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What about if buildings respond to my mood?

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Abstract. This work analyses the possibilities of interaction between the built environment and its users, focused on the responsiveness of the first to the emotions of the latter. Transforming the built environment according to the mood, feelings, and emotions of users, moment by moment, is discussed and analysed. The main goal of this research is to define a responsive model by which the built environment can respond in a personalized way to the users' emotions. For such, computational technical issues, building construction elements and users' interaction are identified and analysed. Case studies where an occurs an interaction between the physical space and users are presented. We define a model for an architecture that is responsive to the user's emotions assuming the individual at one end and the space at the other. The interaction between both ends takes place according to intermediate steps: the collection of data, the recognition of emotion and the execution of the action that responds to the detected emotion. As this work focuses on an innovative and disruptive aspect of the built environment, the recognition of the new difficulties and related ethical issues are discussed.

Keywords: Responsive architecture; interaction; users' responses; user's emotions; ethics.

1 Introduction

Current technology allows us to build in such a way that buildings can be increasingly adaptable, interactive with their users and assume innovative forms of response. In this line of thought, the conception of the built space has been modified along with the technological evolution that allows the space to be morphologically transformed and reactive to its occupants.

The flexibility of the built limits is no longer virtual but is now physical. When, in the 20th century, the walls were freed from their supporting function and could be replaced by glass panels we witnessed the dilution between interior and exterior space and between different interior spaces. Now we want to take the next step, in which “the boxes” that surround spaces can be transformed.

For a building to be truly able to adapt and respond effectively to the occupants, it is necessary to incorporate technological and spatial systems that allow an effective interaction between the building and the occupant. These systems must include a group of sensors that enable the interpretations of events to which an automatic system may respond, coupled with a set of actuators able to act upon the environment. A system that responds to environmental stimuli will have e.g. temperature sensors that, when reaching a certain level, act by increasing or decreasing the air conditioning. On the other hand, a system that responds to the users' stimuli will have possibilities like facial recognition that allows to identify that the user is tired and to suggest a suitable lighting level for that state. These responsive systems use artificial intelligence that offers intelligent systems to analyze and act towards a user's state. Even though these systems allow high degrees of interactivity, its usage should be discussed since its use will imply that people give up personal control and their emotional states will be invaded.

Responsive architecture is currently focused mainly on changes regarding light, thermal and sound aspects of the built environment. Thus, it is not the user who prompt the changes but the environment who dictates them without his/her approval. This work proposes to analyze the mechanisms and discuss the consequences of having the user and his/her emotions dictating changes in space. Therefore, this work analyzes the possibilities of an interaction between the built environments and their users, focused on the responsiveness of the first to the emotions of the latter. Transforming the built environment according to our mood, feelings, and emotions, moment by moment, is discussed and analyzed in the scope of this paper.

The main goal of this research is to define a responsive model by which the built environment can respond in a personalized way to the user's emotions. For such, the emotions in stake, the technical and the constructive elements of interest to be incorporated in the spaces are identified.

The paper has seven main parts. In section two we define responsive architecture. In the following two sections we explore two types of responsive architecture: first the architecture that is responsive to environmental aspects (as light, temperature, wind, sound, etc), and next a section targeting architecture that is responsive to the users' behavior and emotions. In the fifth section we propose a model to be adapted when responsive architecture to user's stimuli is to be adopted. As this work focuses on an innovative and disruptive aspect of the conception and use of space, both from the architectural and technological point of view, the recognition of the difficulties that arise, as well as their effects are discussed at the next section. The work ends with conclusions.

2 Responsive architecture

The use of responsive architecture enables to have the control of the building comfort conditions, so that a building can act more efficiently (e.g. energy management or noise attenuation). The concept of "responsive architecture" was first introduced in the 1960s by the architect Nicholas Negroponte (Kolarevic and Parlac, 2015). The model proposed by Negroponte, inspired by cybernetics theories, derives from the incorporation of computing in architecture (Negroponte, 1970).

Responsive architecture is often associated with kinetic systems. Although kinetic systems have existed for several centuries, it was only in the 20th century that architects began to discuss extensively the integration of this type of systems in architecture. However, the possibility of implementing these systems was only possible by the end of the 20th century, due to technological advances that were taking place in mechanics, electronics, and robotics.

