Design and Development of Low-Cost Portable Immersive Spaces

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Abstract

In this paper, we will explore the potentials of low-cost portable immersive environments that combine ***textile structures, gesture-based interfaces*** and ***multiple projections***.

Our aim is to develop affordable, easy to setup, portable and inviting immersive spaces that can serve as an interface between a web-based geographic virtual environment, experts and lay people.

In this context, after the introduction, we will review a variety of methods, conceptual tools and materials related to textile tectonics and techniques which can be individually used or combined for the development and construction of portable immersive spaces.

In the next section, we will discuss the opportunities and challenges of using a low-cost gesture-based interface (Kinect) to support "touchless" interactions.

Consequently, we will present the design alternatives of low-cost portable immersive spaces that we have synthesized from our background studies. This will be followed by the observations and findings from our prototype development, implementation and preliminary testing processes.

In conclusion, we will discuss our conclusions and recommendations regarding the future development of low-cost portable immersive spaces.

1 Aims, motivations and approach

One of the major motivations of this study comes from a multidisciplinary research project that aims at creating integrated strategies and tools for the representation and communication of urban design alternatives prepared for the Brussels Capital Region (Pak and Verbeke 2011).

The project involves the preparation of various use case scenarios for facilitating the discussion of future developments through an integrated interface; and furthermore, the development and testing of prototypes that demonstrate the application opportunities and challenges. It is currently being conducted in cooperation with the Brussels Territorial Development Agency (ATO) and Brussels Environment Council (BRAL), two of the major actors responsible for urban planning in the Brussels Capital Region.

As a preliminary result of the project, a Web-based Geographic Virtual Environment Prototype has been developed and implemented. This prototype combines Semantic MediaWiki and Google Earth API for representing textual data, imagery, concepts maps, 3D models and time-based information in a geolocated format (Pak and Verbeke 2010).

During the testing phase of the research project, it became evident that there is a need for ***affordable***, ***easy to setup***, ***portable*** and ***architecturally pleasing*** immersive spaces that can serve as an interface between the suggested virtual environment, experts and lay people. Considering these requirements, these spaces had to be significantly different from the classical Cave Automatic Virtual Environment (CAVE), which dates from 1992. CAVE is a static indoor installation; a carefully engineered and optimized set of software, interaction devices and projection screens assembled inside a specific room (Cruz-Neira 1992).

In contradistinction to classical CAVE applications, we aimed at developing various alternatives of immersive “skins” reinforced with low-cost hardware and software, which can be transported, set up and used as temporary outdoor or indoor installations.

In this context, we wanted to explore the potentials of ***textile structures*** to be used as a framework for these environments. A variety of methods, conceptual tools and materials related to textile tectonics and techniques can be individually used or combined for the development and construction of portable immersive spaces. In Section 2, we will briefly review these.

Furthermore, we envisioned to utilize a ***low-cost gesture-based interface (Kinect)*** to support “touchless” interactions. Kinect interface can efficiently sense the natural movements of the human body. However, Kinect is not designed as a "CAVE specific input device" and it has not been thoroughly tested outside the Xbox platform. Further evaluation and development is required for guaranteeing efficient, effective and reliable interactions. In Section 3, we will briefly review our studies and findings relating to these topics.

In section 4, we will present the design alternatives of low-cost portable immersive spaces that we have synthesized from our background studies.

Consequently, in section 5, we will share our experiences, observations and findings from prototype development, implementation and preliminary testing processes. This section will be followed by the discussion of conclusions and future opportunities.

It is important to note that the application possibilities of low-cost portable immersive spaces are not only limited to representation and communication of urban design alternatives to lay people and experts. They can be used in a wide range of areas.

