Borealis sound an interactive wall for situational awareness: the impact of responsive architecture on users

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Abstract. This paper refers to the presence of visual communication elements in public spaces using interactive multimedia surfaces. The state of the art, the development of a proposal and its evaluation is presented. The interactive surface applies to school of music "Escola de Música do Conservatório Nacional", to which a design project was done in an academic context. The proposal aims to explore the incorporation of digital multimedia surfaces enhancing new dynamics while users walk in the interior of the building. Visual content will be displayed and the interaction between users and the multimedia surfaces is done by the sounds produce by people and instruments. To assess the intuitive nature and relevance of the proposal, satisfaction and usability tests were conducted with the potential users. It was concluded that users appreciated the proposal and were able to perceive the effect people's presence have in the interaction with the multimedia surface.

Keywords: Responsive Architecture; Interaction; users' responses; multimedia; interactive wall; sound; user's testing.

1 Introduction

This paper concerns the presence of visual communication elements in public spaces using interactive multimedia surfaces. The state of the art, the development of a proposal and its evaluation is presented. The interactive surface applies to Escola de Música do Conservatório Nacional – EMCN (School of Music of the National Conservatory of Lisbon), to which a rehabilitation and expansion design project was developed in an academic context (**Erro! A origem da referência não foi encontrada.**). Since the task involved a music school, the aim was to develop a proposal that would explore interactive multimedia surfaces that react to what characterizes this space - the sound. The problem identified in EMCN to which this research address is the noisy corridors of the school. The solution presented aims to explore the incorporation of digital multimedia surfaces enhancing new social dynamics while users walk in the interior of the building. Visual content will be displayed, and it will react according to the interaction with the sounds produced by people and instruments. This proposal has therefore a dual goal since on one side it acts as an entertainment and on

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the other as a device to control the sound level of the public areas of the school creating a better learning environment.

To achieve the proposed objectives, a methodology structured in three stages was adopted. The first stage corresponded to the literature review and the research of different examples of multimedia surfaces in order to analyze the current systems and the relevance of their use. Theoretical and technical bases related to the creation of these surfaces were also investigated. The methodologies for technology development that were studied were instrumental to the development of the proposal and allowed the definition of the interactive proposed system design as well as its later evaluation based on user experience. The second stage included two moments. First, the methodology to be applied to the practical proposal was defined. This methodology incorporates the development of the proposal and addresses the architectural and technological aspects. After defining the proposal, a prototype was created to simulate and test the interaction performance. At this moment usability and satisfaction test of the proposed system was carried out in order to assess the intuitive nature and relevance of the proposal. The last stage was related to the analysis of the results obtained with the prototype tests. This analysis aimed at assessing whether the defined proposal corresponds to the intended one.

This paper is divided into three main parts. Section 2 describes interactive multimedia surfaces and the state of the art. Section 3 describes all the steps of the development of the proposal here presented for an interactive multimedia surface from the definition of the initial conditions to the performance and analysis of usability tests. The paper ends with a section of discussion and concluding remarks.

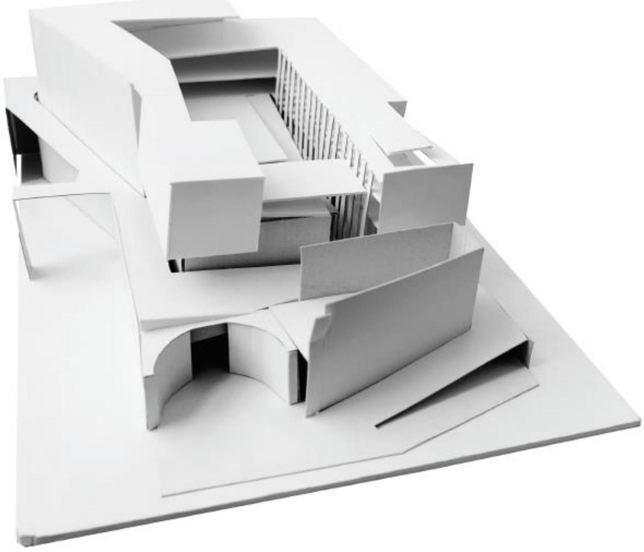

Fig. 1. Model of the proposal

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2 Interactive Multimedia Surfaces

According to Achten (2014), interactive architecture is a special case of "responsive buildings" which are the ones that can anticipate and change their behavior or content according to a schedule. The particularity of an interactive surface is to create a user internal representation. This means that activity(ies) that potentially could be carried by the user(s) were anticipated and introduced in the building system.

