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Towards multi-domain user archetypes for user-centred façade design

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Abstract. User experience and satisfaction with the facade play a significant role in user comfort and energy efficiency of buildings. This paper explores the concept of User-Facade archetypes to inform the user-centred design of shading devices based on the perceived level of importance of different environmental domains at the workplace. A questionnaire was developed to collect data on users' perceived level of importance of different environmental domains, user characteristics and other preferences. Based on the associated level of importance of the domains affected by shading devices (thermal conditions, access to daylight, access to outdoor view, privacy and glare mitigation), users were then clustered into eight different archetypes, which associated different "weights" to each comfort domain. The study also found a significant correlation between the associated level of importance and the reported frequency of interaction with shadings because of thermal comfort, glare mitigation or privacy. Overall, users that associated high levels of importance to several environmental domains also reported high perceived levels of importance for personal control at the workplace. Only one archetype reported low importance for personal control at the workplace. Further work is required to validate these archetypes by capturing actual user behaviour and preferences in real workplaces. However, these findings provide preliminary and valuable insights into the possibility of clustering users on their preferences and using this for informing a more user-centred design or operation of shading devices.

1. Introduction

Shading devices have the primary role of controlling the level of solar radiation through the envelope to maintain comfortable visual and thermal environmental conditions [1]. Adequate design of shading devices is required to allow satisfactory daylight penetration, ensure view, avoid glare, and limit the thermal exchange between indoors and outdoors to provide energy-efficient and comfortable indoor temperatures [2].

Several types of shading devices exist in the market, which can be ranked depending on their performance in the above-mentioned environmental domains via building performance simulations. However, knowledge of user preferences is required to enhance user satisfaction whilst reducing energy consumption. Occupant behaviour with shading elements is affected by their satisfaction with the façade configuration [3] and can have a strong impact on the overall energy performance of a building. Under the same environmental conditions, occupants have shown different levels of comfort, which requires the right selection of façades among the range of available alternatives [4]. This reveals a strong

preference for customised indoor climate, personal control, and a wider range of visual conditions acceptability.

Since environmental preferences among users change, different shades could be more effective than others in fulfilling personal requirements [5], whilst reducing operational energy in buildings. However, capturing user preferences about environmental domains and shading typology is complex since shadings have a multi-domain influence on users, and they can simultaneously impact several domains: satisfaction with an outdoor view, privacy, thermal environment, daylight and glare or even acoustic if the shadings are motorised [6]. Often, these domains compete when it comes to shading operation and performance. For instance, lowering blinds because of glare can compromise daylight access and view or designing shadings to control solar radiation for thermal comfort and cooling demand may compromise view and daylight access [7].

This paper aims to preliminarily explore the creation of archetypes of users based on their perceived level of importance of environmental domains to effectively inform the user-centred design of shading devices. The main hypothesis behind the archetype creation is that users may assign different levels of importance to the comfort domains, and this information could be useful to understand what competing interests of shadings should be prioritised when selecting shading devices. In this way, the comfort domain and preferences that are most important to the user can be enhanced.

To preliminary explore the use of archetypes for façade design, a questionnaire was developed, and data were collected to analyse user comfort preferences in the environmental domains related to shading devices. Then a correlation analysis is performed to identify what user characteristic or belief is significantly correlated with their associated clusters.

2. Methodology

The use of archetypes to inform user-centred shading devices was explored by collecting data on user preferences with multi-domain indoor environmental quality via a questionnaire after receiving approval from the Ethical Committee of the Delft University of Technology. A total of 228 responses were collected from the questionnaire for two months between April 2023 and May 2023 via Qualtrics [8]. These responses were then cleaned, and a total of 171 responses were selected. The questionnaire was distributed to office workers without restriction on location, being shared in several countries throughout the networks of the researchers involved in the research.

As shown in Figure 1, the questionnaire collected data on five main categories: (i) user characteristics, (ii) contextual factors, (iii) user beliefs, affordances, and perception; (iv) personal importance of environmental domains; (v) personal preferences in terms of distance from the window, view content and clarity, and spatial characteristics. In particular, the importance of outdoor view access was evaluated by showing several different images with different view content and blind patterns. External shadings were considered for this survey, in particular venetian blinds with three different slat sizes and roller blinds with different openness factors and colours. Information on daylight patterns created by different shading devices and related user preferences were also collected, but they are not analysed in this paper. In this paper, only the perceived importance of comfort domains and reported frequency of interaction with shading devices are investigated. Consequently, the data were analysed to construct archetypes of user preferences that can inform the effective design of shadings and investigate the correlation between user preferences and characteristics, the associated level of importance of one environmental domain and the cluster.