One of the first names to materialize a responsive structure in terms of architecture was Buckminster Fuller, who created the US pavilion Montreal Biosphere for Expo 67 in Montreal. This project consisted of a geodesic dome, in which a complex shading system inspired by the biological processes of the human body was created to maintain the internal temperature (Bullivant, 2006). Although Fuller first experiments have not been successfully achieved, they open the way for responsive architecture to become more and more a reality beyond theory.

Another name that stands out in this field of study is Tristan-d'Estree Sterk. Sterk criticized that the focus was at that time too centred on aesthetic aspects rather than the functional aspects that responsive architecture allowed (Sterk, 2003). As a starting point Sterk uses the premises created by the precursors of responsive architecture, and creates a model considering the latest technological developments (Henriques, 2015). One of the most important premises to keep in mind for this author is the way the user's needs and wants are considered in the solutions.

The Fun Palace project by Cédric Price was another important moment since it created a unique synthesis of the theories and technologies that were under development at the time, adopting concepts such as cybernetics and artificial intelligence (Meagher, 2015). In fact, in this project, Price believed that through the correct use of technology the occupants of a space would be able to have total control over the environment in such a way that the building would be responsive to their needs and the countless activities that would take place there (Glynn, 2005). “The Fun Palace wasn’t about technology. It was about the people.” (Mathews, 2005). The Fun Palace was a revolutionary project, in which the main aim was to create a space for people to interact directly with it.

2.1 Kinetic Systems

In 1970, William Zuk and Roger Clark published the book Kinetic Architecture (Zuk and Clark, 1970), which inspired a new generation of architects to design buildings with kinetic components. Since then, and due to constant technological developments, kinetic solutions have been developed and applied. The type of kinetic movement applicable to a building element allows its shape to vary in four ways: translation, rotation, scale, and deformation. The ability to control the various transformations and movements is an important feature of kinetic systems.

Thanks to technological developments it is now possible to explore various types of computerized control systems that can be directly activated (activated on the object) or indirectly activated (activated outside the object and through information coming from sensors). Indirect systems can be isolated, when the information comes from only one sensor, or they can be networked, when the information comes from a network sensor system. (Fox and Kemp, 2008)

The fundamental components of a responsive system are sensors and actuators. Sensors are responsible for measuring space properties, such as detecting movement, light, temperature, and humidity. In current buildings, the most used sensors are the ones for detecting presence, thermal, humidity and gas. Sensors broadcast messages to the actuators, which then execute the appropriate commands. Actuators thus have the responsibility to execute actions. These elements control devices such as dimmers, heating and blinds controllers, valves, among others (Kolarevic and Parlac, 2015).

3 Architecture responding to environmental stimuli

The use of a responsive architecture gives the possibility of improving the occupant's comfort by controlling the building conditions and enabling a more efficient usage regarding e.g., energy saving and noise reduction.

John Frazer (1995) in the 90s also experimented with environmental feedback and interaction with the users and external factors. In his experiences, the “environmental information [whether sound, light, colour or movement] was fed to a simplified environmental model which formulated responses based on an evolutionary algorithm” (Frazer, 1995, p. 75).

Other interesting examples of responsive environments are the BIQ (Bio Intelligent Quotient) House by ARUP in Hamburg (2013), the One Ocean Pavilion by SOMA Lima in South Korea (2012) and the Homeostatic Façade System by Decker Yeaon in New York.

In the BIQ House, the shading system (SolarLeaf) consists of a layer of microalgae placed between two layers of laminated glass, whose position adjusts according to the movement of the sun. The controlled growth of these microalgae allows to create shading. In the One Ocean Pavilion, the façade shading system mimics the movement and shape of a fish's gills. The lamellas that make up the system are both resistant and flexible, allowing elastic deformations so that light enters the building. The movement of these lamellae is achieved through actuators located in the upper and lower limits that apply compression forces, and that are individually controlled, producing a dynamic result (Maier, 2012). The Homeostatic Façade System is a self-regulating shading system which automatically adjusts to the outside weather conditions. It is composed of two layers of glass and a layer containing a structure of an intelligent material called dielectric elastomer. This inner layer transforms electrical energy into mechanical work, which enables the alteration of its shape. The expansion of its shape occurs when the structure receives an excessive amount of sunlight. One of the greatest advantages of this prototype is its low energy consumption (Decker, 2013).

4 Architecture responding to users’ stimuli

In 1969, Andrew Rabeneck said that the basic purpose of design is to avoid uncertainty through forecasting. For Rabeneck, the way to increase the useful life of a building was to design it in such a way that, anticipating the future needs of its users, it could continue to respond to them properly (Rabeneck, 1969). For that, architects would have to take advantage of all technological advances in cybernetics, such as process automation.

