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Article

Sensors in support of multi-criteria human comfort-driven structural glass design in buildings

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Abstract: Digital tools are notoriously able to assist designers in solving several issues with high accuracy and minimized computational efforts. In this sense, maximization of human comfort in the built environment is a target for various design procedures, where mathematical models and standardized protocols are generally used for well-being purposes. In this study, recent experimental studies in which various artificial intelligence tools and sensors are used to assess a multi-criteria human comfort-driven design approach for structural glass buildings and configuration. The so-called "emotional architecture" and its associate nervous feelings, human reactions and behaviours, which are intrinsic part of the issue, are quantitatively measured and compared to find possible feedback in structural glass design optimization. Both remote digital technologies based on facial micro-expression analysis and in-field experiments with multiple sensors, able to capture kinematic and biometric parameters of volunteers moving in glass environments, are discussed.

Keywords: Glass structures; sensors; structural design; human reactions; biometric parameters; experiments.

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1. Introduction

Civil engineering design and industry are continuously evolving with the support of advancements in technology. Digital tools are able to assist designers in solving several issues with more accuracy and minimized efforts. In parallel, maximization of human comfort is a target for various design procedures, where mathematical models and standardized protocols are conventionally used to optimize well-being of customers. Major challenges and troubles can indeed derive, structurally speaking, from human reactions, which are related to a multitude of aspects, and may further enforced by slender / transparent glass components. The so-called "emotional architecture" and its nervous feelings are intrinsic part of the issue, and hence the mutual interaction of objective and subjective parameters can make complex the building design optimization.

Several motivations highlight that human comfort in the built environment is a target for a multitude of aspects [1,2]. Various engineering tools are typically used to optimize design in terms of thermal comfort, indoor air quality, visual comfort, noise nuisance, ergonomics, and others. Besides, rather limited attention is generally given to other comfort aspects, such as psychological comfort against vibrations, which directly manifests in the form of different behaviours. Many aspects (like, for example, personal factors, nervous states, architectural parameters) are known to represent additional influencing parameters for human comfort in buildings (Figure 1).

This paper recalls and summarizes some recent studies in which human comfort for glass structures occupants is quantitatively measured, to support an optimal multi-criteria human comfort-driven design. Major efforts are derived from pilot remote experiments based on micro-facial expression analysis and remote photoplethysmography (rPPG) optical measure of heart rate, see [3,4]. Further, multiple sensors are used in in-field experiments to capture kinematic and biometric parameters for customers when moving in structural glass environments of building scenarios [5,6,7].

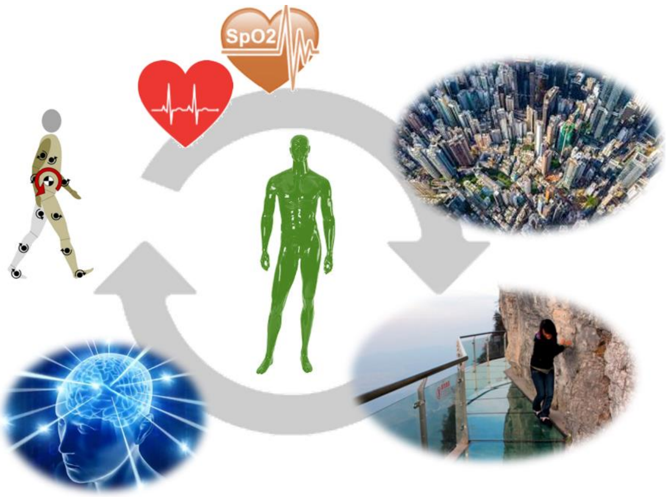

Figure 1. Qualitative concept of human comfort analysis and quantitative measure in glass-built environments (reproduced from [7] under the terms and conditions of CC-BY license agreement).

This means that a long list of aspects and parameters are mutually affected by each other, including the correlation of built environment characteristics and its impact on the occupants' emotions, behaviours, and physical well-being [1]. Modification of emotions and nervous state can result for example in different locomotion features (Figure 1), and thus in modification of moving loads which are transferred by humans on structural members. Psychological states are hence potential influencing parameters with a critical role in engineering issues for design, because resulting in possible unfavourable calculation of classical performance indicators [8-11].

In this scenario, glass components may have a critical role, compared to other constructional solutions. The well-known psychological effect of architecture can in fact have both positive and negative effects on users [12]. Several architectural concepts are voluntarily expected to evoke nervous states in the so-called "emotional buildings" [13,14].