The user archetypes were created based on the perceived level of importance of single comfort domains. The clusters were created by using the k-means algorithm. K-means clustering is a distance-based unsupervised learning algorithm where data points that are close to each other under a distance metric are grouped in each number of clusters/groups [9]. An adequate number of clusters was selected by performing distortion analysis through the elbow method and by selecting the highest possible Silhouette score. A total of 8 clusters were then considered adequate for the obtained datasets. Significant correlations between the perceived level of importance and reported reason and frequency for interacting with shadings were then evaluated with Pearson correlation analysis. These correlations

were then further analysed with the Bonferroni to avoid type I error, i.e. erroneously inferring the presence of a significant correlation, when calculating numerous correlations across multiple variables [10]. Multi-variate ANOVA test was used to assess the significance of the country with environmental domain importance.

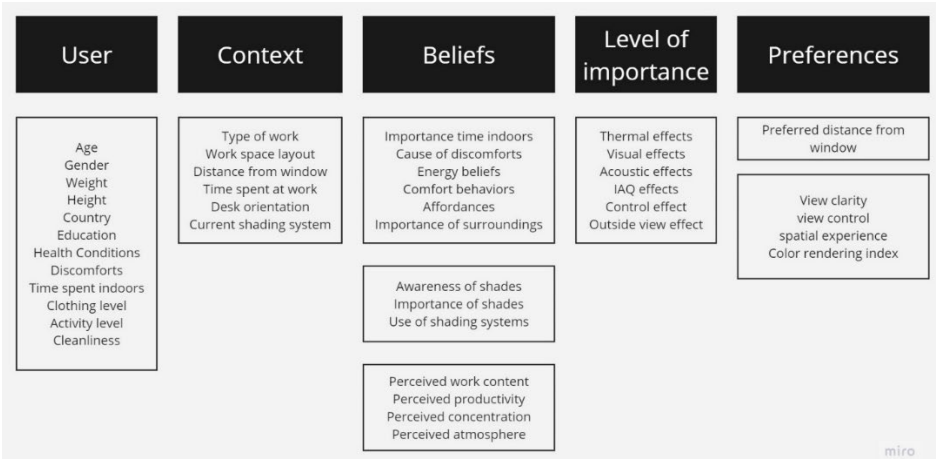

Figure 1. Detailed description for each of the five categories from which data was collected. All the elements in every category were translated into questions for the questionnaire.

3. Results

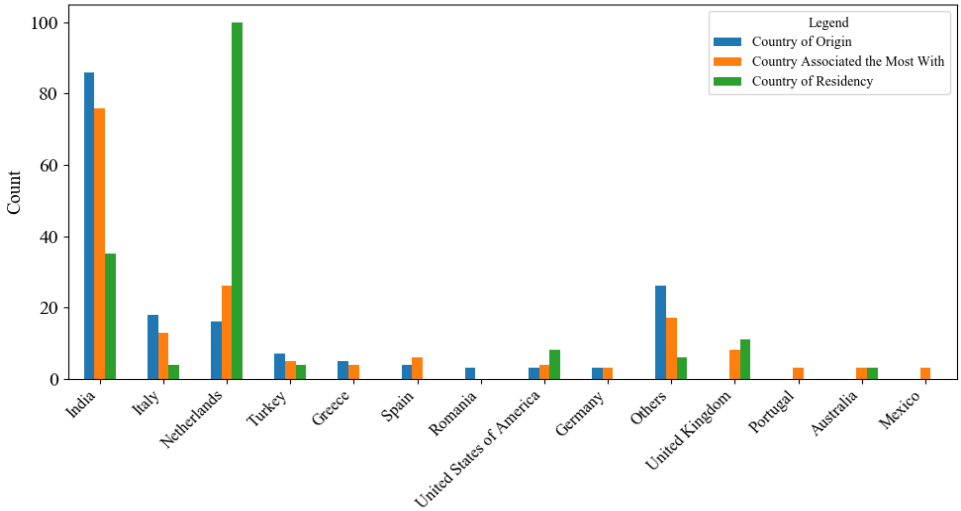

Figure 2. Country of origin, country of residence and country most associated with, the respondents surveyed in the study. Countries represented by less than 3 respondents are classified under "Others".

3.1. Overview of the results from the questionnaire

The respondent's demographics show a relatively even distribution between male and female respondents. The questionnaire dataset contains various ages ranging from 18 to 59, in which the median is 27. Figure 2 displays the respondents' country of origin, country of residence, and the country they associate with the most. A multivariate ANOVA test was then performed to assess the significance of the country of origin, residence and most associated with, with users' scores on the level of importance of each environmental domain. A high level of significance was found (p-value < 0.01) and this is further considered in section 3.1.2.