Several authors have been struggling with issues related to responsive architecture and the impact that such solutions can have on spaces and their occupants (Eastman, 1972). Archigram in 1964[1] defined the concept of the Control and Choice Dwelling in which inhabitants can control their environment and the dwelling is populated with robotised elements. Along this concept, Archigram divided between the “hard” elements that stay in the same place and the “soft” ones that move and are transformable by the interaction of the inhabitant with the building.

In 1972, Charles Eastman created the concept of adaptive-conditional architecture, related to an automatic space adjustment typology, based on spaces and users' feedback. This concept is focused on automation systems. The author describes how these systems could control the building and compares them using the analogy of a thermostat controlling the temperature in a room. Eastman’s system is divided into four elements: sensors distributed to monitor temperature changes; a control system or an algorithm that together with the sensors interprets the results and compares them with the predefined instructions; actuators; and a control mechanism that the inhabitants can regulate according to their preferences (Eastman, 1972).

Another interesting example is that of the architect Michael Mozer, who in the late 90s of the 20th century, implemented a system in an old school. Mozer’s system by observing the behaviors and patterns of its inhabitants, programs itself, and learns to anticipate and therefore accommodate the needs of its users. Mozer and his students installed sensors and actuators, to control light, ventilation and heating. The sensors monitored the temperature, ambient light, sound and movement in each room, and the actuators e.g. acted on opening of doors and windows, among other. By observing the behavior of the inhabitants, the system could predict what actions would be needed to accommodate the users’ needs. For example, the system predicts the period in which the rooms are occupied, initiating a process in which the system controls the correct temperature and light for the occupants, thus providing the greatest possible comfort (World’s “Smartest” House Created By CU-Boulder Team, 1998).

The model that comes closest to the theme of an architecture responsive to the occupant's emotions is presented by Kas Oosterhuis - “a house with a character of its own, sometimes unyielding, sometimes flexible, at one time sexy, at another unpredictable, stiff and unfeeling.” (Oosterhuis, 2003). This author presents a vision of a “time-based architecture”, in which buildings can change their shape, configuration, appearance and environment in response to occupation patterns. Therefore, buildings will be adaptive, interactive, and responsive. Later Oosterhuis with the Hyperbody Reach Group, tries to materialize this model through the prototype “NSA Muscle” (Kievid and Oosterhuis, 2003). NSA Muscle is an inflatable interactive structure that reacts to the touch and presence of occupants, with the ability to physically reconfigure itself. Pneumatic actuators, known as ‘muscles’, orchestrate movement through changes in length, height and width through the pressure associated with each of these. The various actuators

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[1] See http://archigram.westminster.ac.uk/project.php?id=109

work together to change the space in all directions, making the prototype constantly twist, bend, and rotate. The prototype reinforces the idea that architecture becomes a game where its occupants become the players, and architects are the programmers of that game. “We are becoming programmers of behaviours instead of makers of dead objects.” (Oosterhuis, 2003)

The Cerebral Hut artistic installation explores the relationship between architecture, interaction, movement, and human thought. Tradition indicates that space influences occupants. However, this artistic installation is intended to reverse this relationship by creating the possibility for the occupant to reconfigure the physical limits of space through thought. In order to create a space that responds to the occupant’s thoughts, a device that measures brain frequencies is used. By measuring the level of concentration and the blinking of the occupant, and therefore interpreting this data the system would create movement. The movement is created by modules inspired in Japanese origami art, which are inserted in hexagonal modules repeated throughout the structure. Thus, the installation allows its occupants to control its physical limits with their thinking (Office Ozelo, 2015).

5 A model for user’s responding architecture

5.1 Recognition of Emotions

Although there is no consensus from the scientific community about the definition of emotions, they still play a fundamental role in human social life (Gendron and Barrett, 2009). Paul Young, “characterize emotion as a special mental event involving integrated changes in feeling, behaviour, and physiology” (Gendron and Barrett, 2009, p. 334). Gendron and Barrett refer other authors’ definitions of emotion, as William James in the end of the 19th century: “bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur is the emotion”. For Shu et al (2018, p. 1) “emotion often refers to a mental state that arises spontaneously rather than through conscious effort and is often accompanied by physical and physiological changes that are relevant to the human organs and tissues such as brain, heart, skin, blood flow, muscle, facial expressions, voice, etc.” Mulligan and Scherer (2012, p. 346) say that x is an emotion if: x is an affective episode; x has the property of intentionality (i.e. of being directed); x contains bodily changes (arousal, expression, etc.) that are felt; x contains a perceptual or intellectual episode, y, which has the property of intentionality; x is inherited from the intentionality of y; x is triggered by at least one appraisal; and x is guided by at least one appraisal.