Based on their own design installations Fischer & Hornecker (2012) analyzed and compared different spatial configurations in relation to their interaction system. According to the authors, interactive Media Façade interventions, “takes account of the social use of space and of the existing structure of the built environment”. In the SMSlingshot installation designed by the authors for a square they identified seven types of spaces related to the experience of an interactive surface. These are: Display spaces, Interaction space, Potential Interaction Space (PIS), Gap spaces, Social Interaction Spaces (SIS), Comfort spaces, and Activation spaces. According to the authors, “depending on installation type, context, and environment, these spaces can differ in size and position” (Fischer and Hornecker, 2012, p. 4)

Indaverea (2010) considers three approaches to make “media surfaces”. The first consists of creating from scratch digital content to be projected onto a building. An example of this approach is the spatial augmented reality “Perdi o meu coração em Lisboa” (I lost my heart in Lisbon), made by Oskar & Gaspar at Terreiro do Paço, Lisbon, in 2014. The second approach consists of capturing data from the environment and its subsequent interpretation, using digital means to project the content on a building. According to Indaverea (2010), the Tower of the Winds (1986), designed by Toyo Ito, is an example of this second approach. The third approach integrates an interaction with the public, which will thus have a direct influence on the content on display. The difference between the second and the third approach is that while the second reacts to environmental stimulation, the third reacts to human stimulation. As for the content, the author distinguishes the following functions: artistic, playful, community media, public service and news.

This way of classifying interactive surfaces is nevertheless not consensual. In fact, Gehring and Wiethoff (2014) present another way of classifying interactive surfaces, focusing on the communication process between people and buildings. These authors classify the types of interactive surfaces, enumerating what distinguishes them from each other, based on their most striking characteristics. Water Light Graffiti[1] produced by Antonin Fourneau and Art2m, presented at the third edition of LUMINA[2] festival in Cascais 2014, is a good example of an installation with different types of interaction. This installation was considered a breakthrough in terms of interaction in urban architecture by mixing a natural element - water - with technology, LEDs and humidity sensors. The installation allowed an interaction between the public and natural phenomena such as rain. Another example is Perspective Lyrique, interactive video-mapping, designed by the team of architects 1024, and held at the Celestins Thea-

[1] Water light Graffiti in: http://www.waterlightgraffiti.com/about-wlg/

[2] Lumina (2014) in http://lumina.pt/2014/pt/lumina/

tre in 2010, under the Fête des Lumières Festival in Lyon[3]. The artists have integrated an interactive device that causes a succession of visual distortions which were activated by voice. Finally, the SMSlingshot installation consists of a slingshot that "shoots" messages to a facade. It allows the public to momentarily leave a mark on the facade and send signs in the form of color ink balloons (Fischer and Hornecker, 2012).

Achten and Kopriva, (2010), proposed a methodological framework for interactive architectural design developed into four basic stages: Analysis; Concept generation; Simulation; Evaluation. Later, Achten (2014) states that to develop interactive systems there are no design methods that ensure an appropriate solution since, part of the development can be addressed in a methodological way, but another substantial part has to be seized through iterative processes and prototypes to test ideas. In order to form a theoretical basis for the design of interactive architecture. Achten (2014) also defines the principles of agent theory, a key concept originated in the field of artificial intelligence. This concept considers the analysis, the design of complex systems and includes two complementary moments which are the communication directly with other objects and the changes to which it is subjected autonomously without an entry/order. The term "building as agent" describes the interaction, or responsiveness, as if it was a person who is being described. According to that principle, the author suggests five points that support the global design of interactive systems: system response type; type of interaction for the user; type of interaction for the system; style of interaction between the user and the system; and type of interaction activity.

Besides these functional and methodological aspects of developing an interactive wall it is also relevant to be aware of its potential social impact. The presence of digital devices in the places we inhabit are enabling us to access a large set of information in a totally new way. The addition of interactive features enables these devices to be customized to their users which opens a new dimension of space appropriation. Informative panels exist already everywhere we go, with information on outside weather conditions, indoor temperature and humidity, available parking places and the level of CO2 in e.g. an underground parking area, among other examples. This situation awareness and the information given is helpful and enables users to make informed decisions. Situation awareness has been recognized as a critical foundation for successful decision-making across a broad range of situations[4]. This concept has roots in military action as most of the technology development nowadays. Endsley (2001) refers that for complex situations people are having trouble coping with data explosion and that the "answer lies in understanding how people process the vast amount of data around them to arrive at effective performance". Situation awareness comprises three steps: perception – gathering information about the situation; understanding – comprehending the meaning of the information acquired; prediction – anticipating the outcome of future events[5]. These steps are fundamental for good decision making.

