Using virtual environments to test the effects of life like architecture on people

Adi, MNH and Roberts, DJ

http://dx.doi.org/10.1007/978-3-642-45432-5_13

Title	Using virtual environments to test the effects of life like architecture on people
Authors	Adi, MNH and Roberts, DJ
Publication title	Technologies of Inclusive Well-Being: Serious Games, Alternative Realities, and Play Therapy
Publisher	Springer Berlin Heidelberg
Type	Book Section
USIR URL	This version is available at: http://usir.salford.ac.uk/id/eprint/33458/
Published Date	2014

UsingVirtual Environments to Test the Effects of LifelikeArchitecture on People

Mohamad Nadim Adi[1] and David J. Roberts[2]

[1]University of Alberta, Edmonton, Alberta, Canada

5-075 NREF Building, NE of 116 St & 91 Ave, T6G 2W2

m.n.h.adi@edu.salford.ac.uk

[2]University of Salford, Manchester, UK,

Newton Building, M5 4WT

d.j.roberts@salford.ac.uk

While traditionally associated with stability, sturdiness and anchoring, architecture is more than a container protecting from the elements. It is a place that influences state of mind and productivity of those within it. On the doorstep of adaptive architecture that exhibits life like qualities, we use virtual reality to investigate if it might be a pleasant and productive place to be; without incurring the expense of building. Thus this work has a methodological contribution of investigating the use of aspects of virtual reality to answer this question and the substantive contribution of providing initial answers. It is motivated by juxtaposing 1) responsive architecture, 2) simulation in architectural design 3) adaptive computer mediated environments, and 4) use of VR to study user responses to both architecture and interactive scenarios. We define lifelike architecture as that which gives the appearance of being alive through movement and potentially response to occupants. Our hypothesis is that a life like building could aid the state of consciousness known as flow by providing stimuli that removes the feeling of being alone while not being overly distracting. However our concern is that it might fail to do this because of appearing uncanny. To test this we hypothesise that occupying a simulation of a life-like building will measurably improve task performance, feelings of wellbeing, and willingness to return. Our four experiments investigate if people feel more at ease and concentrate better on task and others when the walls around them appear to organically move, are happy for the walls to help them, and prefer to come back to a building that reacts to them.

Background

The use of interactive elements in buildings is on the rise[1] and buildings that possess them are proving to be popular in both private and public projects[2]. However, the temporary nature of most examples does not lend them to studying long term effects such as social behaviour [3]. It seems that popularity relies on a balance between design, content and novelty. Despite this growing popularity, interactive architecture is widely viewed as novelty. We postulate that a convergence of interactive architecture and adaptive computer mediated environments might allow form and content to be responsive to the activity and mood of occupants, thus replacing novelty with usefulness. A more comprehensive picture is set by convergence between and within: animated, reactive and organic and intelligent architecture; and socially intelligent, empathic and virtual environments. It is hoped that this amalgamation would allow buildings to be able to interpret social intentions and needs, evaluate the impact of actions in a group and steer a group of users towards a common goal based on their actions and needs. Yet even without this union, the base question of how a building that seems to move as a living entity could affect its users is still very useful and interesting and this is what is being focused on. Also no direct comparison has been made between a conventional building and an interactive one to assess[4] the effect of interactivity in a building.

With regard to appropriate methods for studying adaptive architecture, the literature falls into one of two broad categories: Interactive or Intelligent Architecture and the appropriateness of virtual reality to test our hypothesis that life like architecture will have a positive effect on their users. Subcategories in interactive and intelligent architecture include architectural theory, building materials and building examples. In the use of virtual reality as a test medium subcategories include presence, virtual environments and the use of virtual reality in include psychotherapy. We also consider the potential of adaptive computer mediated environments.

Responsive Architecture may be categorised as that which is responds to the user, either through the design or more interactively during use.

The first major category is architecture for which the design has responded to people. This is less relevant to our work, that focuses on buildings designed to respond interactively. However, describing them not only helps to set the scene but also explains the inspiration for the organic appearance of our later experiments.

Firstly we consider response to cultural or religious needs or events. Examples include: The Water Temple by Tadao Ando[5], The Umayyad Mosque in Damascus[6], The Jewish museum by Daniel Libeskind[7], The Berlin Memorial by Peter Eisenman[8]. All these projects focus on giving visitors unique experiences that attempt to respond to their needs and provide them with insight to cultural events that led to the construction of these buildings.

Secondly we consider animation-based design. Here the final shape of the building is a response to the recorded and then analyzed movement of people or objects in a similar place over a set amount of time. The designer records the movement of users anticipates it then designs buildings based on the shapes resulting from that movement pattern. Examples include The Endless House by Fredrick J.Kiesler[9], and the works of Berkel [10], Lynn [11, 12] and Spuybroek [13]. Most used flowing organic shapes that through there naturalness are intended to give the feeling of comfort. We use this as inspiration within the design of our lab based experiments that will be described later.

What Keisler, Lynn and Berkel [9-12, 14] have in common is that the organic flowing shapes, which architects produced in these examples, create and encourage comfort as they mimic natural shapes. While this is vital in forming a more thorough understanding of user movement, it does not cover real time change in the building after it is finished, which is the main focus in interactive design. The main focus of these projects is that the final form of the building

does not need to be moving or changing colour in order to be responsive.

The second major category is architecture that responds interactively to the occupant. Reflexive architecture was introduced as a concept by Neil Spiller a decade ago. At that time he felt that little research had been done in the area. He described reflexive architecture as "architecture that is highly responsive and intelligent, able to translate and connect to its contextual environmental surroundings at a new level, while also operating in three or more spaces simultaneously ". Although the need for at least three spaces is unclear.

The responses between interactive architecture and its occupants may include animated behavior that is responsive within seconds or minuets to the user. This is a rapidly emerging area for experimental architectural design. Examples include: KasOosterhuis (the trans_PORTs project)[15, 16], Nox (the H2O Expo) [13, 17], Paul Sermon Tele presence[18, 19], John Frazer[20], Decoi (Aegis Hyporsurface)[21], Usman Haque [22, 23] and David Fisher, The rotating towers in Dubai and Moscow[23, 24]. In the past decade architects, designers and artists have increasingly worked in the field of interactive structures. In many instances these projects were temporary installations rather than being permanent ones [3, 25], An example of a more permanent interactive building is the rotating towers projects by David Fisher[23, 24]. When designing temporary structures or installations an architect often has more freedom to experiment. This is not least as the building typically has fewer functions to support.

Architecture can be considered as a type of language in which the architect and the user engage in speech through the building[26]. Palassma proposes that interactive architecture allows a livelier conversation. Thanks to emerging technologies and materials, structures have become able to interact with users instantaneously [17, 23]. The movement and behaviour of its visitors trigger structures to change any combination of shape, appearance, sound or smell. Arguably in these projects architects arrange rather than

design and allow the users to have conversation directly with the architecture itself.

From this analysis it seems that responsiveness of space is linked to two main factors. First, the materiality of the project and how it is constructed. Second, the sociological dimension of space and how that can be controlled and used to further focus the relationship between architecture and its users. These new ways of interacting with architecture are helping to form a whole new understanding of space that such space becomes part of the user and interaction. Space becomes looked at as a medium of communication. This is apparent in the works of the artist Paul Sermon [18, 19], in which he links users in different locations via live chroma-keying and video conferencing equipment to explore user behaviour and interaction within such telespace. This creates some awkward responses from the users at the beginning and causes them to re-evaluate their environment in a new understanding which depends on space as well as advanced technology.