Emotions imply a relationship between an experience and a particular event, an object or an environment (Frijda, 1994). Ekman refers that, in his studies with colleagues, he had found that every investigator had obtained evidence for six emotions (happiness, surprise, fear, sadness, anger, and disgust combined with contempt) (Ekman, 1992). Another relevant fact brought by Ekman’s research is that he states that observers in Western cultures judge the emotion shown in facial expressions and that there are evidences of universality in those facial expressions. The ability to recognize emotions is one of the characteristics of emotional intelligence (Elfenbein, Marsh and Ambady, 1997), an aspect of human intelligence that has been discussed as being more important than mathematical and verbal intelligence.

5.2 Affective Computing

Affective Computing is the area of computing that enables computers to feel, recognize, respond, and adapt appropriately to the user's emotions. This field intersects with cognitive sciences, psychology and HCI (Human-Computer Interaction). Affective systems use emotions as input and, using machine-learning, learn to recognize emotions, and to adapt to the user through positive or negative feedback.

MIT Media Lab has created a research department for affective computing, in which software and hardware tools are developed. The developed research targets the analysis of how the user can interact with the computer. There are two types of interactions: self-Report and current Expression. Self-Report systems give the users the freedom to communicate their emotions. Usually these systems present different possibilities, where the user selects the icon that best represents an emotion. The advantage of this type of systems is that the user has full control of the message he/she wants to send. However, the user must stop whatever he/she is doing to communicate with the system. Current expression systems can recognize the user's emotion without interrupting a task. Nevertheless, this type of system takes away the user's control over the message sent and, and therefore the user loses his/her privacy (Picard, 2000).

In order to perform emotional recognition, a technological system needs to collect and combine different user’s signals, information about the user's context and preferences. Of the best-known strategies for emotional recognition we find is facial identification, that might be combined with other physiological manifestations, such as breathing, blood pressure, skin conductivity, muscle tension, among others (Shu et al., 2018). Khalili and Moradi (2009) study on emotions detection used several biometric sensors as electroencephalogram, galvanic skin resistance, temperature, blood pressure and breathing. Authors conclude that, for emotion assessment, EEG signals perform better than other physiological signals.

One of the biggest technological challenges in this field is how will a computer recognize emotions correctly, when they are not even always recognized by humans themselves. In fact, one of the biggest disadvantages of facial recognition is that individuals can manipulate it by altering their facial expression to disguise their real emotions. If a more accurate recognition could be accomplished, e.g. through brain waves, this would be avoided.

5.3 Relation between space and emotions

Another aspect that needs to be addressed is how buildings will react to human emotions, so to say, how to identify the appropriate correspondence between different human emotions and the spatial characteristics that will best respond to them. Human perception of space is a subtle act of the human body and mind. Space is self-evident and mathematically described, but the human perception of space is not. Spatial data spans spatial characteristics that need to be feed to a responsive system. For a space to effectively respond to emotions, and moods, there is also the need to correlate those spatial characteristics with the emotions believed to be common for all human beings.

Although studies have already been conducted and some results have been published, still correlating spatial properties with human perception and consequent emotions is still at its infancy. Leite et al (2019) show how safe and unsafe spaces, triggered by using or not handrails in ramps and stairs, influence human perception. Sun et al (1996) investigate the influence of surface slope on human gait characteristics, finding that pedestrians' step length was decreased during ramp descent. Franz el at (2005) studied the quantitative relations between the experience of architectural spaces and physical properties and found that participants prefer spaces whose proportions are close to ratios near to the golden ratio. Grobman and Shemesh (2015) also studied shape properties of space and concluded that non-experts showed no preference towards symmetrical spaces and were significantly more interested by a curvy space than the experts, who showed a tendency to prefer a sharp space. A recent study related to emotions by Quesnel and Riecke (2018) shows how virtual reality simulating space can enhance awe and goose bumps.

Architects like Pallasma (2005) have focused on studying on how architecture is designed for the human senses. In these studies, Pallasma refers to the task of architecture to “create embodied and lived existential metaphors that concretise and structure our being in the world” (2005, p. 71) Although architecture is mainly concentrated in the eye there are a multitude of sensory experiences that can be incorporated in architecture by haptic, olfactory and auditory stimuli.