3.2. User Archetypes based on multi-domain environmental preferences

Figure 2 shows the overall perceived level of importance that users associated with environmental domains, with 1 corresponding to "unimportant" and 5 to "important". Satisfaction with temperature, daylight and glare mitigation were considered equally important when considering the overall group. Satisfaction with the outdoor view and privacy presented a larger scattering. However, when considering individual preferences, users showed associated different levels of importance to each comfort domain. Users differed from each other on the associated level of importance of different environmental domains, thereby showing a wide range of differences in user multi-domain preferences. Consequently, user preferences with indoor environmental quality about shading devices were clustered into eight main archetypes, as shown in Figure 3.a. Figure 3. b shows the number of people associated with the archetypes. The most common archetype (23.4% of users) in the surveyed group of users gave the highest importance to thermal, followed by daylight, glare, view, and privacy. The second most frequent archetype gave the highest importance to daylight access, view, glare and then the thermal domain, with little importance to privacy. The third most common archetype (12.3%) gave a similar level of importance to privacy and glare, followed by thermal domain and daylight, and the least importance to access to outdoor view. Pearson correlation analysis was then performed to assess whether user archetypes were correlated with the country of origin, country of residency or country with which users felt most associated. However, no correlation above 0.2 was found.

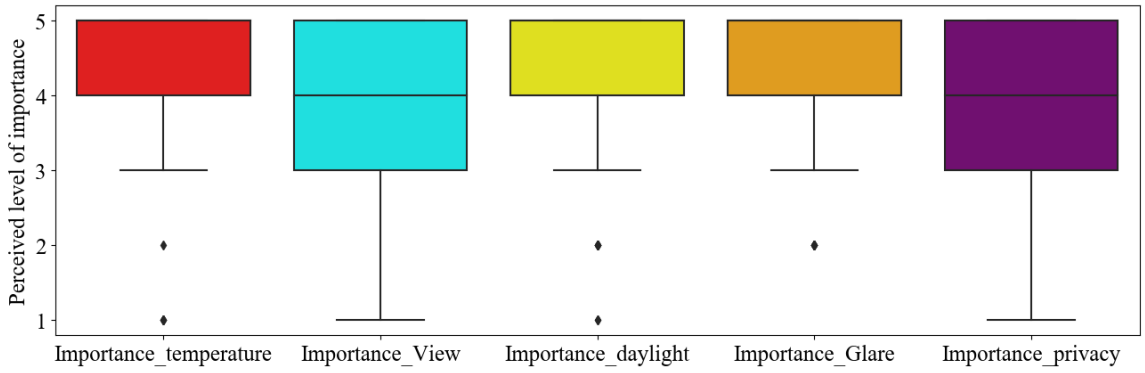

Figure 3. Perceived level of importance of the comfort domains influenced by shading devices for the overall group of users. The box plot shows the overall median, quartiles, and potential outliers of the user responses.

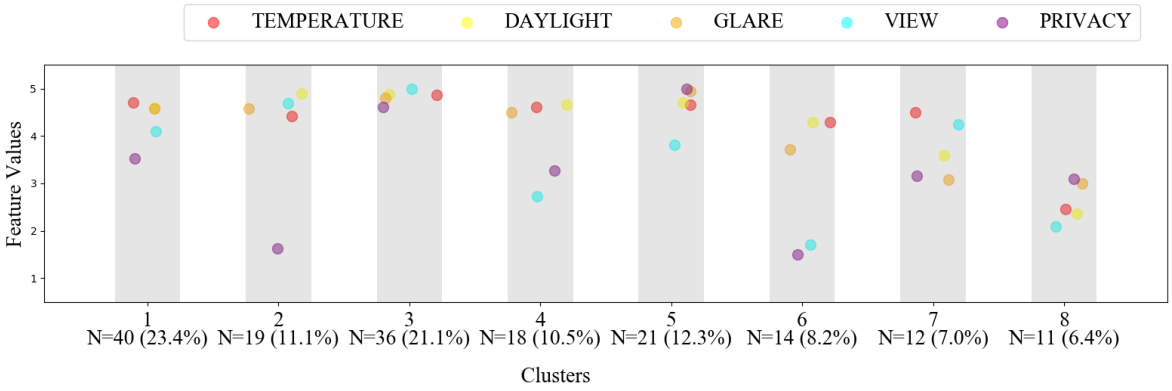

Figure 4. User clusters or archetypes depending on the perceived level of importance of different environmental domains, a) level of importance of different environmental domains, and b) frequency of users per each cluster.

