the occupant interaction with adaptive façades. This ongoing work is part of the Working group 3, COST Action TU1403 “Adaptive Facades Network”, and aims to investigate which are the main drivers of a satisfactory interaction between occupants and façades. This review has been focusing on the main relationships and conflicts between occupants and adaptive façades. Given the existence of multiple potential conflicts within IT and BMS control strategies, adaptive façades and occupants, this paper proposes a conceptual model of interaction strategies as a closed loop of information and actions exchanges in order to connect all the intelligences involved and ensure a smooth and satisfactory interaction strategy.

Next work will further investigate the multi-disciplinary complexity of those interactive relationships, defining which are potential exchanges of feedback and controls between occupants and adaptive façades. Consequently, further work is needed to define which are then the satisfactory modes and frequency of those flow of information and controls.

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