The previous mentioned studies, as well as those from other authors, focus on the following architectural elements: form, material, colour, texture, scale and proportion, light (and shadow), temperature and sound. All these elements and combinations between them may have a correlation with emotions felt by occupants. These elements can be materialized in floors, walls, ceilings, windows and doors, by “hard” or “soft” elements as referred by Archigram[2]. Fixed, or “hard” solutions, e.g. the fix covering of a floor with a carpet, may trigger feelings of comfort in some users and may also trigger feelings of disgust associated with dirtiness in others. Using soft and mutable elements opens the possibility of adapting the responses to different users at different moments of the day.

These studies show us that, by manipulating the environmental conditions or qualities of a space, pre-determined emotions can be induced or provoked in its occupants. It is not a question of creating an emotional architecture, but one of increasing the transformability of the spaces themselves. Psychology and perception of emotions can then be used as a theoretical basis for understanding the personal and subjective nature of the experience of spaces. Observing users experiencing materials, shapes and proportions may enable the mapping of space according to the emotions provoked. Regarding the mutation of space this can be achieved in several ways. From a more physical one, by an elastic and transformable spatial envelope, to a more visual based one by using optical illusions, with the projection of images combined with light, sound and temperature, providing scenic effects.

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[2] See http://archigram.westminster.ac.uk/project.php?id=109

5.4 The Responsive Model

The model presented here for an architecture that is responsive to the user's emotions assumes the individual at one end and the space at the other, as represented by **Erro! A origem da referência não foi encontrada.**. The interaction between both ends takes place according to intermediate steps: the collection of data, the recognition of emotion and the execution of the action that responds to the detected emotion. This last step can be accomplished by using an evolutionary algorithm that searches for the solution that best responds to the detected emotions and current environment sensing, which corresponds to an issuing of the necessary orders for the mutation of the space.

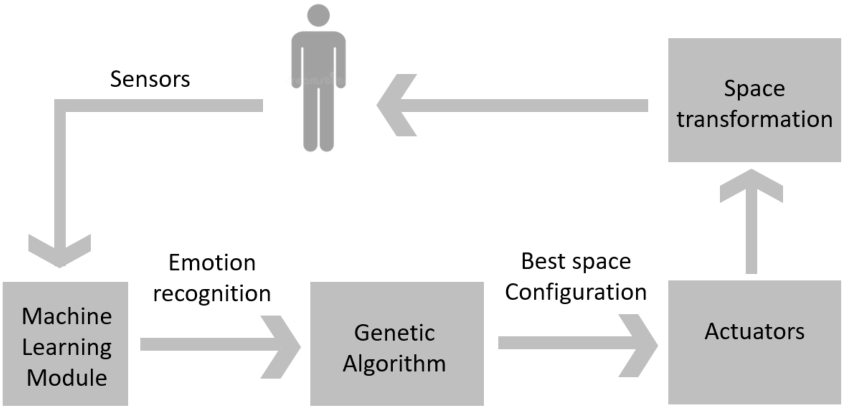

Fig. 1. Model for architecture design that is responsive to the user's emotions

As the occupant goes through the space, different sensors start collecting data. This data is analysed by an intelligent system, in which machine learning models identify the current emotion felt by the occupant. Then, a genetic algorithm is going to search for the proper response, that is, the best state of spatial elements for the space mutation, and using installed actuators, will rearrange the space accordingly.

Emotional recognition can be carried out through various combined instruments, like biometric sensors and video, that analyse the user's physiological and behavioural variables. Studies like (Ménard et al., 2015; Bălan et al., 2019; Leite et al., 2019) use biometric data from electrodermal activation (EDA), electromyography (EMG), electroencephalogram (EEG) and electrocardiogram (ECG) while facial emotion recognition is the focus in (Liu *et al.*, 2018; Samadiani *et al.*, 2020).

As a scenario where precise data for the identification of the user's emotion is to be collected, we propose that data could be acquired directly from the user's brain where emotions are generated by using adequate instruments. In this case, an helmet, able to perform an Electroencephalogram (EEG), that records the bioelectric activity of the brain as in Balan et al (2019), where the authors use it to recognize fear. The next phase will perform data analysis and pattern recognition for emotion identification. In face of a recognized emotion, together with ambience smart data and physical contextualization, a genetic algorithm will return the best spatial elements combination for the space to respond to the users feeling. The end of this cycle is the physical space mutation itself.