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[3] 1024 blog in: https://1024d.wordpress.com/category/event-project/prespective-lyrique/

[4] For more information on Situation Awareness see https://en.wikipedia.org/wiki/Situation_awareness

[5] Situational Awareness matters, see https://www.samatters.com/

There are several studies on the development and impact of situation awareness information displays in several fields as in (Hoferlin et al., 2011; Chen, Qian and Lei, 2016). Most of these studies assess the developed systems by usability tests and do not focus on discussions on how interactive spaces are changing the way we inhabit, appropriate and use indoor spaces. On this matter, Snibbe and Raffle have a very interesting research based on several years of own experience developing interactive systems for public exhibits. The authors use the concept of social immersive media built on simulated narrative models that "create strong emotional responses and social engagement through visceral interaction" (Snibbe and Raffle, 2009, p. 1447).

3 Borealis sound system development

The proposal was prepared using a methodological system present in Achten and Kopriva (2010) and Achten (2014). The methodology used begins stepwise in order to specify the main criteria that allows the future implementation. At the end a simulation is carried out through a proof of concept prototype. The proposal development was done throughout the following five stages: i) definition of the initial conditions; ii) analysis of the context; iii) system specification - requirements; iv) usability testing; v) analysis of the results.

3.1 The creative process

Initially, three different proposals were considered for the current project. Although all the proposal defines distinct interactions, all have the common principle of promoting a connection between sound and image, since they would be inserted in a music school. We briefly describe each of the three proposals (A, B and C) since "to get a good idea, get lots of ideas." (Fudd´s first law of creativity, (Rettig, 1994)).

Proposal A (**Erro! A origem da referência não foi encontrada.**) - The Memory of the Path - consists of the installation of six LED panels, aligned with walls along the north corridor of floor 0 of the EMCN. In this proposal pressure sensors placed on the floor sense people passing and sends information to an actuator to control images and color of lights projected on the walls, varying according to the users' path.

Proposal B (**Erro! A origem da referência não foi encontrada.**) – Musical Fragments - also consists of the application of LED panels in the north corridor of floor 0 of the EMCN. This corridor is a crossing area for students, and the panels aim to promote a playful activity. For this proposal, the participation of more than one student is necessary, so that, when touching on a panel, it emits a short piece of music. The purpose of the interaction is to challenge participants to identify the music playing. In order to decipher the music, it would be necessary to interact with more than one panel, with each panel emitting only a certain part of the music to be deciphered.

In proposal C (**Erro! A origem da referência não foi encontrada.**) – Propagation, Superposition – the panels would be placed perpendicular to the wall. Consequently, these would have a greater impact as they delimit the students' path along the south corridor of floor 1. Both sides of the panel are to be used with one screen on each

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side. The interaction is triggered by touch, which causes the light in a certain panel to turn on. This light spreads to the following panels, each time with less intensity - until the light goes out. The intensity of the light corresponds to the intensity of the touch; the more force is applied, the greater the light emission, making it possible to propagate it to the last panel. The corridor would thus be exposed to a constant rhythm of lights with different intensities.

Besides the aim of entertainment, the second and more relevant aim related to the proposals is to provide a better learning environment.

Fig. 2. Proposal A – memory of the path

Fig. 3. - Proposal B – musical fragments

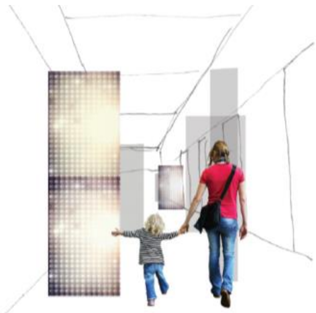

Fig. 4. Proposal C – propagation, superposition

3.2 Stage 1 – definition of the initial conditions

The interactive wall is proposed to the ground floor of the north corridor in EMCN. The design presupposes that all visual content displayed on the screens are triggered by the sound/noise produced by people, devices and musical instruments. According to Lucy Bullivant (2007) "the interaction with a multimedia installation allows people to participate in a different world by adding a transformative effect".

The performance criteria for the visual effects were defined regarding the amplitude and frequency of the sound. These criteria were chosen in order to provide users with a sensory experience that entangles them with the combination of both sound and visual effects. A second aim was to control the volume of the sound in a place where silence, sound clarity needed and noise reduction during the classes is mandatory.