All the previous architects and artists designed interactive buildings that can change colour, shape, sound, layout or all of these elements combined to create an enriched user experience. There are a lot of different types of buildings here ranging from installations [13, 18, 19, 21, 22] to full buildings [15-17, 23, 24]. A recurring theme here, however, is that all these changes are predetermined by the architect at the time of design. It is noticed that there is a great deal of theoretical investigation being done by the designers on the role of such architecture in its environment and its relation to the user's experience [17, 20, 23]. When I interviewed Usman Haque in 2005 he mentioned that the role of the architect or the designer should be more like the role of an operating system in that he sets the rules in which the building operates but the users are the ones who determine the final outcome of the design, this is also supported by Kronenberg[17]. Usman also states that for a building to be interactive there has to be information exchange to and from the building otherwise it's just a reactive system [27]. Other design theories include the works of Yannick Joye[28], Mette Ramsgard Thomsen [29], Juhani Pallasmaa[26], Adrian Forty [30], Peter

Zellner[31], Steven Holl[32] and Bill Hillier [33, 34] all of whom explore the relation between users and space, and how that can affect the experience gained. In particular Yannick Joye[28] looks at how organic and natural elements in architecture can help in reducing stress levels in users. This is an important theme of our work. Buildings here have a somewhat open ended design which builds on the users actions. Usman Haque[23, 27], Mette Ramsgard[29] and Neil Spiller [35] view architecture as a changing user interface, while Juhani Pallasmaa[26], Adrian Forty [30], Steven Holl[32] and Bill Hillier [33, 34] view it as an unchangeable setting for user interaction (which is the classical view of architecture). The term intelligent building or architecture also has many definitions as well, sometimes overlapping with interactive architecture. However, the unifying characteristic in all definitions looked at is that an intelligent building utilizes sensors to acquire user data so it can automatically provide services depending on user behaviour [36-44]

"Human life is interactive life in which architecture has long set the stage"[45]. Humans are flexible creatures capable of manipulating a wide verity of objects and living in varying environments[17] as such it is no surprise that humans want to reflect that flexibility in our buildings as our genes are expressed through our environment[46]. It appears that users are becoming captivated by interactive or intelligent structures as they are seeing their effects on the structure directly and clearly [47]. Their movement patterns and behaviour in general change in accordance to the reactions they see appearing before their eyes as architecture and its users become parts of each other [48]. The possibility of having a more lifelike or living building is becoming more feasible as more artists and architects are experimenting with it [49, 50]. It can be argued that users of such buildings are learning to see themselves in a new light, looking at their new reflections in these unorthodox 'mirrors'. Such new visual reflections can produce new behaviours of the users in accordance to these reflections. Also it with such buildings attracting more audience and gaining in popularity [51], it indicates that they can have a distinct advantage over none interactive buildings especially in public and retail spaces where a high amount of visitors is preferred.

In all the previous projects the materials used were as vital as the designs themselves as the desired level of instantaneous reaction by the building cannot be achieved by traditional materials. combinations of sensors, processors and changeable components (e.g. scent releasing systems, mechanical or hydraulic movement systems, colour changing LEDs ...) were used. Materials like Aero Gel [17], OLED[17], Litracon[17, 52] and smartwrap[53] all push the limits of architectural boundaries and help in creating better models for interactive and intelligent Architecture. Research from the MIT, shows materials that can change shape in real-time [54]. This opens up new possibilities for designing such spaces [54]. Research from Cornell University shows robots that have a limited ability to self reproduce[55]. When incorporated in designs this has the potential to produce self sustaining buildings. While some materials are still in concept mode they are very important in helping to create better designs and conceptual models for interactive or intelligent buildings.

Using virtual reality for testing and evaluating:

This section examines different test mediums that are available in virtual reality assessing each one to determine which is more suitable for testing interactive buildings. It highlights available test environments, how people react in virtual reality environments and how close such reactions are to real life ones.

In architecture, the architect depends on his experience when trying to design and produce a building. In essence knowledge of materials, space and building methods is gained through observation and experience gained from sometimes disastrous trial and error [1]. Apart from architectural drawings and images of 3D models the client is usually buying a product that they cannot see fully until it is constructed in real life [56-60]. Even when using 3D reconstruction video the angles and areas the client sees are limited [56]. It is commonly known that this method has some major draw backs. First

it is very time consuming to construct a building, second it is very expensive to do so. Third and perhaps most importantly is that the client will not know what they are exactly getting until the building is completed. This means that there is no room for error and that amending or adjusting a project would be very difficult. Experimental buildings are not unheard of in architecture, for example: Sky Ear [22], Scents of Space [16, 23, 61], H2O Expo [13, 17]... etc, but making these buildings is very expensive and time consuming. Amending or adjusting them would also be very difficult for the same aforementioned reasons.

A potential test environment is the use of an online social environment. Online social environments are becoming accepted as credible tool for social studies [62, 63] . In particular a number of researchers have indicated that people tend to behave in a very similar way when in Second Life as they would in real life [63, 64]. Users seem to react naturally to social space even though such environments are not immersive [63]. Online environments like Second Life have some distinct advantages. It can be argued that creating content in such environments is quick and cheap. All that is needed is making a 3D model of the building and placing it in the virtual environment, so no time is wasted on construction issues that might arise in real life models. This also means that adjusting a model can be done quickly as well. Research implies that online (even forum like) test environments function as a more generalized simulation than that of a mathematical simulation tool [64]. Equipment wise, all a user needs to use the programme is a midrange computer and an internet connection. This coupled with the fact that the usage of the software is free means that a lot of users will be able to access such an environment with ease. This can increase the number of visitors as every day millions of users spend an average of 22 hours a week interacting with each other thorough avatars [65-67]. Also since visitors can come and go as they please, their behaviour can be closer in quality to real life behaviour. Lastly placing a test building for prolonged periods of time there is relatively cheap.

One issue in such an environment is the lack of realism which can lead to users feeling detached from the environment they are experiencing, another issue is the quality of immersion, since users have to see the environment through a computer screen, they will not feel as immersed as the other two methods we are going to discuss (Immersive environments and head mounted displays) and as such this might cause their reactions to be less realistic [68]. However, previous research shows that online virtual environment users behave in a very similar fashion to real life [62]. Researchers are using Second Life as a viable tool to evaluate social trends [64] and as such we feel that this medium would be good for tests that might require longer periods of time and a larger sample size.

Another method examined is immersive virtual environments IVEs. This technology first existed in 1965 as a lab-based idea [69, 70]. It is usually a room with graphics being projected on its surfaces, usually referred to as a CAVE (square shaped room). The number of surfaces used can vary from 3 upwards. The advantages of using such a method is that it provides a high level of realism as test subjects literally step into the virtual model being tested giving it an advantage over desktop-based methods [71]. Test subjects are highly immersed in the virtual environment and as such might react to it in a more realistic manner. A wealth of presence research indicates that people in such environments react exactly as they would in real life [70, 72, 73] even in low-fidelity scenarios [74, 75] . Mel Slater points out that in an immersive environment almost all test subjects avoid colliding with virtual objects even though they know that they are not there [72]. Also participants usually respond in a realistic manner to events shown to them in IVEs [70]. Such environments have been used as an effective tool for social studies [74, 76, 77] particularly in spatial cognition [78], education [79, 80] and psychotherapy [81-83]. In numerous cases they were successfully used to treat social phobias [84-93] and post traumatic stress disorder [94, 95]. Research also shows that IVEs can evoke real emotions and mental activity as a real situation would [96, 97]. Any adjustments to the model can be made quickly and easily. Also, since such an environment is a lab-based one, all the environmental factors can be easily controlled (such as lighting, time limits, etc.)

enabling researchers to specifically focus on the variables or elements that they want to study.

Since a CAVE or OCTAVE is a lab-based environment it has some disadvantages. The amount of people that you can have there at once is limited due to the size of the room. Also people cannot stay there for long periods of time. Since the equipment is delicate a researcher has to be present with the test subject at all time which means that reactions of test subjects might not be as natural as hoped. Perhaps the biggest disadvantage is that people cannot come and go at will. Even with such disadvantages it is still the preferred test method for short term experiments. It provides a high level of immersion that is comparable to that of constructing a life-sized model of the environment while at the same time having the flexibility, controllability and repeatability of using 3D simulations.