The system uses an adaptative machine learning algorithm and includes parameters that change over time, to adapt to the data being received and to learn the user's reaction to the changes in the space. The analysis of this data is continuous. The main data source is the brain and the data are brain waves signals that must be related to emotions, attention, and cognitive processes. The evolutionary algorithm has an adjustment mutation factor which, in addition to responding to human emotion by giving indications to the space to change, also analyses the individual's reaction to this change, incorporating positive or negative feedback into the current spatial state, adjusting it for a more customized change in the future, thus creating increasingly knowledgeable and stimulating systems.

5.5 Discussion

Imagining a space that complements our existence and reacts to our moods is an ambition that is closer to be fulfilled.

The first question is how this model can be materialized. Although in an early stage, the advancement of technologies leads us to believe that, with new and more flexible materials, it will be possible to provide space mutation. The customization trend reaches its maximum expression with this proposal. Here we overcome the issue of adornment in architecture, special coverings, furniture, and instead we conceive an almost second skin of an architectural space that acts, moment by moment, as an extension of ourselves. As said before we propose that the mutation of space may be done either through transformable spatial envelope or by using optical illusions that provide scenic effects. The connection between what is desirable to happen in the space and the user's emotion at a given moment is the most difficult issue to establish. We can define associations of spatial configurations with emotions, but the real purpose will only be fulfilled when the space will be able to adapt to a given individual, designing itself in a customized fit.

A second question is related to the way that a space should react to an emotion. Suppose that the user is sad. Should the space react to cheer him/her up or should it embrace the user and comfort him/her in their sadness. Such decisions would need to be customized to the personality of users. Although we are all different, it is still possible to find common denominators. Thus, a set of basic spatial parameters that respond to generic emotions for any human being could be created. For that, we use architectural spaces and elements and we associate them with the feelings and emotions they generically induce. Kate Gordon refers to “horizontal lines as "peaceful", vertical as "ambitious," diagonal as “action” and curved lines "voluptuous" (Gordon, 1906) Gordon continues saying that curves are graceful and avoid the harshness of some straight lines”. Therefore, when the user shows to be stressed, the response of the space could be to emphasize the referred predominance of horizontal lines, for instance using lights. If, by contrast, the intended response was to react to a lethargic state, e.g. if the user was in his/her working space, vertical lines, or even diagonal lines for greater dynamism would be highlighted. When the emotion recognized by the building indicates that the user is tired, the space's response could be related to emphasizing more organic shapes (like rounding off the edges). In fact Gordon (1906) refers that "curve suggests smooth and easy movement". As such, we envision not the traditional masonry walls and flat concrete ceiling but more flexible elements like membranes, fabrics and lights associated with simple kinetic structures.

A third question to be posed is the personal and collective nature of the proposal. As it is presented, this proposal targets mainly one user in a space that can be customized for him/her. When in a public area, as a museum or a restaurant, several people are together such model needs to be extended and a smarter approach for the dialogue between building and user must be taken into consideration. In such situations, one side of the problem is the technological solution adopted which needs to collect data from a group of people and analyse it based on a criterion of fitness, e.g. most predominant or most effusive "wins". Another side of the problem is the social issue, since the solution is for the majority, it might be not adapted to a small but relevant group of users.

6 Do we want responsive architecture?

This theme raises ethical questions regarding the use of a responsive architecture: that of the user's privacy and behavioural manipulation.

On the one hand, we are witnessing a rampant data collection by the digital devices and services we use, much of this was, and still is, done opportunistically and without the user's informed consent. To use technologies, users by default give permissions for applications to receive personal data that is often sold to third parties for unknown purposes.

On the other hand, we accept some collection of data for our own convenience, e.g. for optimizing internet searches to get the best possible response to our requests. The information we provide to strangers about our preferences and behavioural patterns helps to manipulate and condition our behaviour very effectively. Suggestions for shopping and places to visit are a first step in this manipulation that "leads" us to let go of our own options and accept others' as better for us.

In a model where constant monitoring of the occupant is required in order to optimize spatial qualities, the biggest questions are: Who else will access the data collected? and, Will technology manipulate our behaviour in a way we do not want?

Even if the data acquisition is performed anonymously, intelligent systems already have the possibility to create profiles and easily discover the user's identity. In the end, what will be the degree of privacy that the user has and of the security of personal data?