The current proposal consists of a set of LED matrices (**Erro! A origem da referência não foi encontrada.**). In order to adapt the visual content to the chosen real situation, the performance of the installation is divided into two distinct periods, a quieter in a low amplitude sound environment and a second one in a higher amplitude sound environment. Each one works within a stipulated time frame, the period (I) occurs during the classes and the period (II) occurs in the absence of classes. At the period (I) the content reacts depending on the amplitude and during the period (II) the content reacts depending both on the amplitude and frequency. These two periods are distinguished in terms of both the visual content displayed and the volume picked up not in terms of interaction. For the period (I) two scenarios were designed: 1) a single person in the corridor, 2) a group of people in the corridor. For the period (II) only one extra scenario was designed: 3) student rehearsing in the corridor. Scenarios 1) and 2) may also occur at the period (II).

We then applied the five points that support the creation of a global design of interactive systems following Achten (2014). The points are type of system response; type of interaction for the user; type of interaction for the system; style of interaction between the user and the system; and type of interaction activity.

The designed system is reactive regarding the type of interaction since it includes as a condition that any sound produced in the corridor triggers an action in the displays. In such a design the user is active since he/she is the main sound source of interaction. The type of interaction by the user is designed as unintentional since the system does not require a voluntary user participation. Thus, the system is said to be indirectly associated with the user. When the user is active, and the system is indirect, the resulting interaction style is called assistant (Achten 2014). In assistant interaction to operate the system does not imply the user to have the knowledge of how the system works.

Controlling the sound produced in the corridor and acting as a mean of entertainment are the main objectives of the proposed interactive wall. When the sound produced in the corridor exceeds a preset limit (85 dB, equivalent to a human scream) an

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alert message is transmitted (red stain). To avoid disturbance in the school, it was intended that this visual signal should serve as a limit indicator for the volume and not has a disturbing alert.

Exploration was considered as the interaction activity. The combination of this exploration activity with the defined objectives (entertainment and sound regulation in the corridor) describes the type of user experience which is based on improvising. This type of experience allows the user to explore various options and configurations of the content, without a pre-defined objective or performance criterion.

To set out principles for the performance, an analysis of the properties of sound was done. To explore the amplitude property in both periods (I) and (II), types of sounds were associated with a low, medium and high amplitude (sounds considered weak, medium and strong). The frequency was introduced as a performance criterion in the period (II) by analyzing the frequency that the three types of instruments more likely to be tested in the hallway such as wind, strings and percussion. The proposed three scenarios can help distinguishing the dynamics occurring in each period. For them seven different criteria were proposed which in turn cause seven variations of visual content, two for Scenario 1), two for Scenario 2) and three for Scenario 3).

The Northern Lights were chosen to be the visual content of the interactive wall because of their beauty. In nature these lights are the result of weather events. In the proposed application the images of the Northern Lights will, in analogy, result of the different sounds captured by the sensors (microphones). The goal was not to reproduce their beauty, but rather to take advantage of the visual impact that is embodied in the movement of the lights in all directions.

In the first two scenarios, the performance criterion is the amplitude. The visual content (color stain) varies in size - when the amplitude is low, the stain is small, and when the amplitude is medium, the spot is bigger. If the amplitude reaches high, the visual effect, "freezes" and a red stain will flood the corridor. This red light intends to act as an alarm calling for the users' attention to reduce the volume (too loud) that they are producing. This reaction of the interactive system condemns the "noise" considered negative by all the users of the school. To the third and final scenario created, a color scale was associated with a range of frequencies: in the presence of low frequencies the colors are warm; for mid-range intermediate colors will be used; for high frequencies cold colors.

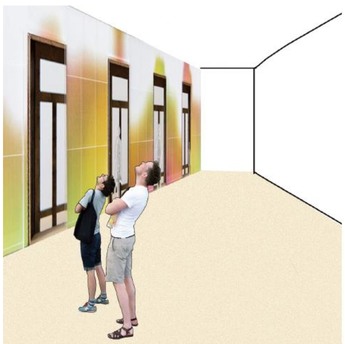

Fig. 5. – The interactive multimedia Wall for EMCN

3.3 Stage 2 – analysis of the context

A total of six audio samples collected on-line and a sample recorded for this purpose were used. These samples are associated with the designed scenarios with the goal of matching each sound to a type of situation. Sounds samples included a person walking, a phone ringing, people talking out loud. The samples for the instruments were bass, guitar and violin.