Among various constructional solutions, this paper gives a special care to structural glass applications in buildings. Known as versatile but vulnerable constructional material, glass transparency and capacity to adapt to various setup configurations make it a largely used solution. Most importantly, glass applications are often known as "architectures of vertigo" [15], where transparent structures are conceived as spaces of visceral thrills and intense psychophysiological stimuli with deep sensory experience and socio-spatial implications. The high aesthetic impact of glass structures can be thus sometimes in contrast with the need of more efficient feeling of protection for the occupants, as it could be for extreme accidents, pedestrian systems, or uncomfortable configurations.

2. Materials and Methods

In order to achieve the prefixed research goals, two different experimental strategies are taken into account. In doing so, multiple response and performance indicators are collected to find correlations in the field of architectural and structural design concepts. For the presently reported results, the first experimental strategy was implemented remotely during Winter 2020 – Spring 2021. The second experimental strategy, characterized by laboratory and in-field measurements, was exploited starting from Autumn 2021.

2.1. Remote experimental analysis of human reactions

The first approach consisted in the use of a virtual reality environment in which volunteers were asked to take part to a glass environment presentation and visual stimuli. Major outputs from this first stage of experiment can be found in [3,4]. To that end, the FaceReader™ automatic facial expression recognition software (version 8, Noldus Information Technology bv, Wageningen, Netherlands) was used in support of the quantitative analysis of experimental measurements (Figure 2). Two different visual stimuli were designed to assess the reactions of volunteers, namely, consisting of a set of "static" input items and a "dynamic" virtual reality (VR) video clip of pre-recorded walks in glass environments. The post-processing analysis of experimental measurements from was partly based on the automatic FaceReader™ software analysis, and further elaborated as discussed in [3,4]. A group of 10 volunteers was actively involved in remote experiments. Video recording of facial micro-expressions, more in detail, was used to detect and measure:

- nervous states and emotions based on facial micro-expressions, and
- Heart Rate (HR) parameters and variations to the imposed stimuli, based on rPPG optical technique.

When exposed to a selection of 27 pictures (every 5 seconds) or to a dynamic clip of 120 seconds.

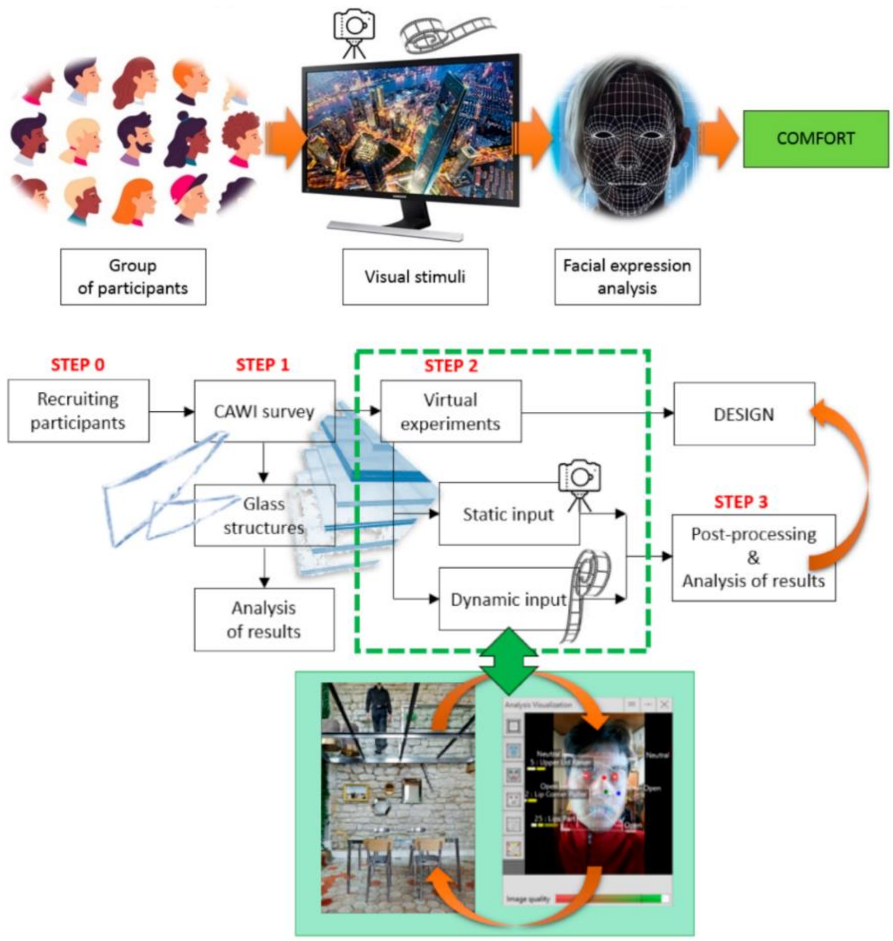

Figure 2. Experimental setup for the analysis of human comfort based on remote facial micro-expressions and optical HR measurements (figures reproduced from [3,4] under the terms and conditions of CC-BY license agreement).