7 Concluding remarks

The introduction of technology into the built environment is a paradigm shift that allows architects to abandon the static characteristic of buildings and to enable them to acquire a kinetic character. With the evolution of computing, artificial intelligence, and affective computing, it becomes possible to further customize space, as well as the creation of a time-changing architecture that fits the occupant's emotions. The latent paradigm shift in this type of architecture is the search for a model in which the occupant, through his/her emotions, directly influences the space.

For Frazer the new architecture will be unpredictable and based on behaviours. The emphasis will be on the evolutionary and descriptive processes which will enable the “expression of an equilibrium between the endogenous development of the architectural concept and the exogenous influences exerted by the environment” (Frazer, 1995, p. 103)- Fraser estimates that the future will not be a “static picture of being, but a dynamic picture of becoming and unfolding – a direct analogy with a description of the natural world”.

The theoretical basis that was developed in this work went through the identification of the possibilities of responsive architecture in two different ways. Firstly, the building reacting to external stimuli such as temperature; secondly, as the focus of this paper, the building reacting to the occupants. The analysis of current responsive architecture practices allowed to identify innovative examples and the available technologies that can enhance a time-based architecture. In this paper we defined a model for responsive architecture based on its occupants’ emotions and which could act on both physical flexible elements like membranes and fabrics associated with simple kinetic structures. and non-physical ones like projections and lights.

According to Beesley et al. "the next generation of architecture will be able to sense, change and transform itself" (Beesley, Hirosue and Ruxton, 2006). In an architecture that is responsive to the emotions of the occupants it is important to combine the different areas of knowledge, such as computing, psychology, among others, and therefore the architect should include other players in the design process.

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References

Bălan, O. *et al.* (2019) ‘Fear Level Classification Based on Emotional Dimensions and Machine Learning Techniques’, *Sensors*. Multidisciplinary Digital Publishing Institute, 19(7), p. 1738. doi: 10.3390/s19071738.

Beesley, P., Hirosue, S. and Ruxton, J. (2006) ‘Toward responsive architectures’, in *Responsive Architectures: Subtle Technologies*. Riverside Architectural Press.

Bullivant, L. (2006) *Responsive Environments : Architecture, Art and Design*, *V & A contemporary series*.

Decker, M. (2013) ‘Emergent Futures: Nanotechology and Emergent Materials in Architecture’, *{Conference: Tectonics of Teaching - Building Technology Educators Society (BTES)}*, (February).

Eastman, C. (1972) ‘Adaptive-Conditional Architecture’, in *Design Participation, Proceedings of the Design Research Society’s Conference Manchester*. London: Academy Editions, pp. 51–57.

Ekman, P. (1992) ‘Are There Basic Emotions?’, *Psychological Review*, 99(3), pp.

550–553.

Elfenbein, H. A., Marsh, A. A. and Ambady, W. I. N. (1997) ‘Emotional Intelligence and the Recognition of Emotion from Facial Expressions’, in Barrett, L. F. and Salovey, P. (eds) *Emotions and social behavior. The wisdom in feeling: Psychological processes in emotional intelligence*. The Guilford Press, pp. 37–59.

Fox, M. and Kemp, M. (2008) ‘Interactive Architecture’, in *Interactive Architecture*.

Franz, G., Von Der Heyde, M. and Bülthoff, H. H. (2005) ‘An empirical approach to the experience of architectural space in virtual reality-exploring relations between features and affective appraisals of rectangular indoor spaces’, *Automation in Construction*, 14(2 SPEC. ISS.), pp. 165–172. doi: 10.1016/j.autcon.2004.07.009.

Frazer, J. (1995) *An evolutionary architecture*. London: Architectural Association. Available at: https://opasquet.fr/dl/texts/Frazer_An_Evolutionary_Architecture_1995.pdf.

Frijda, N. H. (1994) ‘Varieties of affect: Emotions and episodes, moods, and sentiments.’, *The Nature of Emotion: Fundamental Questions*.

Gendron, M. and Barrett, L. F. (2009) ‘Reconstructing the Past: A Century of Ideas About Emotion in Psychology’, *Emotion Review*, 1(4), pp. 316–339. doi: 10.1177/1754073909338877.

Glynn, R. (2005) *Fun Palace – Cédric Price*. Available at: http://www.interactivearchitecture.org/fun-palace-cedric-price.html.

Gordon, K. (1906) *Esthetics*. New York: Henry Holt and Company.

Grobman, J. Y. and Shemesh, A. (2015) ‘Space and Human Perception – Exploring Our Reaction to Different Geometries of Spaces’, in *20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA*.

