USING IMMERSIVE ENVIRONMENTS TO EVALUATE MULTI-SENSORY RESPONSIVE SURFACES

Matthew Wagner[1], Ivica Ico Bukvic[1], Dane Webster[1]
[1]Virginia Tech, Blacksburg, Virginia

ABSTRACT:
Our research identifies purposeful uses for multi-sensory responsive surfaces. The premise of our research explores spatial typologies which we believe would benefit from such surfaces. Digital fabrication tools and technology, as well as material characteristics and mechanisms, provide a strategic means for navigating the multitude of forces at play.

Serving as the activating link between material research and design innovation, the relationship between the designed object and the forces surrounding that object are always present, perceivable, and tactile. Both Programmatic as well as physical complexities guide the methodology of our design process, which progresses through a series of focused strategies. Through a specific disposition, we evaluate each responsive surface for performance potentials.

Our goal is to study the effects on how human behavior positively changes as a result of our multi-sensory responsive surfaces. Our responsive surfaces seek to reduce fatigue and distraction in both office environments -- daylighting, as well as educational multi-use spaces -- noise.

For interior performance and comfort in office environments, our responsive surface optimizes interior lighting levels by constant actuation. Each individual module is set with parameters controlling a mechanical curl ratio mandated by true material allowance uncovered through performative weather data and real-time lighting metrics. For educational multi-use spaces, our responsive surface optimizes interior environments by adapting to the changing reverberation rhythms of voices and footsteps. It can also be parametrically calibrated to a desired acoustic setting, which allows for increasing or decreasing acoustic dampening depending on the needs of the interior space and its occupants.

Additionally, our research is testing the capabilities of an augmented reality design tool, for real-time, immersive data visualization experiences within a virtual space. Through an immersive digital environment, we are able to view a digital prototype in a space at full size. The information visualized and collected assists in the design refinement of our digital prototype. The virtual environment provides a strategic understanding of how the responsive surface responds to multi-sensory input (proximity, light, and sound), as well as how it performs in various spaces.

KEYWORDS: responsive surfaces, multi-sensory, material performance, digital fabrication, immersive environments

INTRODUCTION

The purpose of our responsive surface research begins with the question of whether or not interior spaces can contextually and autonomously respond to its occupants. Artificial intelligence is changing the way many industries function and perform, from information gathering, to self-driving cars. Algorithmic approaches to informed and autonomous decision making is becoming the new normal, and what we should expect for the future (Stanford University 2016). We want to understand how these principles can lead to better scenarios in buildings and spatial typologies. While artificial intelligence doesn't have much of a presence in architecture and interior design, the fundamental ideas of smart building systems are perhaps the building industry's equivalent. Mainstream interests in energy efficiency, renewable energy, and environmental design have been brought to the forefront of architecture. As a result, building control systems leverage the use of environmental data, informing new architectural approaches and outcomes. By responding to environmental factors, this form of autonomous architecture has established a new baseline for energy performance (International Energy Agency 2011).

The aim of our work is not to focus on how to further optimize buildings for energy performance, but how to optimize buildings for occupant performance. We take a creative design approach to contextualizing interior elements that can become autonomous systems. By responding to their immediate interior environment, self-regulating surfaces have the ability to increase occupant performance and overall well-being (The WELL Building Standard v1 2015). With this framework in mind, our research began with responsive surfaces designed to mitigate workplace distractions. As office cultures trend toward collaborative working environments with mobile workstations, office space designs are becoming increasingly open. There is a growing need to mitigate distractions such as solar glare and interrupting noise. Our

research demonstrates efforts to generate examples of potential solutions to these distractions through the use of responsive design elements.
Naturally for us, we are just as much problem-makers as we are problem-solvers. Our means to conceptualize autonomous methods to optimize occupant performance has re-informed our overall design process. As a parallel research effort, we have reasoned with the idea that a data-driven design process will result in a more informed, and overall, a more effective approach to realizing prototypes.

Our early prototypes used parametric software to assist in visualizing our digital assumptions of what distractions might occur, and how to represent our response through design. With the emergence of well-developed virtual reality and augmented reality tools, we are taking our visualization techniques from parametric assumptions, to mixed reality realizations. This method streamlines the prototyping process by evaluating the effectiveness of a digital prototype through multi-sensory experiences and real-time data visualization. By evaluating the specific design parameters needed to visualize responsive data on changing surfaces, a more informed prototype design can be digitally optimized and approved for empirical testing. This paper describes the process we designed to yield efficient and more accurate results.