The final immersive display method examined is head mounted displays; it has the same advantages as the immersive environments mentioned before [68]. It allows for a very high level of immersion and content can be created and edited quickly as well [68]. Our main reservation about this medium is that the person becomes disembodied (as they cannot see their body in the virtual environment) and thus the experience is less lifelike. Also the equipment a test subject has to wear is heavy and it can cause discomfort. The low field of view it provides has been linked to motion sickness and a lower sense of presence which is likely to impact the awareness, attention and action of users [68]. This will be a major issue as people tend to lose focus and interest when they are fatigued. Also issues might arise if the experiments incorporate the use of real objects rather than virtual ones.

Crossover and relations:

This section examines possible relations between the two main research areas investigated previously and how they relate to each other. One project that is relevant here is an interactive entertainment space built for the Swiss national exhibition Expo in 2002. It was

investigating if users can associate buildings with life in what is called the ADA project [23, 51, 98-100]. This project consisted of a room where the floor was covered with pressure sensitive plates that changed colours and collectively displayed different colour patterns as you stepped over them. If one followed them fast enough the room rewarded the user with a special pattern. It turns out that the majority of users enjoyed being in this responsive space and a good percentage of them were convinced that the space could be considered as a living organism. The public reaction to the project was overwhelmingly positive [101]. ADA was the most popular IT related exhibit at the expo [51]. This suggests that with the right level of interaction people can actually start to view buildings as active participants in a group rather than just passive spectators. It also shows how popular and crowd attracting interactive buildings can be, although no direct comparison have been made between and interactive building and a non-interactive one to understand the explicit effect of interactivity on visitor numbers. The ADA project was an entertainment space; it would be interesting to see whether similar success could be achieved in a work oriented environment. Also this project demonstrated how human response can be inferred from observing behaviour as well as the potential to use ADA to automatically deduce group attitudes opening the door to possibly influence their behaviour [99].   It is noticeable that ADA had only short term reasoning as it responded to users directly but had no mid or long-term goals. Even though users still enjoyed being in this space which is encouraging. Theoretically, this would suggest that a building with two layers of reasoning would provide a better and more enjoyable environment for its users and visitors. This project is the only project that we found that combined research in virtual environments and architecture. It demonstrates that users can have meaningful experiences with an interactive environment, and as mentioned before also highlights the popularity of this type of space [51, 101].

The use of virtual reality or rather virtual reality visualising methods is common in architecture. What is meant here is that architects often use virtual 3D models of buildings to produce rendered images or fly through videos that they show to clients and some potential

users [56-58]. The use of virtual reality or virtual environments in design focuses more on the construction methods rather than design elements in most cases [56]. The main issue with this approach is that architects tend to show clients what they, as designers, want them to see without giving the client the ability to navigate and experience the space on their own [58]. It can also be argued that the virtual models shown to clients and users tend to be at the final stages of design when most decisions have been taken. Models placed in virtual environments such as the Second Life, CAVE or OCTAVE like environments tend to give the client (users of the building) a high level of freedom enabling them to experience every part of the building and interact with it however they want [56].

Virtual environments have been used earlier to effectively treat phobias and other mental issues such as trauma. The papers looked at in the virtual reality section earlier indicate that VEs are useful tools that can produce meaningful results because people react in them in the same manner as they would in real life [70, 73, 102]. Research done in this field also suggests that, when measured in similar scenarios, the human brain exhibits the same level of neural activity in both virtual and real scenarios [81-86, 88, 89, 91-95].

An issue that remains to be seen is if users were interacting with the environment or with objects in that environment. In the case of shell shock it is almost certain that users were reacting to the environment as the experiment procedure focuses on having users go through similar war-like scenarios. Although in these cases it can be argued that users are interacting with either the environment (shell shock) [94, 95] or objects in the environment like avatars (anxiety and public speaking phobia) [84, 85, 87, 88] or the cause of phobia itself (heights, flying, etc.) [91-93, 96]. But the main interaction is guided through the presence of a therapist who uses and controls these objects as they see fit during the treatment procedure [72, 91, 103-105]. What this research wants to see is the effect of the building itself on the user with minimal interference from the designer or owner isolating and studying what effect interactive or intelligent buildings might have on their users.

In general papers reviewed on the matter of the use of virtual environments in the treatment of phobias, regardless of phobia type, establish two things. First, Molinari [88] concluded that virtual environments are as good if not better in treating phobias than real-life environments. They also have the advantage of allowing high control and to tailor fit the required virtual environment to the exact needs of the individual's treatment [88] also there are over a hundred research papers within that reference that agrees and reaches the same conclusion.

Second, when using a VE even through a desktop system it was recorded that subjects reacted in the same manner as they would in real life [70, 73-75, 102]. One major issue arises here is the lack of physical interaction between the subjects and their environment [84, 85, 87-96]. This can be attributed to the nature of phobia treatment. Phobia treatment, in real or virtual environments is based on exposing the patient gradually to their fear [72, 91, 103-105]. This means that the person treating them is the one who interacts with the patient and controls how the treatment session goes. Even in the case of treating shellshock where the patient goes through a premade scenario there is no interaction with the environment just exposure to different conditions [94, 95]. In these cases it can be argued that users are interacting with either the environment (shell shock, post traumatic stress disorder, etc.) [94, 95]or objects in the environment like avatars (anxiety and public speaking phobia) [84, 85, 87, 88] or the cause of phobia itself (heights, etc.) [91-93, 96] the main interaction is guided through the presence of a therapist who uses these objects as they see fit and there is no interaction happening in from the environment to the user. This leads us to believe that there might be a possible lack of literature on how might having an interactive/intelligent environment affect its users.

Research direction:

The previous sections reviewed papers in relation to the fields of interactive and intelligent architecture and the use of virtual environments as an evaluation method. That main aim was to propose a definition of interactive, intelligent or lifelike architecture, assess the usefulness of virtual environments as a test medium and see if there are any research projects that have attempted to study the effect of interactive or intelligent buildings on their users.

Architecture is becoming so intertwined with a network of other disciplines that a new hybrid form of practice and architecture itself is emerging [106]. While the sheer amount of new interactive architecture is apparent from previous examples, we attempted to go past the momentary popularity and ask if such projects are useful to their users. It was found that first, there are multiple definitions of interactive architecture and through reviewing a selection of projects we defined interactive architecture as architecture that can react to its users and change its properties (colour, shape, sound) in real time, intelligent architecture furthers that by adding a level of reasoning with which the building analyzes input from its users to achieve a set of goals. Based on these definitions derived from the literature, we further define lifelike architecture as interactive architecture that has some resemblance of being alive. This might be through moving or interacting as if alive and or through exhibiting intelligence. Interactive projects have proved to be popular and potentially valuable when it comes to attracting visitors. Second, papers reviewed indicated that virtual environments are a viable test medium with users reacting in similar or almost the same way in a virtual environment as they would in real life to the same input or scenario. Papers reviewed in the medical field indicate that brain activity in virtual environments is the same as brain activity in real life, given that the scenario is the same. It is concluded that both online social environments and immersive virtual environments are suitable test environments that can be used for long-term and lab-based experiments respectively. They both provide sufficient levels of freedom and immersion (semi immersion in the case of online

environments) and they are both accepted test mediums for social interaction as people tend to react very naturally in them, to social or environmental stimuli. Third, it is apparent that every method of measurement in virtual environments has some advantages and disadvantages [107]. Methods used in measuring presence in virtual environments are varied and no single method is universally accepted [107]. It is possible that a combination of evaluation methods would provide better data for experiments, as mixed methods can assist and complement each other, eliminating or minimizing the disadvantages that can occur from using a single method. From that it can be concluded that a mixture of evaluation methods should be used in experiments to produce good high quality data from experiments.