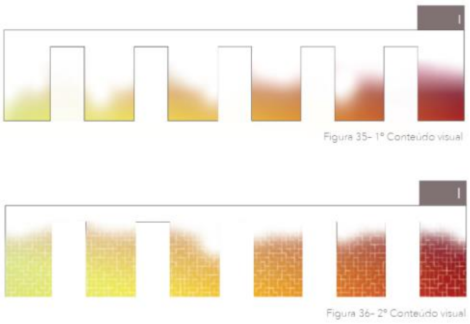

Fig. 6. (Top) first visual content, (bottom) second visual content.

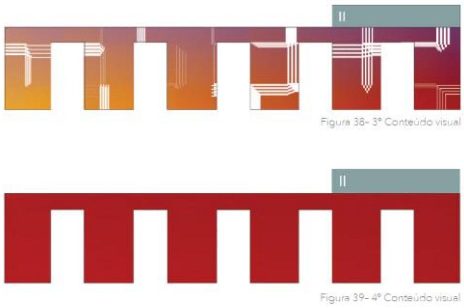

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Fig. 7. (Top) third visual content, (bottom) fourth visual content.

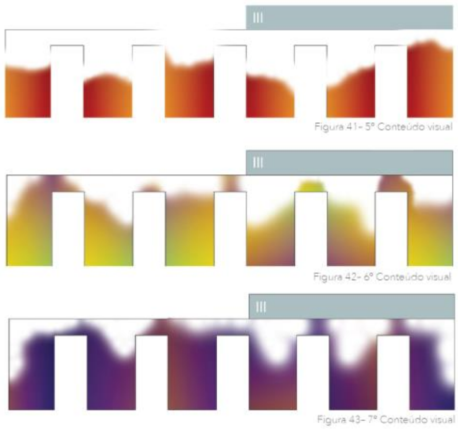

Fig. 8. (Top) *fifth visual content*, (middle) sixth visual content, (bottom) seventh visual content.

The samples were reproduced in the Abbleton Live 9[6] software in order to export the spectrum graphics for each sound. As support for the definition of the specific performance criteria proposed spectrum graphs were produced. This allows an analysis of the amplitude and respective frequencies, making it possible to distinguish the loud from the low sounds as well as the sounds in which the low, medium or high frequencies predominate.

For scenario 1 in the situation of reaction to a single person we defined that the amplitude corresponding to the sound of the steps in the corridor reaches 36 dB, whereas the amplitude corresponding to the sound of the cell phone corresponds to 65 dB. The first performance criterion is defined by a maximum amplitude of 36 dB - when this value is reached, the installation generates the first visual content. The second performance criterion is defined by an amplitude greater than 65 dB, thus generating the second visual content. The two visual contents created for the present scenario can be found in **Erro! A origem da referência não foi encontrada.**.

In scenario 2 a group of people is in the corridor. The two sounds present in this scenario correspond to a conversation, the first sound is of a medium amplitude with 65 dB and the second sound a high amplitude with 72 dB. Each amplitude give rise to two more visual contents (**Erro! A origem da referência não foi encontrada.**).

Scenario 3 corresponds to a moment when one or more students are rehearsing in the corridor during class hours. The sounds present in this scenario correspond to a bass, an acoustic guitar and a violin. In this scenario it was defined that the visual content appears when the amplitude of the sound produced is above 10 dB. It was concluded that the bass sound is predominantly low, the guitar sound is predominantly medium, and the violin is predominantly high. Thus, each type of frequency gener-

[6] See https://www.ableton.com

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ates distinct visual content. Considering the three frequency variations, these represent the fifth, sixth and seventh performance criteria. It was decided to associate a color scale to each of these frequencies, in the presence of a low frequency, the fifth content occurs in red tones, for medium frequency, sixth content, yellow tones and for a high frequency, seventh and last content, blue tones are shown (**Erro! A origem da referência não foi encontrada.**).

3.4 Stage 3 – system requirements and specifications

The development of this proposal required research about digital signal, display controllers and sound capture regarding the type of approach to achieve the expected results. Even though the proposal was designed for the EMCN, it was considered the possibility of implementing it in other public spaces and therefore the technical requirements should adapt to different space characteristics.

Digital Signage can refer to various display technologies. "Video wall" generally refers to multi-monitor installations for large format video presentation. These consist of arrangements of standard format monitors (such as 16:9) with thin bezels, with common monitor sizes being 47 or 55 inches. The monitor display technologies vary between: TFT-LCD or LCD (thin-film transistor liquid crystal display); OLED (organic light-emitting diode); E-Paper (non-illuminated display technology that uses charged white and black particles in microcapsules to reproduce greyscale images); LED matrices for large scale displays; and Flip-disc displays which are now obsolete in terms of cost and complexity compared to modern display technologies but are still widely used and have a unique and interesting aesthetic.