2.2. Laboratory and in-field body measurements in glass-built environments

The second approach involved the interaction a single volunteer (from the previously defined group of 10) asked to walk in different environments when equipped by several devices able to capture motion kinematics and biometric parameters (Figure 3). For the present pilot study, the attention was given to the combined use of:

- a Wi-Fi triaxial MEMS accelerometer, fixed in the body Centre of Mass (CoM) of pedestrian, to record acceleration body CoM inclinations during walks [5,6];
- a Bluetooth professional sportwatch, to measure walk parameters (speed, gait length) and biometric parameters (HR, SpO2, etc.);
- a Bluetooth finger pulse saturimeter, to capture biometric parameters during walks (HR, SpO2, etc.), for double check of recorded data.

The above instrumentation was used to capture, during normal walking conditions, possible modifications in biometric parameters due to emotional states and potential discomfort, as well as to find possible correlation with kinematic parameters of pedestrians and substructure. As far as a single Wi-Fi sensor with Bluetooth devices were used as in Figure 3, the advantage of collected experimental records was represented by the lack of connection from any kind of laboratory setup, and thus the simple in-field experimental analysis in different locations and configurations.

Figure 3. Experimental setup for the analysis of human comfort based on kinematic and biometric parameters (detail photo reproduced from [7] under the terms and conditions of CC-BY license agreement).

5. Results and conclusions

The optimization of human comfort in the built environment is a target for several design fields and applications, but rather challenging issue, given that it depends on a multitude of aspects and interactions. For structural engineering applications, mathematical models and simplified procedures can allow to take into account conventional models of building occupants (i.e., deterministic stride loads, etc.), but these models can present intrinsic weakness.

In this summary, the attention was focused on the use of technological devices and tools to measure quantitatively some body parameters for customers, with the aim of assessing their human reactions and interactions with glass-built environments. The extended procedure with major outcomes can be found in [3-7].

At this present stage, the analysis of remote experimental evidences (with a group of 10 involved volunteers) confirmed that human reactions may suffer for psychological discomfort especially for customers asked to interact with glass load bearing components characterized by possible risk of fall (like for example balustrades, pedestrian systems, etc.), see for example Figure 4. Such an outcome was also partly confirmed by in-field measurements for an involved volunteer asked to walk on a rigid substrate or a more flexible (and thus sensitive to vibrations) transparent floor. In this latter case, however, laboratory and in-field measurements were carried out for 1 volunteer only (from the group of 10), and thus further extension of measurements is needed for robust analysis.

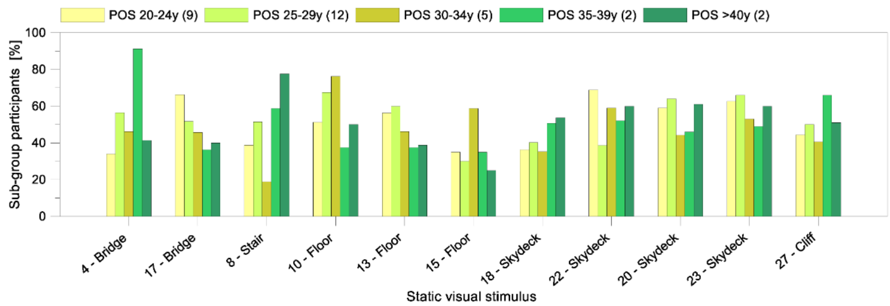

Figure 4. Experimental outcomes from micro-facial expression analysis of different subjects (grouped by age) subjected to various static visual stimuli of glass constructions (selection reproduced from [3] under the terms and conditions of CC-BY license agreement).

In this sense, such a kind of pilot experiments emphasized the need of large sets of measurements to correlate human comfort trends and needs to classical mechanical parameters for structural glass design. Further additional volunteers will be necessarily involved to extend the discussion of parametric outcomes, under different operational conditions and building context scenarios.

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