Experiments

Each experiment involves having a test subject complete different yet similar tasks in a series of virtual environments. Test subjects can be completely alone or accompanied by an examiner depending on the individual experiment and the research question it is trying to address. Apart from the last experiment all our experiments are undertaken within a surround display system called the OCTAVE. The OCTAVE is an immersive large screen projection system. It projects computer graphics images on 8 surround walls and the floor. This test environment surrounds the subject in a life size simulation, and thus can give the impression of being within a simulated room better than looking into that room through a desktop display, thus providing a better sense of being there (presence) to test subjects and making the experience seem more natural. In this work immersive stereo was not used, so the participants did not have to wear stereo glasses. The last experiment (experiment 4) was made using an online social virtual environment called Second Life.

Figure 1.The Octave, the environment and the author.

The first experiment designed was a pilot experiment that explored the second research question: How might being inside a room with walls that appear to come to life impact on a person's feeling and performance? Doing a quick pilot experiment at the beginning of the research helped in understanding practical limits and issues that might rise in later experiments. Issues that were made clearer through the pilot experiment were the number of participants needed, how long should the experiment last and what task should be used. For instance, in the pilot experiment we used a task that required the user to play a game on a laptop while in the OCTAVE. We noticed that test subjects were focusing more on the laptop and taking no notice of their surroundings, also they were repeating the same game in all test conditions which made any results unusable (their score improved because of repetition). That is why we opted for a simpler task in later experiments that can be placed directly in the test environment without the need for interface equipment (laptop or 3D glasses) and can be varied with ease to eliminate the problem of repetition. Feedback from the experiment using questionnaires and interviews also helped in highlighting any potential issues that might have not been covered in the literature survey. All experiments can potentially help in answering unclear points identified by the literature review and some problems raised via the methodology.

Experiment 1

How might being inside a room with walls that appear to come to life impact on a person's feeling and performance?

Task: Solving a jigsaw puzzle alone in an Octave, while walls are blank and static or display moving patterns.

To be able to assess the impact of an animated environment on an individual we had to conduct the following experiment. Test subjects had to complete a task in different environment settings. Their performance in each task was measured and compared. Post

experiment interviews and questionnaires were also used to assess the appeal and attractiveness of animated environments.

The task that test subjects had to do was completing a jigsaw puzzle. We felt that this is a simple task that most test subjects should be familiar with and that we can vary with ease. Another reason jigsaws were chosen was that they require both concentration and allow performance to be easily quantified. Tasks were completed in an immersive display system called the OCTAVE. Two test environment settings were used, one with blank walls and one with moving lifelike walls, which simulate that they are moving around the test subject. The performance of test subjects was measured by the amount of puzzle pieces they assembled in each setting.

A within subjects design was used for this experiment, this method provides more statistically sound results and is more practical as less resources are required in terms of number of test subjects and time required [108-110].
To ensure that participants performance was improved because they were familiar with the task, we varied the order of puzzles and conditions across subjects. This meant that some began with puzzle A and some with B; and 50%were inside a simulation of moving walls first while the remainder where surrounded by blank display walls first. 20 Test subjects were used.

Findings
The results of this experiment have shown that when a person is placed in a small room both their comfort and performance when doing a jigsaw puzzle are increased if the walls appear to move. 90% of subjects performed better when the walls appeared to move around them and upon analysis results were highly significant with a probability value less than 0.0001 this meant that the chances of having the same results would be nearly 100% if the experiment was repeated. No subjects reported disliking the moving walls and more often than not test subjects reported feeling more comfortable, and better able to concentrate and do the work. Many reported the feeling of something missing when being in the blank environment

while specifically mentioning being calmed and more relaxed when the walls moved around them.

Experiment 2

How can seemingly lifelike architecture impact people's ability to follow instructions from a teacher?

Task: Solving a puzzle in an octave by depending solely on verbal instructions from a tutor, while different projections are displayed on its walls.

To answer the above research question we conducted the following experiment. This time, instead of working alone, the participant had the part of a learner in a simple teacher learner scenario following a set of standardized spoken instructions given to them by an instructor to guide them in completing a task in three different conditions. The flow of data was one way from instructor to subject. This was done to standardize the amount of information given to test subjects. The performance of test subjects for each task was measured and compared. Questionnaires and interviews were used to assess the appeal and comfort of animated environments.

The task remained similar to the previous experiment so comparisons can be drawn allowing the effect of the teacher learner experience to be isolated from that of working alone. An instructor (confederate) explained the procedure of the test and what the test subject should do before the experiment started. Every experiment involved both the test subject and confederate entering a series of conditions. Tasks performed in each condition were split into a series of stages. Test subjects had to follow a series of spoken verbal instructions given to them in key stages during the test by the instructor in order to complete the task, while being aware that they could not communicate with the instructor during the test. The task test subjects had to do was completing a jigsaw puzzle while relying only on the oral instructions given to them by the instructor. Tasks were completed the Octave. The performance was measured by

calculating the percentage of completion for each puzzle in each setting. 30 test subjects were used here to provide better statistical data than the previous experiment.

Findings

In this teacher learner setting the performance of 93% people was improved when they were in the animated environment the overall average improvement was 38.77 % compared to the blank environment and 21.25% when compared to the patterned environment. When analyzed, the results proved to be highly significant with P values less than 0.0001. Previously people universally preferred the experience of seemingly moving walls and some reported finding it comforting. Questionnaires and interviews made in this experiment indicate that most people prefer a room with moving walls stating that it improved their concentration levels which was reflected in the improvement of their scores. This suggests that surround projection or physically moving walls are likely to be beneficial in the classroom setting and unlikely to be detrimental. In particular they seem to complement the presence of a teacher especially when giving instructions. Using a combination of virtual models and surround projection gave clear results. The ability to transfer such results to the real world is yet to be tested, but results further imply that real environment tests would be worth doing in the future.

Experiment 3

How can seemingly intelligent lifelike architecture impact people's ability to follow instructions from a teacher?

Task: Solving a jigsaw puzzle in an octave with verbal instructions from a tutor, while different projections are displayed on its walls. In one of the settings one of the walls provides visual hints to aid the test subject.

Here we expand the previous experiment by convincing the participant that the environment around them is intelligent and that it

can understand what is happening inside it and try to assist them in their task. The same teacher learner setting was used here as in the previous experiment. The participant had the role of a learner in a simple teacher learner experience following a set of standardized spoken instructions given to them by an instructor to guide them in completing a task in three different conditions. The flow of data was one way from instructor to subject. This was done to standardize the amount of information given to test subjects. The Performance of test subjects in each task was measured and compared. Questionnaires and interviews were used to assess the appeal and comfort of animated environments.

In the last condition a wizard of Oz approach was used to make the room appear intelligent through the use of an additional confederate. The task in this experiment is the same as the one in the previous experiment so that a direct comparison can be drawn allowing the effect of having a helpful environment to be separated and compared to the effect of an animated one. An instructor (confederate) explained the procedure of the test and what the test subject should do before the experiment started. Every experiment involved both the test subject and confederate entering a series of conditions. Tasks performed in each condition were split into a series of stages. Test subjects had to follow a series of spoken verbal instructions given to them in key stages during the test by the instructor in order to complete the task, while being aware that they could not communicate with the instructor during the test. The task test subjects had to do was completing a jigsaw puzzle while relying only on the oral instructions given to them by the instructor except in the final condition. Tasks were again completed within an immersive display system called the OCTAVE. The performance was measured by calculating the percentage of completion for each puzzle in each setting.