Some of the possible use case scenarios can be listed as:

- An outdoor immersive environment to be used as an information medium
- An easy-to-set-up immersive membrane for on-site architectural visualizations
- An indoor immersive environment for gaming

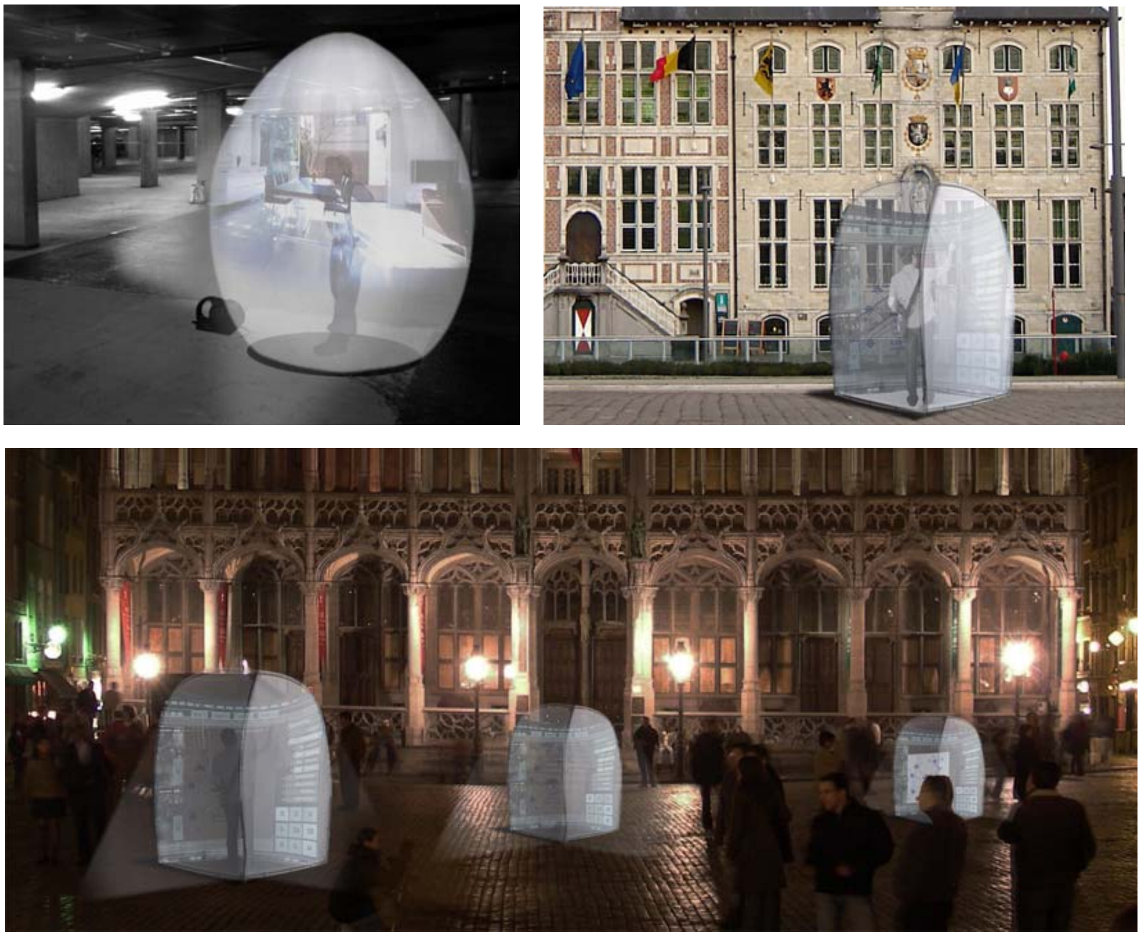

Figure 1. Preliminary illustrations representing two of the use case scenarios (On the top left an inflatable structure for on-site architectural visualizations; on the top right and bottom, an outdoor immersive environment)

2 Portable Textile Structures as a Thin Interface between the Virtual and Real Environments

Historically used as projection screens, textile structures are lightweight and highly adaptable. They can also be shaped into complex double curved surfaces. In this sense, qualities of the textiles structures fit well into the design problem of building portable immersive spaces.