1.0. USEFUL PURPOSES FOR MULTI-SENSORY RESPONSIVE SURFACES

1.1. Daylight mitigation: FlowerWall

Conceptualized as a response to the sun, FlowerWall (Figure 1) is a responsive surface that optimizes interior environments by adapting to changing outdoor environments. While exploring the physical space that exists between building and nature, the design for this responsive surface was informed by the natural response of phototropic flowers.

For interior performance and comfort, the responsive surface optimizes interior lighting levels by constant actuation. Each individual module is set with parameters controlling a mechanical curl ratio mandated by true material allowance uncovered through performative weather data and real-time lighting metrics.

FlowerWall's array responds to commands from an automated control system based on outdoor weather conditions and interior lighting levels. It can be operated manually by occupants with a smartphone or tablet interface. It can also be seen as an aesthetically pixelized scratch pad where users can doodle with various visual arrangements and consequently a desired privacy level.

For an experiential effect, flowers can be programmed to create dynamic patterns across one single module or an entire surface. Programmed arrays can also provide an interactive response to human proximity, maintaining a one to one scale interface of human and system interaction.

The FlowerWall concept is a prototype that was the springboard for our research. This surface which is activated mechanically with light cables and computer controlled motor actuators, allows unique folding panels to be separately controlled. The panels can be "arranged" to control views and privacy, ventilation, air flow, and strategic sun-shading from morning to afternoon (Figure 2). The tune-able facade optimizes interior environments by adapting to changing outdoor environments. An automated system responds to commands from a smart building control system based on outside weather conditions; it can also be operated manually by the homeowner with a smartphone, or tablet interface.

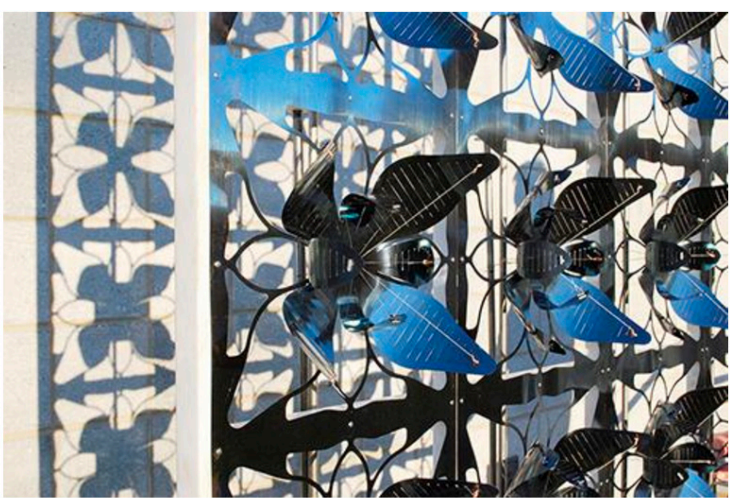

Figure 1: FlowerWall, photograph. Source: (Wagner 2012)

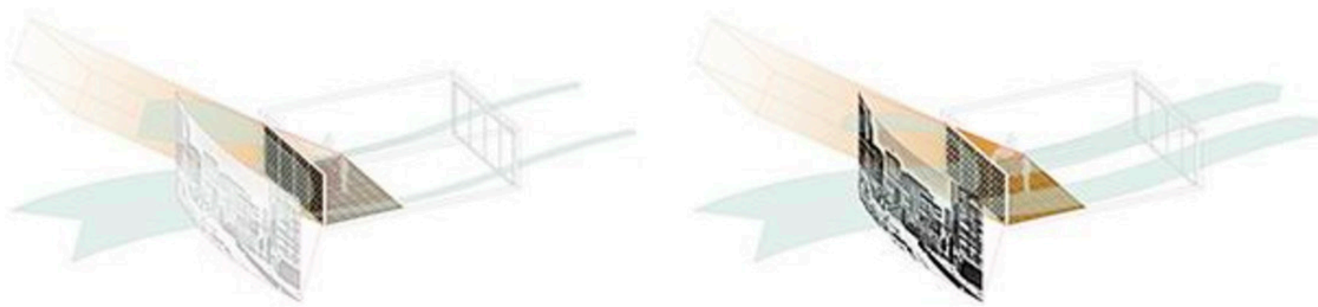

Figure 2: FlowerWall, conceptual diagrams: solar shading, cross ventilation, privacy, views. Source: (Wagner 2014)