A within subjects design was used for the experiment. The order of puzzles and environments was randomized across subjects to avoid any effects that puzzle order or environment order might have had on our findings. We split the participants into two equal groups. The first group environment order was blank, static patterned, intelligent

and the second group environment order was intelligent, static patterned, blank. The puzzles used in each condition was randomized as well. 30 test subjects were also used here.

Figure 2.The position of the test subject within the environment in accordance to the helpful wall. The arrow shows the flashing area where the assembled puzzle pieces should be placed.

Findings

Building on a previous experiment where we improved the performance and moods of people doing jigsaw puzzles by surrounding them with projections of walls that appeared to move, a teacher and informative graphics were added to these walls to begin to study the potential impact on a teacher learner interaction. The previous experiment [111] improved the performance of 90% of participants and the average improvement was 14%. In this teacher learner setting the performance of 93.33% people was improved and the average improvement was 62.84% in comparison with the average score of test subjects in the blank environment and 42.07% in comparison to the average score of test subjects in the patterned environment. When analyzed the difference was statistically significant with a P value of 0.001. Questionnaires and interviews conducted after the experiment indicate that most people prefer a room with moving helpful walls. Analyses of the video recordings also indicate that people were more engaged with the helpful environment than any other condition regularly looking at the helpful wall. In addition to the results transferring to concentration on instructions from a teacher, people liked the helpful graphics in front of the moving walls. This suggests that surround projection or physically moving interactive helpful walls are expected to have a positive effect in a classroom setting and unlikely to have a hindering one. Specifically interactive buildings seem to complement the presence of a teacher and other information on the walls. The combination of using virtual models and surround projection has once more yielded clear results. The transferability of these results to the real world is remains to be tested, but the results indicate that physical, real environment tests are a very viable option.

Experiment 4

In an online virtual environment, would people be in favour of visiting, returning and staying in an interactive building over a static counterpart?

Users did not have to do a task here, instead the number of visitors and the amount of time spent in each virtual building was recorded and compared.

Our main concern about previous experiments was that they were made in a lab setting and they were short time wise. In this experiment we wanted to test the appeal and attractiveness of an interactive environment over an extended period of time while trying to provide as much freedom to visitors as possible. To do that, two virtual building models were constructed in an online social virtual environment (Second Life). The only difference between them was that one was interactive and the other was not. They were placed in Second Life for a total of six months, during which we took various measurements to do with the number; length and properties of visits (e.g. number of groups and number of return visits). Feedback on each building was collected from a separate group of 20 participants as an extra measure.

The online social virtual environment was used to provide greater levels of freedom for participants as there were no examiners present and there were no restrictions on access times. This means that reactions and actions of test subjects should mirror what might happen in a real life scenario more accurately and conclusions drawn from this experiment could be applied to real life situations more rapidly. The reason for conducting the test for six months was that we felt it was a sufficient period to produce meaningful results, it was also due to this research time restrictions. In addition to measuring visitor numbers and the qualities of their visits to each building feedback from a separate focus group was collected. It was calculated that using 20 people for feedback would provide meaningful results for this type of experiment.

Figure 3.Interactive building. The ground tiles illuminate as visitors walk on them and the walls move away from the visitor when they get close to them.

Findings

With the rising popularity of using interactive elements in architecture, we asked: Would people more willingly return and bring their friends to a building if it had interactive elements? Second life, an online social environment was used to answer this question, testing the appeal of interactive architecture in comparison to a non-interactive equivalent.

The aforementioned research question was divided to two sub-questions. The first sub- question was "could an interactive building produce more visitors, return visits, group visits and be a more sociable place when compared to a static building?". Results demonstrated that people revisited our interactive online gallery more often, stayed there longer and were more likely to bring friends when its walls and floor where interactive. The interactive building managed to generate 408 visits compared to 92 visits generated by the static building. There was also more return visits to the interactive building as well with nearly nine times as much as the static building. The interactive building also had more unique visitors (102 visitors) than the static building (57 visitors) and a bigger percentage of its visitors chose to return to the interactive building over its static counterpart. (68.627% compared to 26.316%). Another finding is that interactive building had more group visits than the static building with the static building having only one group visit throughout the period of study to 22 group visits that were made to the interactive one. The main and perhaps the most significant difference however, was the total amount of time spent in each building. Visitors to the interactive building spent a significantly longer period of time in comparison to the visitors of the static building with the average of 50.322 minutes spent in the interactive building for each minute spent in the static counterpart.

The second sub-question was "would the presence of interactivity within a building create a significant boost in the above mentioned

qualities?".Our analysis proved results to be significant with all our P values below 0.0001 which is statistically highly significant. Questionnaires indicated that the vast majority of people (85 to 90 %) favoured the interactive building and found it more appealing, with the ability of interacting with the building being a major attraction factor. No dislikes to the interactive building were stated and the majority of visitors favoured socializing within it.

This implies that interactive buildings are more appealing to be in and are a more attractive place to socialize within. Results also showed that interactivity can generate a sustainable interest in a building thus increasing its projected life span and revenue, especially in buildings that depend on visitors like exhibition halls, museums and public buildings. The online virtual environment Second Life proved a valuable tool for this study. In particular it addressed the issue of allowing regular and freedom of access to participants over a period of weeks or longer. It also provided anonymity and as such made test subjects more comfortable and willing to take part in such an experiment.

Discussion

In all experiments the interactive or seemingly intelligent environments proved to have an advantage over normal (non intelligent, interactive or moving) environments. In the three lab based experiments people performed better and stated that they were more comfortable and preferred interactive or seemingly intelligent environments over other environments which were blank and patterned environments. From observation and interviews people seemed to behave similarly in both normal (where the walls were either blank or with static patterns) and seemingly interactive or intelligent settings. There was no mention of distraction or feelings of alienation during interviews. This was also reflected in the scores as the majority of participants scored better in the interactive and intelligent settings. In the third experiment test subjects were interacting with the intelligent environment as it gave them visual hints on how to complete their task and their scores improved in the intelligent environment. Subjects stated that they were more comfortable in interactive and seemingly intelligent environments.

Results from experiment four indicate that over longer periods of time it seemed that the interactive building generated more visitors and appeared to have more appeal than a static building. This agrees with papers relating to the ADA project [2, 51, 101] which indicate that interactive buildings appear to be more popular and attract more visitors than none interactive buildings. The interactive projects reviewed in the literature did not have none interactive counterparts to be compared to. This means that their popularity could be contributed to other factors than interactivity (e.g. design, materials or novelty). The results from this experiment suggest that interactivity has a strong positive effect on the popularity of a building. This is also supported by Haque [47] as he states that interactive or intelligent buildings captivate their users as they see their effects on them. They also confirm the views of Delbrück and Bäbler [51] that interactive or intelligent buildings attract more audience and are more popular than non interactive ones.

In lab based experiments a within subject design was used and subjects had to do different tasks in test environments in one go. Care was taken to ensure that test subjects were not bored or tired out by the end of the experiment, mainly by changing the order in which they experienced the environments. It can still be argued that having the test subjects do multiple visits and perform different tasks on different visits might produce better results, although upon analysis the results were highly significant. There is also a risk in having test subjects perform multiple visits, as they could practice tasks at home thus corrupting the data. To counter both, tasks must be sufficiently different or complex, both of these things would making analysing data difficult or even make data sets incomparable due to the difference. Another potential issue of having complicated or different tasks is that there would be a higher learning curve involved. This means that experiment have to be longer to counter that which risks people becoming tired or losing interest, it would also make recruiting test subjects more challenging.