The LED matrices were considered to be the most suitable display for the present proposal. They are the most common and cost-effective method of implementing large scale displays. Pixels are produced by individual LEDs (light-emitting diodes) instead of TFT arrays. LED matrices generally have much lower pixel densities than LCD or OLED displays. Regarding the visual content proposed the monitor does not need a very high resolution. Matrices are commonly sold as bezel-less modules, that allow them to be combined and form a larger display without any noticeable lines between the modules, compared to video walls which usually require a small bezel in-between the displays. Matrix modules come in different sizes, normally square (1:1) or rectangular (1:2), and in resolutions of powers of two: such as 8x8, 16x32, 64x64 and more. Due to their smaller size and ability to be tiled in any direction, LED matrices allows to cover walls of unique dimensions, unlike video walls which are generally limited to large rectangular standard sizes displays. LED matrices may be full color (RGB) or of limited or individual colors, such as the low-resolution matrices used in transportation signage. Transparent displays and LED curtains are a variation of LED matrices where a transparent base material and wide pitch allow for a translucent appearance. Using Addressable LED Strip or Strings is an alternative way to construct an LED matrix, which can be more cost effective for very large pitch displays of lower resolutions, and allows for even more unique display forms and configurations, including textile based "soft" displays. Extra low-resolution displays can be combined with diffuser materials for novel lighting effects and unusual pixel formation.

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In terms of display controllers, the hardware requirements for digital signage can be reduced to a small computer with a very capable graphics card, or several computers networked together; some video walls have a dedicated computer for each monitor. LED matrices have lower computational requirements given their low resolution. A single controller can drive many matrix modules, but a small computer may still be necessary to process the sound inputs and produce a video signal. Low resolution matrices or LED strips/strings have even lower requirements, and are likely easily driven by a microcontroller, possibly even without the need for a computer to produce the video signal, depending on how the sound is being processed.

For the sound capture, the omnidirectional microphones would be used as sound sensors hanged along the corridor (omnidirectional condenser low profile for AT4022413 recording). These microphones capture the sound independently of the sound source in relation to the direction of the microphone.

To decide how capture sound in the space depends greatly on the desired visualization and how the viewer reacts/interacts with it. Indeed, microphones can capture sounds differently from different angles.

3.5 Stage 4 – usability testing

In order to evaluate the usability and user satisfaction of the developed proposal a test was held using a prototype of the solution. The chosen method for the test, known as paper-prototype, is a low-fidelity prototyping test commonly used in design processes that focus on user experience (Rettig, 1994). Rapid prototyping (low-fidelity prototyping or paper prototype) is an effective method to be used in design processes with a focus on user experience (Rettig, 1994). It is a method generally used for designing human-computer interfaces, websites, computer applications, hand-held devices, and proof-of-concept prototypes. This method not only allows to show users the visual appearance and performance of an interface, but also defines a technique for quickly obtaining criticism and feedback in an early development phase. This would not be possible if another method of design conception was used, such as, coding in the application language or by a simulation made with software. These methods require more time and involve higher costs.

The usability analysis method called cognitive walkthrough was applied (Mano and Campos, 2004) in the tests. This evaluation technique is used to evaluate the interface design, by simulating the steps that a user (without any prior knowledge of the system) would do to reach a goal (Mano and Campos, 2004). In this method the user is being guided throughout the experiment by a "facilitator" who simulated the performance of the installation. The demonstration of the performance of the proposal starts in a simple scenario and leads the participant to the most complete scenario. It was intended to verify if the visual contents used in the three scenarios were effectively assimilated as messages and if not, proceed with the improvement of the project.

20 individual tests were carried out on a sample of Iscte architecture students and EMCN students. These tests were carried out to assess the relevance of the installation in the school context and the degree of satisfaction of the participants as well as usability issues.