1.2. Noise mitigation: AuralSurface

AuralSurface (Figure 3) is inspired by the need to control ambient noise created from everyday life in the office, while also serving as an adjustable separator that maintains a sense of open space. For workplace performance and comfort, the responsive interior surface optimizes interior environments by adapting to the changing reverberation rhythms of voices and footsteps. AuralSurface can also be parametrically calibrated to a desired acoustic setting, which would allow for increasing or decreasing acoustic dampening depending on the needs of the interior space and its occupants.

The WELL Building Institute writes in The WELL Building Standard, "Built environments can harbor sounds that are distracting and disruptive to work or relaxation. Employee surveys show that acoustic problems are a leading source of dissatisfaction within the environmental conditions of an office" (The WELL Building Standard v1 2015, 119).

There is a growing need to mitigate distracting and interrupting noise. Studies show that exposure to noise generated within the building can lead to reduced concentration and mental arithmetic performance, and increased distraction due to reduced speech privacy (The WELL Building Standard v1 2015, 124).

The proposed AuralSurface is an innovative multipurpose intelligent modular tile system designed to dynamically adjust space acoustics, privacy, as well as serve as an adaptable visual enhancement.

AuralSurface seeks to reduce fatigue and stress in the workplace by controlling ambient noise disturbances. Employee fatigue affects their well-being, productivity, and their propensity to commit errors; in addition, one study showed that a three-hour exposure to low-intensity office noise induced a small increase in adrenaline level (Jahncke 2012). AuralSurface's design allows it to autonomously deploy an acoustic material at specific locations when the perceived decibel levels are higher than normal. In addition to a physical response, the acoustic material may be seen as a visual cue once deployed. Those holding conversations may recognize this as a subtle sign to speak more softly or to take a conversation to another area. AuralSurface, a panelized surface, is an otherwise seemingly typical modular system.

AuralSurface's array can respond to commands from an automated control system based on various noise levels, or can be operated manually by occupants with a smartphone or tablet interface. Like the FlowerWall, AuralSurface can also be seen as an aesthetically pixelized scratch pad where users can doodle with various visual arrangements and consequently a desired privacy level, both visually and aurally.

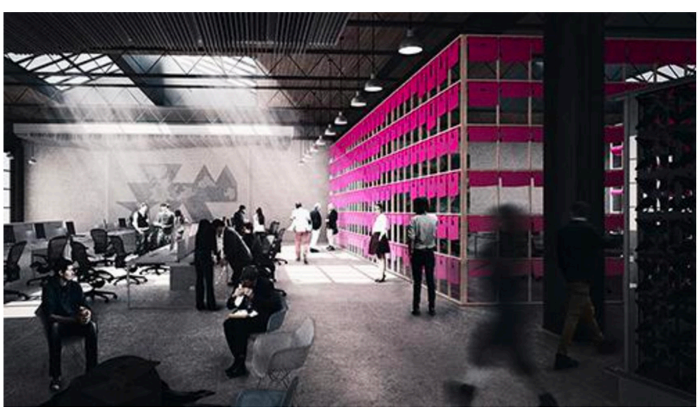

Figure 3: AuralSurface, rendering. Source: (Wagner 2016)

2.0. IMMERSIVE DATA VISUALIZATION

2.1. Re-informing the design process

With the emergence of our parallel research, the use of immersive data visualization along with the development of a responsive surface, gained traction through the idea that we will end up with a more informed design to take into the prototyping phase. Early design iterations were hit or miss when built prototypes, particularly with the FlowerWall project. Our assumptions about the effectiveness of the surface design, as well as the materials, mechanisms, and sensors used, were not evaluated until we had a completed prototype. While each new prototype was fully functional and served a purpose as another proof of concept iteration, our process was not efficient and lacked pre-evaluation assessment. Further elaboration on this is in the following chapter, 3.0. Design Methodology.