Henriques, G. C. (2015) ‘Sistemas responsivos: relevância, estado da arte e desenvolvimentos’, pp. 200–206. doi: 10.5151/despro-sigradi2015-60042.

Khalili, Z. and Moradi, M. H. (2009) ‘Emotion recognition system using brain and peripheral signals: Using correlation dimension to improve the results of EEG’, *2009 International Joint Conference on Neural Networks*. IEEE, pp. 1571–1575. doi: 10.1109/IJCNN.2009.5178854.

Kievid, C. and Oosterhuis, K. (2003) *Muscle NSA, a basis for a true paradigm shift in architecture*. Available at: http://www.hyperbody.nl/research/projects/muscle-nsa/index.html.

Kolarevic, B. and Parlac, V. (2015) ‘Adaptive, responsive building skins’, in *Building Dynamics: Exploring Architecture of Change*. doi: 10.4324/9781315763279.

Leite, S. *et al.* (2019) ‘Physiological Arousal Quantifying Perception of Safe and Unsafe Virtual Environments by Older and Younger Adults’, *Sensors*, 19(2447), pp. 1–19.

Liu, C. *et al.* (2018) ‘Multi-Feature Based Emotion Recognition for Video Clips’, in *Proceedings of the 20th ACM International Conference on Multimodal Interaction (ICMI ’18)*. New York, NY, USA: Association for Computing Machinery, pp. 630–634.

Maier, F. (2012) *One Ocean – Thematic pavilion for EXPO 2012*. Available at: https://www.detail-online.com/article/one-ocean-thematic-pavilion-for-expo-2012-16339/.

Mathews, S. (2005) ‘The Fun Palace: Cedric Price’s experiment in architecture and technology’, *Technoetic Arts*, 3(2), pp. 73–92. doi: 10.1386/tear.3.2.73/1.

Meagher, M. (2015) ‘Designing for change: The poetic potential of responsive architecture’, *Frontiers of Architectural Research*. Elsevier, 4(2), pp. 159–165. doi: 10.1016/j.foar.2015.03.002.

Ménard, M. *et al.* (2015) ‘Emotion Recognition based on Heart Rate and Skin Conductance’, in. doi: 10.5220/0005241100260032.

Mulligan, K. and Scherer, K. R. (2012) ‘Toward a Working Definition of Emotion’, *Emotion Review*, 4(4), pp. 345–357. doi: 10.1177/1754073912445818.

Negroponte, N. (1970) *The architectural machine: towards a more human environment*. Cambridge: MIT Press.

Office Ozelo (2015) *Cerebral Hut*. Available at: http://www.ozeloffice.com/new-page.

Oosterhuis, K. (2003) *Hyperbodies : toward an E-motive architecture*. Birkhäuser.

Pallasma, J. (2005) *The eyes of the skin. Architecture and the Senses*. John Wiley & Sons.

Picard, R. W. (2000) ‘Toward computers that recognize and respond to user emotion’, *IBM Systems Journal*.

Quesnel, D. and Riecke, B. E. (2018) ‘Are you awed yet? How virtual reality gives us awe and goose bumps’, *Frontiers in Psychology*, pp. 1–22. doi: 10.3389/fpsyg.2018.02158.

Rabeneck, A. (1969) ‘Cybermation: A Useful Dream’, *Architectural Design*, pp. 497–500.

Samadiani, N. *et al.* (2020) ‘A multiple feature fusion framework for video emotion recognition in the wild’, *Concurrency Computation Practice and Experience*. doi: https://doi.org/10.1002/cpe.5764.

Shu, L. *et al.* (2018) ‘A Review of Emotion Recognition Using Physiological Signals’, *Sensors*, 18(2074). doi: 10.3390/s18072074.

Sterk, T. D. (2003) ‘Building Upon Negroponte: A Hybridized Model Of Control Suitable For Responsive Architecture’, *Automation in Construction*, 14(2), pp. 225–232.

Sun, J. *et al.* (1996) ‘The influence of surface slope on human gait characteristics: a study of urban pedestrians walking on a inclined surface’, *Ergonomics*, 39(4), pp. 677–692.

World’s “Smartest” House Created By CU-Boulder Team (1998). Available at: https://www.oecd-ilibrary.org/docserver/518742334033.pdf?expires=1580242037&id=id&accname=oid015503&checksum=AF990ADD908741CBBB25670E25137FB4.

Zuk, W. and Clark, R. H. (1970) *Kinetic Architecture*. Van Nostrand Reinhold.

Short bios

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