The study was divided into four stages:

- Stage I: The first stage consisted of creating a 1:50 scale model of the location where the interactive surface is to be proposed and the interactive wall itself (**Erro! A origem da referência não foi encontrada.**). MDF (Medium-Density Fiberboard), acrylic, black spray paint and glue were used for the model. The visual contents for the three scenarios were printed on paper. One of the fundamental aspects of rapid prototyping is to avoid using complex technologies to simulate the interactive behaviour of the proposal. In this way, all alteration of visual content was handled "manually" by the researcher, ensuring that the illusion that the prototype created simulated the performance of the interface in a similar way to the real scenario.
- Stage II: The second stage consisted of receiving the participants, presenting the goals of the simulation and asking the participants to sign an informed consent form.
- Stage III: In the third stage, tests were carried out (**Erro! A origem da referência não foi encontrada.**). The registration of observations and comments of the participants during and after the tests, allowed to carry out a qualitative analysis of the proposal presented. Two researchers were present during the tests to ensure that no interruption was needed.
- Stage IV: After performing the tests satisfaction and usability questionnaires were given to participants which allowed to obtain a quantitative assessment of the proposal.

Fig. 9. (Left) a test performed at Iscte, (right) a test performed at EMCN

Fig. 10. The prototype for tests

3.6 Stage 5 – results analysis

A qualitative assessment and a quantitative evaluation were performed with the data from the previous stage. The results of the observations, the written suggestions and videos recorded during the simulations constituted the data to do the qualitative assessment. The quantitative evaluation was done with the posttest questionnaire, which focused on fundamental aspects to validate the relevance and effectiveness of the proposal, such as: being aware of the transformation of the visual content; understanding the visual content present on each scenario; the awareness of the relationship between visual content and sound properties; and the intuition level of the interactive experience.

Both the Iscte students and the EMCN students considered that the visual content has changed in all scenarios which allowed us to conclude that all participants understood that the proposed panel will be in constant transformation.

Participants were asked in what extent they perceived that there was an alteration of the visual content related to an action in the space. Results are presented in **Erro! A origem da referência não foi encontrada.** and it is visible that a large extent of participants had that perception. Participants were also asked how intuitive the interactive effect in the visual content caused by the sound was. 45% of the participants found the experience intuitive (level 6) and 40% considered it very intuitive (level 7). The remaining 15% considered it in level 5.

EMCN students had no difficulty in locating the model in the context of the school. The students made several suggestions to the visual content presented, namely a greater variation of visual content, in addition to the association of frequencies with a color scale and variation in the size of the stain associated with the amplitude. It was also suggested to use timber as a performance criterion. EMCN students inquired if two instruments were playing with different frequencies the installation would recognize the two instruments and react differently to each one. Finally, a positive observation was made regarding the implementation of the proposed installation for the EMCN. One student comment that this approach would be a much more interesting way of alerting students for the noise they cause in the corridors. Currently, the way to prevent this situation is by using papers posted on the walls of the corridors with the message “Silence, there are classes taking place.” In general, the participants showed interest in the proposal.

Table 1. – Number of participants that were asked regarding the cause-effect relation between the action done (production of sound) and the visual content displayed. Participants answered questions on a scale of level 1 to level 7, where level 1 corresponds to “not noticeable” and level 7 to “very noticeable”.

	Scenario 1				Scenario 2				Scenario 3			
	Iscte	EM.	Total	%	Iscte	EM.	Total	%	Iscte	EM.	Total	%
Level 1												
Level 2												
Level 3												
Level 4	1		1	5%	1		1	5%	1		1	5%
Level 5	4	1	5	25%	5	1	6	30%	3	3	6	30%
Level 6	4	3	7	35%	3	2	8	25%	6		6	30%
Level 7	6	1	7	35%	6	2	6	40%	5	2	7	35%

4 Discussion and Concluding remarks

The goal of the proposal was to create a surface for a school of music that would act as an informative piece with the aim to change users’ behaviors to promote a better study environment as well as to be entertaining while users pass by in the public areas of the school.

The development of the proposal for an interactive wall for EMCN focused on the configuration of the interactive installation, the relation with the place where it will be inserted, the definition of the performance criteria of the interaction and the creation of visual content. Tests were carried out with a low-fidelity prototype. The used methodology constitutes an inexpensive and effective method to assess the impact of a design a priori its execution and therefore prevents wrong decisions to be made. Since the proposal implies a direct relation with users (person-machine interaction), it was essential to carry out tests that simulated the way the relation is established in order to assess its effectiveness. The usability and satisfaction tests performed to assess the proposed system reveled that users understand the message of the wall regarding the noise control and they consider this method as an interesting way of doing such a control.

The result of this study allows a reflection on how media façades can add value and solve identified problems in society, in the present case a problem identified by the end-users of EMCN - students and employees. We envision that such an interactive wall as the one proposed could be used in other environments where an automatic triggered soft alert (rather than e.g. an audio alarm or an alert given by a person) would potentiate a more conscious behavior by users. Places like libraries, working areas, hospitals and clinics and schools (when classes are occurring) are good examples for the use of such devices.