Test subjects recruited for the experiment were mostly students and employees of the University of Salford. Also there was imbalance in the sample between male / female or nationality or profession (most were research students from the computer science department). It could be argued that the test subjects sample is not representative nether in gender nor in profession. However, since we are looking for non gender/profession specific findings that can be overlooked. Further, as these experiments are possibly the first to investigate this field we felt that a random sample of people would be sufficient. Since performance and the possibility of improving it can be linked to work or study environments, which in many cases might not be varied or balanced, performing experiments on a random group of test subjects also made sense. From the experiments looked at in the literature review a number of 20 participants was adequate in most cases. The number of participants aimed for was 30 people for each lab experiment, this was done to provide better data and produce more significant results. The first experiment only had 20 participants but produced statistically significant results.

In the last experiment, made in an online environment, the main issue was that the experiment was performed in an area with low traffic (visitors). Also the low amount of content in both buildings might have deterred people from visiting or revisiting the experiment area. However, it can be argued that the simplicity of the buildings helped in isolating and clarifying the effect interactive components had on visitors. The results of the experiment were highly significant and even with low traffic the experiment managed to attract 159 visitors in total. This increases the confidence in our results and supports what the literature indicated that interactive buildings tend to be popular. It also indicates that the popularity of such projects can be attributed to their interactivity.

While the results of the experiments all confirm that simulated interactive or intelligent architecture can have a positive effect on its users, it is not known if such results would be transferable to real life. However, literature reviewed indicates that virtual reality is a credible tool for studying how people might react to a real life situation [62-64, 70, 73-75, 102]. Ultimately, the only way to be sure is to perform similar tests to our experiments using real life buildings. Results from experiments made in this research indicate that doing them, although requiring a lot of time and resources, is a credible future option that can yield meaningful results.

Conclusion

We set out to determine from analysis of the results if lifelike architecture is likely to be a pleasant and productive place to be. Experiment one concluded that being surrounded by walls that appear to come life and move has a positive effect on an individual's performance. 90% of test subjects performed better when the walls moved around them. Results also show that 60% of individuals preferred it to blank walls as well as 65% of them felt more comfortable in it.

Experiment two concluded that being inside animated lifelike architecture improves the ability of people to follow instructions from a tutor. 93.33% of subjects performed better in the animated environment. Data shows that 54.33% of test subjects prefer it to similar environments with blank or patterned walls and 60% of them felt more comfortable in it.

Experiment three furthers the results of the previous experiment by introducing a seemingly intelligent to test environment. It concluded that people's performance increases in a seemingly intelligent environment in a task that requires following instructions from a teacher. 93.33% of subjects had better scores in the seemingly intelligent environment. 63% of test subjects were more comfortable there and 60% of them preferred it. Comparison with experiment two revels that 90% of people performed better in a seemingly intelligent environment compared to an animated one.

Experiment four conducted online concluded that over a long period of time an interactive building significantly generates more visitors and social activity than a non interactive counterpart. The interactive building had, on average 4.5 visits to each visit that was made to the static building. As for return visits the ratio was 8.743 to 1 in favour of the interactive building. Visitors also spent more time there with an average of 50 minutes spent in the interactive building for each minute spent in the static counterpart. Data from questionnaires indicate 85% of people preferred the interactive building, wanted to

spend time there and 90% wanted to promote it and socialize within it.

All of this suggests that the presence of interactive or intelligent elements within a building is likely to have positive effects on its users, increasing the productivity and comfort of its users. Experiment 4 also suggests that interactive buildings can generate more visitors and that people tend to socialise more within them. The transferability of these results to experiments made using real buildings or models is yet to be tested. Experiments made here coupled with the increasing popularity of interactive or intelligent building projects suggest that conducting real life experiments are a viable option for future experimentation.

There was strong correlation between the measures. An excellent example of this is that during experiment one a participant was heard humming to herself when the walls were static but not when they were moving. Her task performance was significantly better with seemingly moving walls around her. She reported in questionnaires having an improved experience when the walls appeared to move. In post interview she volunteered that she had felt lonely in the static wall condition and so hummed to herself but had not felt lonely or hummed when the walls appeared to move.

References

1. Addington D. M and Schodek D. L, *Smart materials and new technologies: for the architecture and design professions*. 2005, Elsevier: Oxford.

2. Bullivant L, *4D Space: Interactive Architecture introduction.* ARCHITECTURAL DESIGN, 2005. **75**(1): p. 5-7.

3. Garcia M, *Otherwise Engaged: New Projects in Interactive Design.* Architectural Design, 2007. **77**(4): p. 44-53.

4. Bauman Z, *Liquid Arts.* Theory Culture & Society, 2007. **24**(1): p. 117-127.

5. Galinsky Pepoe Enjoying Buildings Worldwide. *Water Temple (Shingonshu Honpukuji)* 2006 [cited 15 December, 2011]; Available from: http://www.galinsky.com/buildings/watertemple/index.htm.

6. Stierlin H, ed. *Islam Volume Early Architecture From Baghdad to Cordoba.* 1996, Taschen: Italy.

7. Schneider B, et al., *Jewish Museum Berlin: between the lines*. 1999, Munich; New York; Prestel: NAL Pressmark.

8. Eisenman P, ed. *Blurred Zones: Investigations of the Interstitial*. 2002, Monacelli Press: New York.

9. Kiesler FJ, ed. *Endless Space Los Angeles*. 2001, MAK Center for Art and Architecture: Los angeles.

10. Van Berkel B & Bos C, ed. *Techniques Network Spin Amsterdam*. 1999, UN Studio & Goose Press: Amsterdam.

11. Lynn G, *Predator.* Architectural Design, 2002. **72**(1).

12. Lynn G, ed. *Animate Form*. 1999, Princeton Architectural Press: New York.

13. Spuybroek L, ed. *NOX: Machining Architecture*. 2004, Thames & Hudson: London.

14. Van Berkel B, ed. *Mobile Forces*. 1994, Ernst & Sohn: Berlin.

15. *Structures of Other Projects,.* n.d [cited 25 August, 2008]; Available from: http://www.azw.at/otherprojects/soft_structures/oosterhuis/trans_PORTs.htm.

16. Bouman O, *Architecture, Liquid and Gas.* ARCHITECTURAL DESIGN, 2005. **75**(1): p. 14-22.

17. Kronenburge R, ed. *Flexible Architecture that Responds to Change, .* 2007, Laurence King Publishing: London.

18. Net, M.A. *Telematic Dreaming*. 1992 [cited 15 December, 2011]; Available from: http://www.medienkunstnetz.de/works/telematic-dreaming/

19. Net, M.A. *Telematic Vision*. 1993 [cited 15 December, 2011]; Available from: http://www.medienkunstnetz.de/works/telematic-vision/

20. Frazer J, ed. *An evolutionary architecture.* 1995, Architectural Association: London.

21. Burry M., *Between Surface and Substance.* ARCHITECTURAL DESIGN, 2003. **73**(2): p. 8-19.

22. Bullivant L, *Sky Ear. Usman Haque.* ARCHITECTURAL DESIGN, 2005. **75**(1): p. 8-11.

23. Fox M and Kemp M, eds. *Interactive Architecture*. 2010, Princeton Architectural Press: New York.

24. *Dynamic Architecture*. 2011 [cited 15 December, 2011]; Available from: http://www.dynamicarchitecture.net/.

25. Croci V, *Relational Interactive Architecture*. ARCHITECTURAL DESIGN, 2010. **80**(3): p. 122-125.

26. Pallasmaa J, ed. *The Eyes of The Skin : Architecture and The Senses*. 1996, Academy Group Ltd: London.

27. Haque U, *Architecture, Interactions, Systems* Arquitetura & Urbanismo, 2006. **149**.

28. Joye Y, *Cognitive and Evolutionary Speculations for Biomorphic Architecture*. . Leonardo, 2006. **39**(2): p. 145-152.

29. Development, C.o.R. *Dr Mette Ramsgard Thomsen*. 2008 [cited 25 August 2008]; Available from: http://artsresearch.brighton.ac.uk/research/academic/ramsgard_thomsen.