A comprehensive background review on textiles reveals that we can distinguish between three major topics: textile tectonics, textile techniques and textile products (Vrouwe et al. 2011).

Textile tectonics can be considered as ways in which multiple fibers, interlock into a collective whole with "a shared intelligence" (Bell 2004). ***Weaving, knitting and knotting*** are examples of textile tectonics. Textile techniques, on the other hand, are techniques through which textile tectonics can be processed. ***Patterning, folding and pleating*** are examples of these techniques.

Both textile tectonics and techniques are ***material independent***, which makes them open for innovation and materialization in a contemporary manner. Some of the techniques are ***constructively independent*** and demand a structural support to be erected. For instance¸ ***knitted and knotted surfaces*** require structural support around their borders.

In this context, ***weaving*** stands out as a key tectonic for constructing portable immersive spaces due to its self supporting quality. The woven fibers interlock loosely and create a semi-open surface that reduces the weight of the structure and allows light and projection beam(s) to pass through (Bell 2004).

A variety of membranes can be used to maximize the portability of ***immersive spaces***. These membranes are ***constructively dependent*** and can be pneumatically tensioned (inflatables) or supported by an external structure. Furthermore, the use of ***double curved geometries*** can contribute to an even distribution of illumination on the projection surface, especially in big scale applications.

As an alternate strategy, it is possible to ***reframe*** existing structural frameworks (introduced by Engel 1998) and specific textile techniques. For instance, anticlastic ***form-active systems*** can be reframed into ***patchwork frameworks*** to create a double curved geometry by smaller square elements (Vrouwe et al. 2011) (Figure 2).

Another important issue to be addressed is the optimization of the building geometry, which plays a vital role in the development of projection surfaces. Ideally, when considering the requirements of the immersive spaces, the surface geometry should facilitate the uniform projection of the beams. For instance, a curved surface can be bended in single radii to eliminate excessive visual corrections and its materialization should be seamless to avoid disturbing distortion in the projection itself.

Unfortunately in most architectural structures, especially portable variants, joints and material seams are unavoidable. In portable structures, transportable parts are connected by seams; which limits the size of the individual surface components. Similar to clothing, desired developable shapes can be cut out of the building material and assembled together by joints and seams to create a whole.

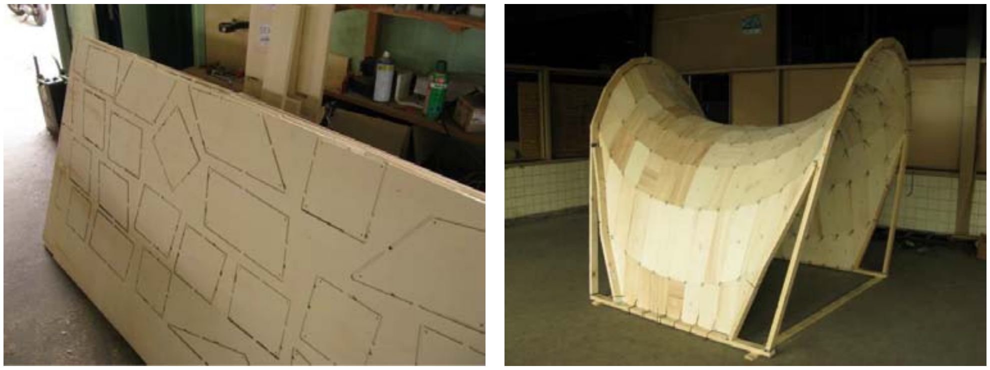

Figure 2. A form active membrane structure, built with solid components. Similar to clothing, desired developable shapes can be cut out of the building material and assembled together by joints and seams to create a whole (Vrouwe et al. 2011).