2.2. Multi-sensory data channels

Through immersive data visualization, we will be able to evaluate the effectiveness of several design parameters through multi-sensory environmental channels prior to prototyping. For AuralSurface, such parameters include material effectiveness, acoustic properties, surface module design and form optimization, structural framework design, mechanical response time, and scale. Each of these parameters is a factor that influences the outcome of the next one.

One of our design options is evaluating the acoustic absorption impact that felt has. The felt sheet will deploy by unrolling when digital sensors respond to real-time people and voices in the space trigger environmental acoustic decibel sensors (Figure 4). The responsive function of the modular surface will pinpoint the origin point of sound through proximity sensors (Figure 5), and each adjacent panel will have a gradient association: the loudest location will have fully deployed panels, each panel adjacent will be slightly less deployed, etc.

These multi-sensory data channels are both viewed and heard through the augmented reality headset. By adding a graphic layer of data visualization seen through the augmented reality headset, we will be able to not only hear acoustic differences, but also verify the material effectiveness visually with acoustic data. For material effectiveness, we will have the ability to test multiple thicknesses of the felt. We will be able to virtually evaluate 1/8" felt to visualize and experience its effectiveness, and then be able to immediately swap the virtual material data asset to evaluate 1/4" felt.

The study of the responsive surface through an augmented reality headset is only valid for our research when it is calibrated and synchronized with real-time environmental sensors in the space being evaluated.

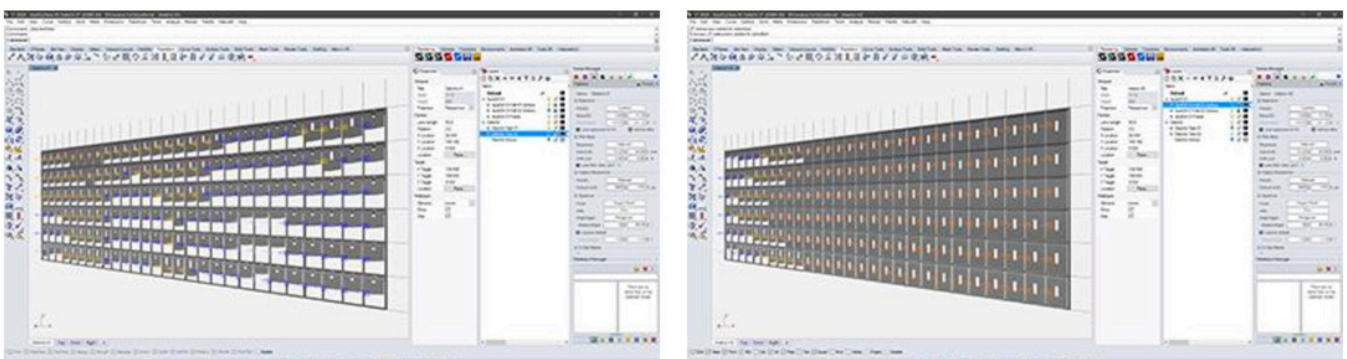

Figure 4: AuralSurface, digital representation of decibel data parameters per panel. Source: (Wagner 2017)