3.3. Correlation between the importance of environmental domains and reported frequency of interaction

Since user behaviour can be a reliable proxy of user preferences, an analysis was then performed to evaluate the correlation between the perceived level of importance and reported reason and frequency for operating shadings, perceived importance of controlling window vents or shadings (including improving temperature, glare, privacy, light conditions, view or satisfaction with internal space aesthetics), or controlling HVAC (Figure 4). There was a significant correlation between users that reported temperature, glare and privacy as important at their workplace and their reported frequency of interaction with shadings to improve these domains. A high level of importance with daylight and access to outdoor view was not correlated with high frequent interaction with shadings to improve daylight or view access. However, since there may be a discrepancy between the reported frequency of interaction and actual behaviour in real office spaces, an experimental campaign should be conducted to monitor actual user behaviour versus reported one and perceived level of importance. Overall, there was a significant trend to associate high importance to personal control (of shadings, vents or HVAC) by users that associated high importance with temperature, glare, daylight, view and privacy.

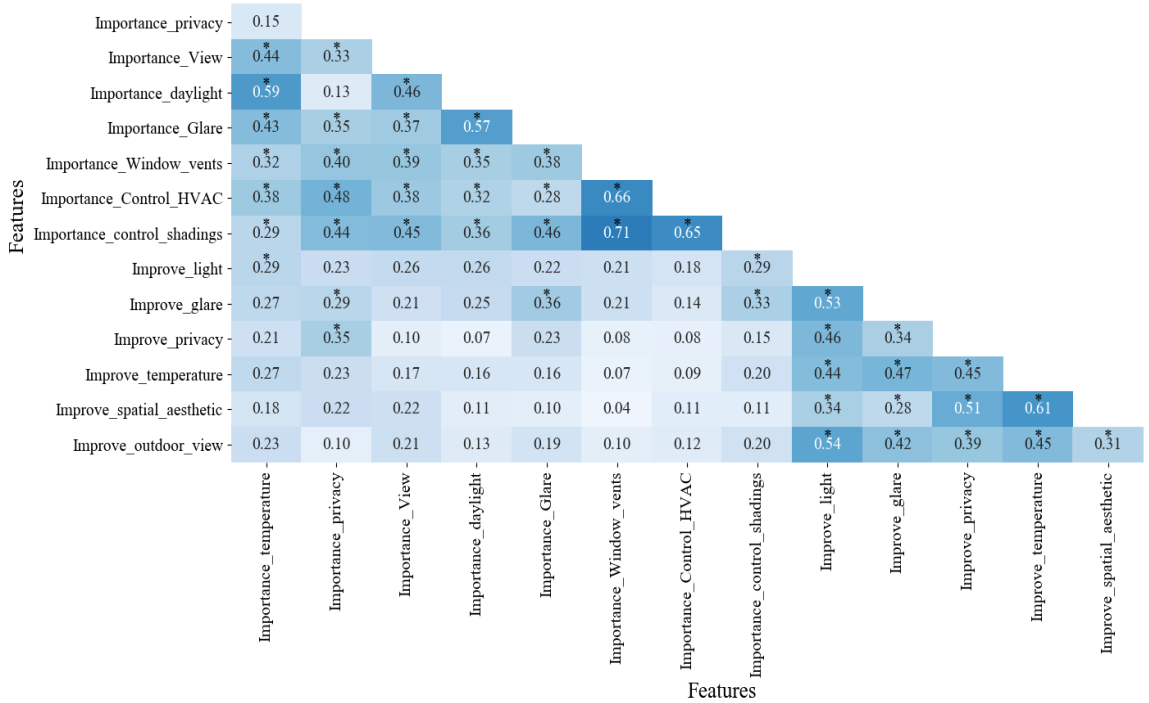

Figure 5. Pearson correlations between the perceived level of importance of each environmental domain (daylight access, outdoor view access, glare mitigation, thermal environment and privacy) and frequency of interaction with shadings. The * indicates where the correlation was significant according to the Bonferroni test.

4. Conclusion

This work showed a preliminary development of user archetypes based on reported differences in the perceived level of importance of environmental domains at the workplace. These archetypes can be used to assign weights to the different environmental domains, which in turn could be used to weight shading performance in different domains (e.g., daylight access, view access, glare mitigation, control of solar radiation for overheating) and accordingly define a multi-criteria and multi-domain selection process. Given that shading devices often have competing performance requirements, the use of weights on the base of user preferences can inform a more user-centric design of shading devices.

This initial work was useful to explore the possibility of clustering users depending on the associated level of importance to different environmental domains. Differences were found across users, such that archetypes could be developed based on these differences. Future work should now focus on evaluating

the difference between the perceived and declared importance that users give to these environmental domains, and their behaviour in buildings, which can also be influenced by other contextual factors, such as several occupants in the room.

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