30. Forty A, ed. *Words and Buildings A Vocabulary of Modern Architecture*. 2000, Thames & Hudson: London.

31. Zellner P, ed. *Hybrid space : new forms in digital architecture*. 2000, Thames & Hudson: London.

32. Holl, S., J. Pallasmaa, and A. Perez-Gomez, *Questions of Perception Phenomenology of Architecture Architecture and Urbanism (A+ U)*. 1994, Tokyo: A + U Publishing Co. Ltd.

33. Hillier B, ed. *The social logic of space* 1989, Cambridge University Press: Cambridge.

34. Hillier B, ed. *Space is the machine : a configurational theory of architecture* 1996, Cambridge University Press: Cambridge.

35. Spiller N, *Reflexive Architecture*. Architectural Design, 2002. **72**(3): p. 88-93.

36. Yamahra H, Takada H, and Shimakawa H, *An individual behavioural pattern to provide ubiquitous service in intelligent space*. WSEAS Transactions on Systems, 2007. **6**(3): p. 562-569.

37. Aoki S, et al., *Detection of a Solitude Senior's Irregular States Based on Learning and Recognizing of Behavioral* IEEJ Transactions on Sensors and Micromachines, 2005. **125**(E(6)): p. 259-265.

38. Hara K, Omori T, and Ueno R, *Detection of unusual human behavior in intelligent house*, in *Paper presented at the Neural Networks for Signal Processing XII, IEEE Signal Processing Society Workshop* 2002. p. 697-706.

39. Mori T, et al., *Sensing room: Distributed sensor environment for measurement of human daily behavior*, in *Paper presented at the 1st International Workshop on Networked Sensing Systems (INSS2004)*. 2004. p. 40-43.

40. Nakauchi Y, et al., *Vivid room: Human intention detection and activity support environment for ubiquitous autonomy*, in *Paper presented at the 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2003. p. 773-778.

41. Isoda Y, Kurakake S, and Nakano H, *Ubiquitous Sensors based Human Behavior Modeling and Recognition using a Spatio-Temporal Representation of User States*, in *Proceedings of the 18th International Conference on Advanced Information Networking and Applications*. 2004. p. 512.

42. Kidd C D, et al., *The Aware Home: A Living Laboratory for Ubiquitous Computing Research*, in *Paper presented at the Second International Workshop on Cooperative Buildings, Integrating Information, Organization, and Architecture*. 1999. p. 191-198.

43.   Matsuoka k, *Smart house understanding human behaviors: who did what, where, and when*, in *Paper presented at the 8th World Multi-Conference on Systems, Cybernetics, and Informatics*. 2004. p. 181-185.

44.   Sherbini K, *Overview of intelligent architecture*, in *1st ASCAAD International Conference, e-Design in Architecture KFUPM, Dhahran, Saudi Arabia*, 2004, Editor. 2004.

45.   McCullough, M., ed. *Digital Ground* 2004, MIT Press: Cambridge, Massachusettes, London,England.

46.   Anderson J, *Manifesto Upgrade:From Comfort to Happy, Flourishing Super Monkeys.* Urban Scrawl, 2009(3): p. 16 - 19.

47.   Haque U, *Distinguishing Concepts: Lexicons of Interactive Art and Architecture.* Architectural Design, 2007. **77**(4): p. 24-31.

48.   Cruz M, *Cyborgian Interfaces.* ARCHITECTURAL DESIGN, 2008. **78**(6): p. 56-59.

49.   Catts O and Zurr I, *Growing Semi-Living Structures Concepts and Practices for the Use of Tissue Technologies for Non-Medical Purposes* ARCHITECTURAL DESIGN, 2008. **78**(6): p. 30-35.

50.   Armstrong R, *Artificial Evolution A Hands-Off Approach for Architects* ARCHITECTURAL DESIGN, 2008. **78**(6): p. 82-85.

51.   Delbrück T, Eng K, and Bäbler A, *ADA a Playful Interactive Space.* Interactions, 2003. **IFIP 2003**(1): p. 4-1.

52.   Litracon Light-transmitting cincrete. *Walls Pavements Design Art*.   2011   [cited 15 December, 2011]; Available from: http://www.litracon.hu/aboutus.php.

53.   Design Boom. *Smartwrap: the mass customizable print facade*. 2010 [cited 15 December, 2011]; Available from: http://www.designboom.com/eng/funclub/smartwrap.html.

54.   Regine. *A makes move toward vehicles that morph*. 2011 [cited 15 December, 2011]; Available from: http://www.we-make-money-not-art.com/archives/2006/03/mit-engineers-r.php.

55.   Zykov V, et al., *Robotics: Self-reproducing machines.* Nature, 2005. **435**: p. 163-146.

56.   Patel N K, Campion S P, and Fernando T, *Evaluating the Use of Virtual Reality as a Tool for Briefing Clients in Architecture*, in *Sixth International Conference on Information Visualisation (IV'02)* 2002: London, England

57.   Aouad G, et al., *An IT Map for a Generic Design and Construction Process Protocol.* Journal of Construction Procurement 1998. **4**(1): p. 1-14.

58.   Barrett P and Stanley C, eds. *Better Construction Briefing*. 1999, Blackwell science: Cornwall.

59.   Bucolo S, Impey P, and Hayes J, *Client Expectations of Virtual Environments for Urban Design Development*, in *Information Visualisation ,Fifth International Conference*. 2001: London, UK. p. 690-694.

60.   Frost P and Warren P. *Virtual Reality Used in a Collaborative Architectural Design Process* in *Information Visualization, IEEE International Conference* 2000. London - UK.

61.   Haque U, *Scents of Space: an Interactive Smell System*, in *SIGGRAPH '04 ACM SIGGRAPH 2004 Sketches.* 2004: New York, USA.

62.   Friedman D, Steed A, and Slater M, *Spatial Social Behavior in Second Life.* Lecture Notes in Computer Science, 2007. **4722**: p. 252-263.

63. Heldal L, et al., *Immersiveness and Symmetry in Copresent Scenarios* in *Virtual Reality, IEEE* 2005.

64. Yee N, *The Unbearable Likeness of Being Digital: The Persistence of Nonverbal Social Norms in Online Virtual Environments.* Cyberpsychology and behavior, 2007. **10**(1): p. 115 - 121.

65. Yee N, *The Demographics, Motivations and Derived Experiences of Users of Massively-Multiuser Online Graphical Environments .PRESENCE: Teleoperators and Virtual Environments.* Cyberpsychology and behavior, 2006. **9**(6): p. 772-775.

66. Yee N, *The Labor of Fun: How Video Games Blur the Boundaries of Work and Play.* Games and Culture, 2006. **1**(1): p. 68 --71.

67. Griffiths M, Davies O, and Chappel D, *Breaking the Stereotype: The Case of Online Gaming.* Cyberpsychology and behavior, 2003. **6**(1): p. 81-91.

68. Wolff R, et al., *A Review of Telecollaboration Technologies With Respect to Closely Coupled Collaboration.* International Journal of Computer Applications in Technology, 2007. **Volume 29**(1): p. 11 - 26.

69. Sutherland I E. *The Ultimate Display*. in *IFIPS Congress* 1965. New York.

70. Slater M, *Place Illusion and Plausibility Can Lead to Realistic Behaviour in Immersive Virtual Environments.* The Royal Society OF BIOLOGICAL SCIENCE, 2009. **364**(1535): p. 3549-3557.

71. Maizell D W, et al. (2002) *Comparing Immersive Virtual Reality With Other Display Modes for Visualising Complex 3D Geometry*. **Volume**,

72. Marks I M and Gelder M G, *A Controlled Ret rospect ive Study of Behavior Therapy in Phobic Patients.* British Journal of Psychiatry, 1965. **111**: p. 571 - 573.