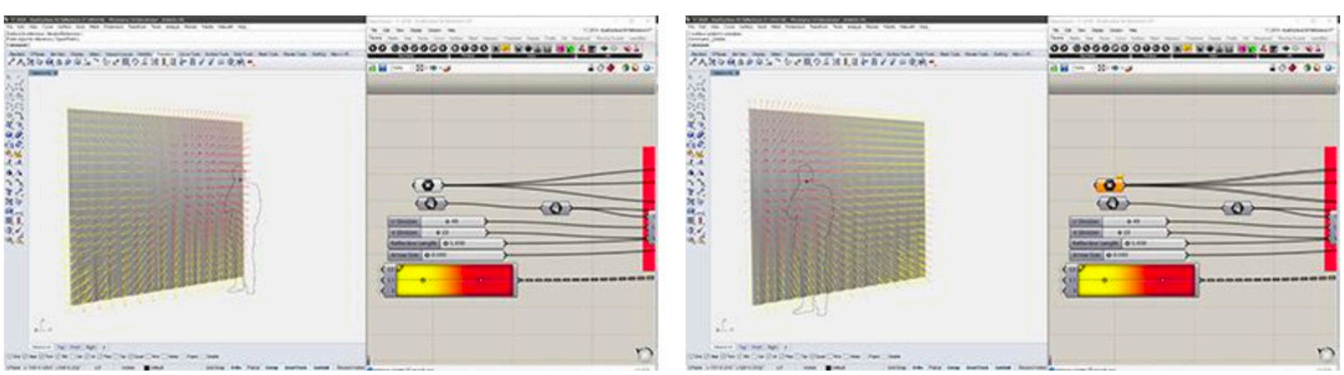

Figure 5: AuralSurface, digital representation of proximity data parameters per surface. Source: (Wagner 2017)

3.0. DESIGN METHODOLOGY

3.1. Parametric analysis

Parametric software was used in early design stages to inform decisions based on assumptions for both conceptual idea and material tolerances. For the FlowerWall, we relied on this method of visualization to understand the curl ratio of spring steel, a material that will maintain its original form without deformation (Figure 6). For AuralSurface, we simulated wavelengths (Figure 7) that represented sound waves to visualize how the surface would respond. With the visual outcome being much of an assumption, we recognized the importance to move forward with the new process of using data visualization in immersive environments.

Figure 6: FlowerWall, digital process in Grasshopper. Source: (Wagner 2012)

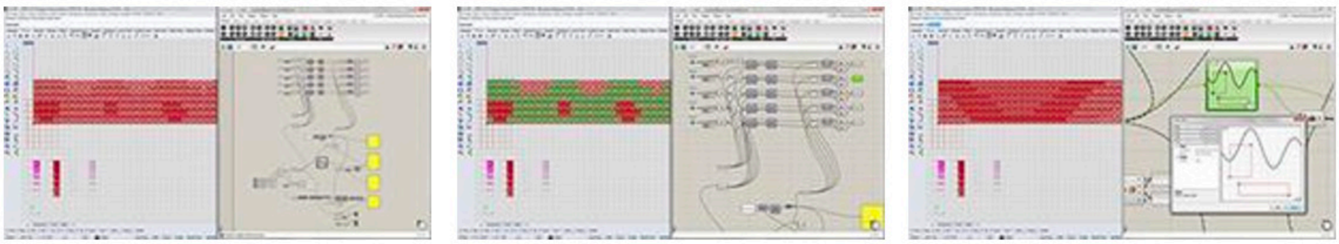

Figure 7: AuralSurface, digital process in Grasshopper. Source: (Wagner 2016)

3.2. Material characteristics

Through performance and evaluation, material characteristics shaped each iteration by revealing tolerances and limitations. As a result, design criteria had to evolve with each prototype. The FlowerWall design adapted to a unique mechanical movement that accommodates solar shading and interior lighting levels by curling an array of flowers CNC laser cut from shape memory spring steel (Figure 8). Each flower consists of petals that are activated mechanically with light cables and electronically controlled motor actuators.

A common research continuum within the design and prototyping stages will be material exploration. We can rely on a variety of materials to each provide different results within our performance criteria. It is our goal as educators, and stewards of this earth, to choose materials that not only help to optimize our research results, but that also come from safe resources. Whether rapidly renewable or recycled and reclaimed, we will strive to make decisions that are best for our environment and promote sustainability (Figure 9).

Figure 8: FlowerWall, photographs: material studies // spring steel. Source: (Wagner 2012)

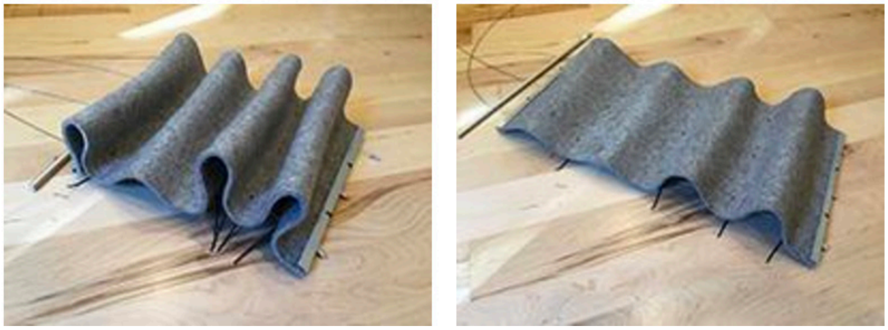

Figure 9: AuralSurface, photographs: material studies // felt. Source: (Wagner 2016)