Another reflection that emerges from this study is how will multimedia surfaces reshape our relationship with the built environment and in what extend will it change the way we appropriate those spaces. Such surfaces introduce a type of mutable element with digital contents that does not exist in traditional static physical buildings. Such a new intruder in buildings will have an impact on the organization of space and on its appropriation by users. For Oddey and White (2006) large digital displays can be appropriated as windows that connect the interior space to a particular visual field extending the physical space and playing with the notion of presence. Digital contents will no longer be confined in our pockets and bags but are already assuming positions on the rigid surfaces that we are accustomed to be static and with which we will start to interact with. Snibbe and Raffle (2009) also show how media walls promote social engagement and how we can control user behaviour by choosing different interaction techniques. Kuikkaniemi et al (2011) say that such interactive walls have the potential to motivate individual and group interaction and will transform passive viewing into an involved performance. These authors also highlight that digital displays augment spatial information and make it more flexible and engaging compared to when analogue signs are used.

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References

Achten, H. (2014) 'One and Many: an agent perspective on interactive architecture.', in *ACADIA 2014 Design Agency: Proceedings of the 34th Annual Conference of the Association for Computer Aided Design in Architecture.* Toronto: Riverside Architectural Press, pp. 479–48.

Achten, H. and Kopriva, M. (2010) 'A Design Methodological Framework for Interactive Architecture', in *Future Cities*. Zurich: ETH Zurich, pp. 169–177.

Bullivant, L. (2007) '4dsocial', *AD 4dsocial Interactive Design Environments*, 77(188).

Chen, Y. V., Qian, Z. C. and Lei, W. T. (2016) 'Designing a Situational Awareness Information Display: Adopting an Affordance-Based Framework Interaction Design', *Informatics*, 3(6). doi: 10.3390/informatics3020006.

Endsley, M. E. (2001) 'Designing for Situation Awareness in Complex System The Challenge of the Information Age', in *Proceedings of the Second intenational workshop on symbiosis of humans, artifacts and environment*.

Fischer, P. T. and Hornecker, E. (2012) 'Urban HCI: Spatial Aspects in the Design of Shared Encounters for Media Façades', in *Proceedings of the 2012 ACM Annual*

Conference on Human Factors in Computing Systems, pp. 307–316. Available at: http://www.ehornecker.de/Papers/UrbanHCISpatial.pdf.

Gehring, S. and Wiethoff, A. (2014) ‘Interaction with Media Façades’, *Informatik-Spektrum*, 37(5), pp. 474–482. doi: https://doi.org/10.1007/s00287-014-0818-0.

Hoferlin, B. *et al.* (2011) ‘Interactive auditory display to support situational awareness in video surveillance’, in *The 17th International Conference on Auditory Display (ICAD-2011)*. Budapest, Hungary.

Indaverea, M. (2010) ‘Fachadas Tecnológicas: de como la arquitectura se convierte en un media.’, in *Actas del Segundo Congreso Internacional sobre Imagen, Cultura y Tecnología*. Universidad Carlos III, pp. 59–70.

Kuikkaniemi, K. *et al.* (2011) ‘Interactive Screens Will Life’, *Computer*, pp. 40–47.

Mano, A. and Campos, J. C. (2004) ‘Aplicação de um cognitive walkthrough: estudo de caso’, in *Interação 2004 - 1a. Conferência Nacional em Interação Pessoa-Máquina.*, pp. 256–258.

Oddey, A. and White, C. (2006) ‘Introduction: The potentials of space’, in Oddey, A. and White, C. (eds) *The Potentials of Spaces: The Theory and Practice of Scenography & Performance*, pp. 11–24.

Rettig, M. (1994) ‘Prototyping for Tiny Fingers’, *Communications of the ACM*, 37(4), pp. 21–27.

Snibbe, S. S. and Raffle, H. S. (2009) ‘Social Immersive Media’, in *CHI 2009 ~ New Media Experiences 2*, pp. 1447–1456.

Short bios

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Couto, B., Eloy, S. (forthcoming) Borealis sound an Interactive wall. Intervention for the Escola de Música do Conservatório Nacional de Lisboa. In Formal Methods in Architecture - Proceedings of the 5th International Symposium on Formal Methods in Architecture (5FMA), Lisbon 2020. Edited by Eloy, S., Viana, D. L., Morais, F., Vaz, J. V. Cham, Springer.