73. Slater M, *Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire.* Presence, 1999. **8**(5): p. 560-565.

74. Pertaub D P, Slater M, and Barker C, *An Experiment on Public Speaking Anxiety in Response to Three Different Types of Virtual Audience.* Presence: Teleoperators and Virtual Environments, 2001. **11**(1): p. 68-78.

75. Roberts D, et al., *Factors Influencing Flow of Object Focussed Collaboration in Collaborative Virtual Environments.* Virtual Reality, 2006. **10**(2): p. 116-133.

76. Blascovich J, et al., *Immersive virtual environment technology as a methodological tool for social psychology.* Psychological inquiry, 2002. **13**(2): p. 103-124.

77. Jang D P, et al., *Analysis of Physiological Response to Two Virtual Environments: Driving and Flying Simulation.* Cyberpsychology & Behavior 2002. **5**(1): p. 11-18.

78. Peruch P and Gaunet F, *Virtual Environments as a Promising Tool for Investigating Human Spatial Cognition.* Current Psychology of Cognition, 1998. **17**(4/5): p. 881-899.

79. Roussos M, et al., *Learning and Building Together in an Immersive Virtual World.* Presence: Teleoperators and Virtual Environments, 1999. **8**(3): p. 247-263.

80. Salzman M C, et al., *A Model for Understanding how Virtual Reality Aids Complex Conceptual Learning.* Presence: Teleoperators and Virtual Environments, 1999. **8**(3): p. 293–316.

81. Rothbaum B O, et al., *A Controlled Virtual Reality Exposure Therapy for the Fear of Flying.* Consulting and Clinical Psychology, 2000. **68**: p. 1020-1026.

82.   Vincelli F, *From Imagination to Virtual Reality: The Future of Clinical Psychology.* CyberPsychology and Behavior, 1999. **2**(3): p. 214-248.

83.   Rothbaum B O, Hodges L F, and Kooper R, *Virtual Reality Exposure Therapy.* Psychotherapy Practice and Research 1997. **6**: p. 291-296.

84.   Slater M, et al., *An Experimental Study on Fear of Public Speaking Using a Virtual Environment.* Cognitive and Behavioral Practice, 2003. **10**: p. 240-247.

85.   Anderson P, Rothbaum B O, and Hodges L F, *Virtual Reality in the Treatment of Social Anxiety: Two Case Reports.* Cognitive and Behavioral Practice, 2003. **10**: p. 240-247.

86.   Harris S R, Kemmerling R L, and North M M, *Brief Virtual Reality Therapy for Public Speaking Anxiety.* CyberPsychology & Behavior, 2002. **5**(6): p. 543-550.

87.   Roy S, et al., *Definition of a VR-Based Protocol to Treat Social Phobia.* CyberPsychology & Behavior, 2003. **6**(4): p. 411-420.

88.   Molinari E, Riva G, and Wiederhold BK, eds. *Virtual Environments in Clinical Psychology and Neuroscience*. 1998, IOS Press: London, UK.

89.   Stanney K M, ed. *Handbook of Virtual Environments: Design, Implementation, and Applications. Human Factors and Ergonomics*. 2002, Lawrence Erlbaum Associates Publishers: Mahwah, NJ, USA. 1232.

90.   Rizzo A, et al., *Virtual Environment Applications in Clinical Neuropsychology* in *IEEE Virtual Reality Conference 2000 (VR 2000).* 2000: New Brunswick, New Jersey.

91.   Hodges L F, Kooper R, and Meyer T C, *Virtual Environments for Treating the Fear of Heights.* Computer, 1995. **28**(7): p. 27-34.

92.   Wiederhold B K, Gevirtz R, and Wiederhold M D, *Fear of Flying: a Case Report Using Virtual Reality Therapy with Physiological Monitoring.* Cyberpsychology & Behavior, 1998. **1**(2): p. 97-103.

93.   Huang M P, et al., *Comparing Virtual and Real Worlds for Acrophobia Treatment.* Studies in health technology and informatics, 1998(50): p. 175-179.

94.   Hodges LF, et al., *A Virtual Environment for the Treatment of Chronic Combat-Related Post-Traumatic Stress Disorder.* Cyberpsychology & Behavior, 1999. **2**(1): p. 7-14.

95.   Rothbaum B O, et al., *Virtual Reality Exposure Therapy for PTSD Vietnam Veterans: A Case Study.* Traumatic Stress, 1999. **12**(2): p. 263-272.

96.   Regenbrecht H T, Schubert T W, and Friedmann F, *Measuring the Sense of Presence and its Relation to Fear of Hights in Virtual Environments.* International journal of Human Computer Interaction, 1998. **10**(3): p. 233-250.

97.   Brogni, A., et al., *Touching Sharp Virtual Objects Produces a Haptic Illusion Virtual and Mixed Reality - New Trends.* 2011, Springer Berlin / Heidelberg. p. 234-242.

98.   Eng K, et al., *An Investigation of Collective Human Behavior in Large-Scale Mixed Reality Spaces.* Teleoperators and Virtual Environments, 2006. **15**(4): p. 403-418.

99.   Eng K, Mintz M, and Verschure P F M J, *Collective Human Behavior in Interactive Spaces* in *IEEE International Conference on Robotics and Automation (ICRA05)* 2005.

100.   Eng K A and Bäbler A, *Design for a brain revisited: The neuromorphic design and functionality of the interactive space.* Reviews in the Neurosciences 2003. **14**(1-2): p. 145-180.

101.   Bullivant L, *Ada the Intelligent Room.* ARCHITECTURAL DESIGN, 2005. **75**(1): p. 86 - 90.

102.   Slater M, *Depth of Presence in Virtual Environments.* Presence, 1994: p. 130-144.

103.   Kaplan, Sadock B J, and Grebb J A, *Synopsis of Psychiatry: Behavioral Sciences, Clinical Psychiatry.* 6th ed. 1991, Williams and Wilkins, Baltimore, USA.

104.   Crowe M J, et al., *Time-limited desensitisation, implosion and shaping for phobic patients: A crossover study.* Behaviour Research and Therapy, 1972. **10**(4): p. 319-328.

105.   Tran C, et al., *2011 Toronto notes clinical handbook*. 2011, Toronto, ON, Canada: Toronto Notes for Medical Students, Inc.

106.   Guallart V and Diaz M. *Hyper Habitat: reprogramming the world* in *Proceedings of the 11th International Architecture exhibition: Out There: Architecture beyond Building.* 2008.

107.   Van Baren J and IJsselsteijn W (2004) *Measuring Presence: A Guide to Current Measurement Approaches.* **Volume**,

108.   Psych Connections. *Within-Subjects Design*. 2011 [cited 15 December, 2011]; Available from: http://web.mst.edu/~psyworld/experimental/within_subjects.html.

109.   Experiment-Resources. *Within Subject Design*. 2011 [cited 15 December, 2011]; Available from: http://www.experiment-resources.com/within-subject-design.html.

110.   MacKenzie, I.S. *Within-Subjects Designs*. 2011 [cited 15 December, 2011]; Available from: http://www.yorku.ca/mack/RN-Counterbalancing.html.

111.   Adi M N and Roberts D, *Can you help me concentrate room?*, in *IEEE ACM Virtual Reality*. 2010: Waltham, MA. p. 131 - 134.

Glossary:

Adaptive Architecture: Buildings that can change their properties to adapt to different environments or users.

Animated architecture: Buildings that can change their properties in real time according to input from users or the surrounding environment.

Intelligent architecture: like animated architecture. But it also has a set or short and/or long term goals that it bases its actions on.

IVE: Immersive virtual environments. Environments that immerse their users in virtual simulations.

Life like architecture: : Buildings that can change their properties in real time according to input from users or the surrounding environment. similar to a living organism.

Responsive space: Space that has similar qualities to animated architecture.

VR: Virtual reality.