3.3. Sensors and mechanisms

Digital fabrication tools and technology provided a strategic means for navigating the multitude of forces at play. Serving as the activating link between material research and design innovation, the relationship between the designed object and the forces surrounding that object are always present, perceivable, and tactile. The methodology of this design progressed through a series of focused strategies. Each prototype was created by simple operations, undertaken through a specific disposition, and evaluated for performance potentials. Prior to our re-designed process through the use of immersive environments, early steps were taken to develop various functions of the FlowerWall (Figures 10-15)

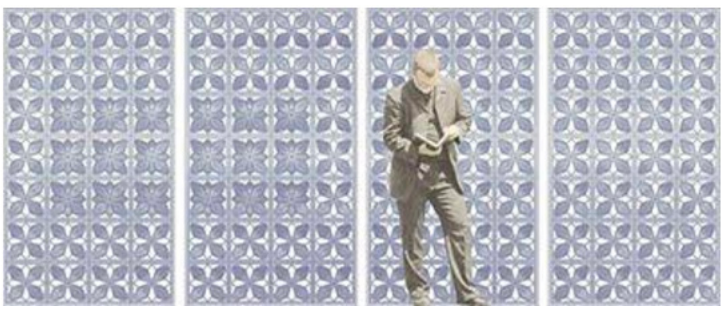

Figure 10: FlowerWall, elevation study: tuning potential // array variation. Source: (Wagner 2014)

Figure 11: FlowerWall, photographs: opening sequence. Source: (Wagner 2012)

Figure 12: FlowerWall, elevation study: tuning potential // column variation. Source: (Wagner 2014)

Figure 13: FlowerWall, photograph: servo motors. Source: (Wagner 2014)

Figure 14: FlowerWall, elevation study: tuning potential // individual variation. Source: (Wagner 2014)

Figure 15: FlowerWall, photograph: stepper motors. Source: (Wagner 2014)

The AuralSurface system is prototyped using the Raspberry Pi computer in conjunction with the Pd-L2Ork (Bukvic 2014) rapid prototyping visual programming environment. This setup offers unique affordances in terms of comprehensive monitoring, adequate computational power, and ability to create an intelligent network of sensors. In order to adjust the audio-visual "porousness" of the AuralSurface, the Raspberry Pi is coupled by an efficient low noise servo motor responsible for coiling the AuralSurface's insulating material. In addition, the system relies on a photoresistor to measure the amount of light and more importantly a two microphones to monitor noise levels in the immediate vicinity on each side of the individual panel. The ensuing system inherently supports WiFi and Bluetooth connectivity that allows for users to actively partake in designing an optimal environment.

There are three modes of interaction: the default autonomous mode, the manual/collaborative mode, and the artistic/installation mode. The autonomous mode allows panels to fold and expand the dampening material based on the observed noise in the immediate vicinity of each individual panel. Based on the default settings, each panel can further respond to provide the desired amount of lighting, as observed by the photoresistors. Inevitably, the two sensory stimuli need to be ordered in terms of precedence to avoid stale-mate-like configurations where the two inputs are at odds and as a result the AuralSurface fails to satisfy either condition.

The manual mode is optional and can be enabled and coordinated through a centralized Raspberry Pi server or a dispatch. Such a node is networked with all the other panels and is capable of providing overriding states. As a result, users can intentionally change the current state of the AuralSurface array by either selecting one of the built-in presets, or by individually and/or collaboratively by altering individual panel states. Lastly, the installation mode focuses on using the environmental data to create a dynamic collage of possible panel arrangements, resulting in an interactive and responsive environment and an architectural space. The ensuing system is low cost, low power, and inherently malleable, including remotely administered software updates and configuration through a custom centralized client that can be run on a remote computer or in a form of a mobile app (Figure 16).

Figure 16: AuralSurface, renderings: surface deployment sequence. Source: (Wagner 2016)

After initial AuralSurface conceptual models were decided upon, the production process moved from a parametric modeling environment into software more conducive to animation and real-time rendering in a virtual environment. A reduced polygon versions of the parametric curtain was modeled in Autodesk's Maya (Figure 17). Deformation of the curtain surface was achieved with the use of a simple joint chain running down the long axis. Nested inverse kinematics handles were used to simplify the animation process while still giving the impression of a folding curtain. Given the limitations of polygon counts for objects used in a game engine like Unity, the animations aim only to be approximations that allow for rapid prototyping of the larger systems. Further version will look to refine the simulation fidelity of the cloth surface within the virtual environment.

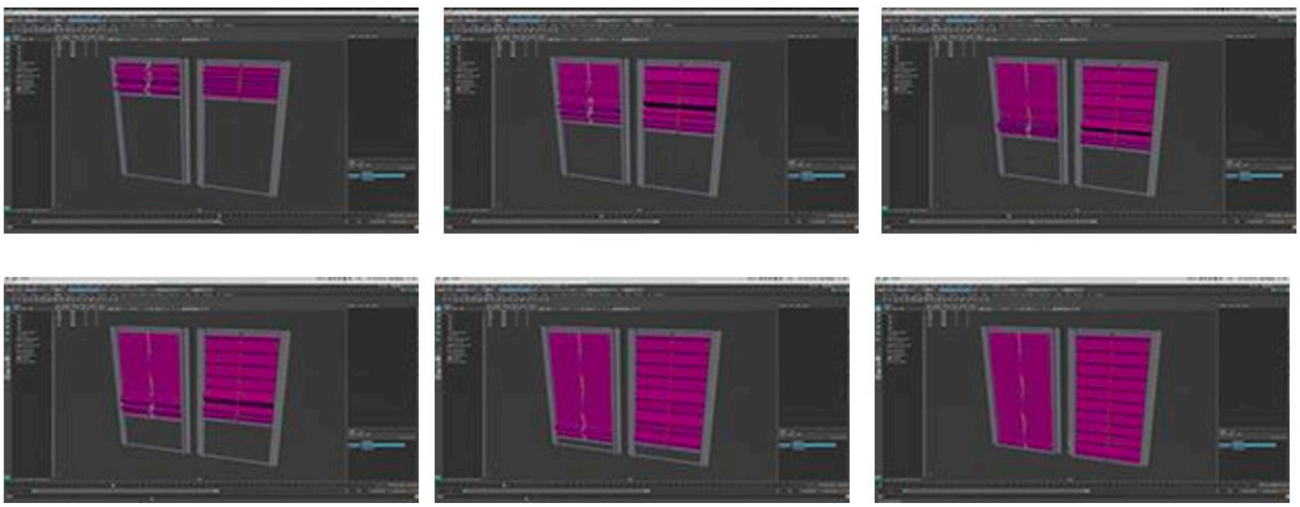

Figure 17: AuralSurface, digital process in Maya: surface deployment simulation. Source: (Webster 2017)

4.0. EVALUATION OF EFFECTIVENESS

4.1. Immersive environments

Our work-in-progress research will be testing the capabilities of a multi-sensory responsive surface (AuralSurface) in existing spaces. We have pinned down two typologies: open office environments, as well as mixed-use educational spaces. We believe there is potential to visit case study environments to understand human interactions and behavior patterns prior to the implementation of AuralSurface. Once we are in location, we hope to find success in studying interactions while viewing the space as an immersive environment through an augmented reality tool such as Microsoft's HoloLens. We are working to program responsive sensors within the digital model that will respond to both human proximity as well as any sound generated from human interactions (Figure 18). The aspect ratio of 16:9 (Kreylos 2015) can be somewhat limiting, but we expect to visualize our results without issue. The immersive environment should provide a better understanding of how the responsive surface responds to multi-sensory input (proximity and sound), as well as how it performs in various spaces.

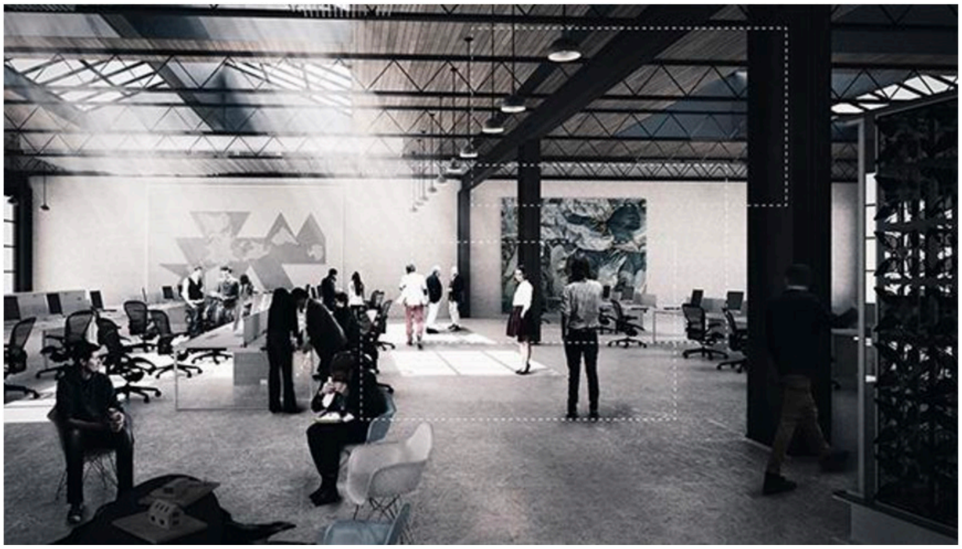

Figure 18: AuralSurface, rendering: immersive environment // existing space. Source: (Wagner 2017)

4.2. Real-time data visualization

We are working to implement an augmented reality design tool for real-time immersive data visualization experiences within existing spaces. Through the immersive environment, we will be able to view a digital prototype in a space at full scale. The data visualized and collected will contribute to the evaluation of our design, which we see as a step toward refinement with our digital prototype that did not previously exist. This approach should streamline the prototyping process by evaluating the effectiveness of a digital prototype through multi-sensory experiences, leading us to a more informed prototype design (Figure 19).

Figure 19: AuralSurface, rendering: real-time visualization // view through HoloLens. Source: (Wagner 2017)

5.0. RESULTS

5.1. Redefined design process

The use of immersive environments will be critical to visualize the effectiveness of AuralSurface as a responsive surface. While the process is still a work-in-progress, the method provides promise for the future of AuralSurface's development. By involving people in real-time behaviour, we are able to see our digital model respond to their actions.

5.2. Empirical testing

Technical feasibility will focus on answering whether it is possible to implement a proof of concept that is capable of scaling. We will assess this based on system's reliability and sturdiness. Something we intend to explore iteratively through the development cycle. Efficacy will focus on prototype's ability to perceptibly alter room acoustics. We will measure this by conducting a series of preliminary audio tests to ascertain the potential impact on the room acoustics. Marketability will focus primarily on the prototype's potential cost overhead in small, medium, and large scale deployments. This data will be used to determine next steps, including potential pursuit of technology transfer opportunities.

5.3. Positive effects on human behavior

This section is reserved for future studies of the AuralSurface prototype implemented in both office environments as well as mixed-use educational spaces.

ACKNOWLEDGEMENTS

The authors would like to thank Joe Wheeler, Robert Dunay, Chip Clark, Denis Gracanin, and Daniel Senning for their contributions to the development of FlowerWall.

REFERENCES

Stanford University. (2016). "One Hundred Year Study on Artificial Intelligence (AI100)," https://ai100.stanford.edu (accessed February 20, 2017).

International Energy Agency. (2011). "Technology Roadmap: Energy-Efficient Buildings: Heating and Cooling Equipment."

International WELL Building Institute. (2015). "The WELL Building Standard v1."

International WELL Building Institute. (2015). "The WELL Building Standard v1." p. 119.

International WELL Building Institute. (2015). "The WELL Building Standard v1." p. 124.

Jahncke, H. (2012). "Cognitive Performance and Restoration in Open-Plan Office Noise. Lulea University of Technology." p. 9-10.

Bukvic, I. I. (2014). "Pd-L2Ork Raspberry Pi Toolkit as a Comprehensive Arduino Alternative in K-12 and Production Scenarios." in NIME. p. 163–166.

Kreylos, O. (2015). "On the road for VR: Microsoft HoloLens at Build 2015, San Francisco." http://doc-ok.org/?p=1223 (accessed September 27, 2016).