In order to avoid seams to interfere with the projection, using contemporary production techniques and structural systems is essential. Following the ***"file-to factory"*** method can reduce production errors and spaces between the seams, making them almost invisible. Joints can be smaller and therefore less visible and less difficult to implement with a reduced error margin during the positioning and assembly processes (Sopeoglou 2007).

We combined various methods, conceptual tools and materials that are referenced above and created five low-cost alternative structures for realizing immersive spaces. These designs will be presented in section 4.

3 Gesture-based Interfaces and Immersive Environments: towards Ubiquitous Spaces

Gesture-based interfaces integrated with advanced visualizations can lead to the development of novel immersive "event-spaces". These points of attraction can be connected to the global information cloud and become context-aware ubiquitous environments of the future.

For public use, gesture-based interfaces have enormous potential because they do not require the users to wear gloves or utilize other controllers. When combined with immersive visualizations, gesture-based interfaces can give way to new public environments for information sharing, communication and decision making.

Currently, various research institutions are working on developing prototypes that combine immersive visualizations and gesture-based interfaces.

The most relevant one to this paper is the prototype that Microsoft Research presented in the ACM Interactive Tabletops and Surfaces 2010 Conference. Through this prototype, Benko and Wilson (2010) tested the use of a wide-angle projector bundled with an infrared camera that can recognize hand gestures. This system projects tilted omnidirectional images on the interior of an inflatable dome, creating an interactive immersive experience. It is apparent that Microsoft Research's prototype has various potentials to be improved further by incorporating advanced sensors.

For the future development of gesture-based immersive space prototypes, Kinect sensor stands out as an affordable, advanced and effective alternative. Recently, a variety of open source software, libraries and drivers are made available to the public (Primesense 2011)(OpenNI 2011)(Kinect for Windows SDK Beta 2011). Through these software, it is possible to map the depth readings of the Kinect's infrared sensor to specific input commands and use them to control regular interfaces.

Notable and recent uses of these functionalities are the applications developed in the framework of SmartGeometry 2011 “interacting with the city workshop cluster”. During these workshops, the participants have created various “multidimensional tangible table prototypes” and an interactive augmented reality environment that combines Kinect and online data sources (Jaworski, Salim and Kaftan 2011). These valuable applications do not necessarily aim gesture-based interactions, but include functionalities related to the real-time mapping and superposition of physical object transformations onto the virtual ones (and vice versa).

4 Immersive Skin Designs and Concepts

We have defined an initial set of requirements for a skin or structure to be transportable and portable:

- The structure’s parts have to be carried by a maximum of two people
- The structure has to be erected by a maximum of two people
- The structure has to be erected in a maximum of 90 minutes.

Based on these requirements and our background research on immersive environments, gesture-based interfaces and textile structures, we have created five design alternatives to be built and tested (Figure 3). These alternatives mainly focus on the desibn of the immersive surface and its structural support.

Due to cost limitations, the design alternatives are planned to work with 3 or 4 projection devices that generate seamless panoramic visualizations (Figure 4).

Alternative a1 employs an inflatable structure as a beaming surface. It is supported by a fiberglass frame to avoid deflation while entering and exiting the space, sealed with an airtight zipper.

Alternative a2 is the most lightweight and easy to setup variant. It is a ***form active*** structure tensioned by fiberglass supports that connects two fiberglass rings on the bottom and the top of the membrane.

Alternative a3 combines a retractable wooden woven structure with a membrane lining which provides a surface for inside-out projection.

In ***alternative a4***, polyvinylchloride (PVC) sheets are shaped in a shell form to create a self supporting and stiff surface structure. These sheets can be rolled, transported and stored easily. On the top and bottom, there is a steel ring for fast assembly.

Alternative a5 is a form-active membrane structure, built with faceted PVC sheets. Borders are stiffened by steel tubing. This surface construction is derived from a recent study by Vrouwe et al (2011) reframing anticlastic form-active systems into patchwork frameworks.

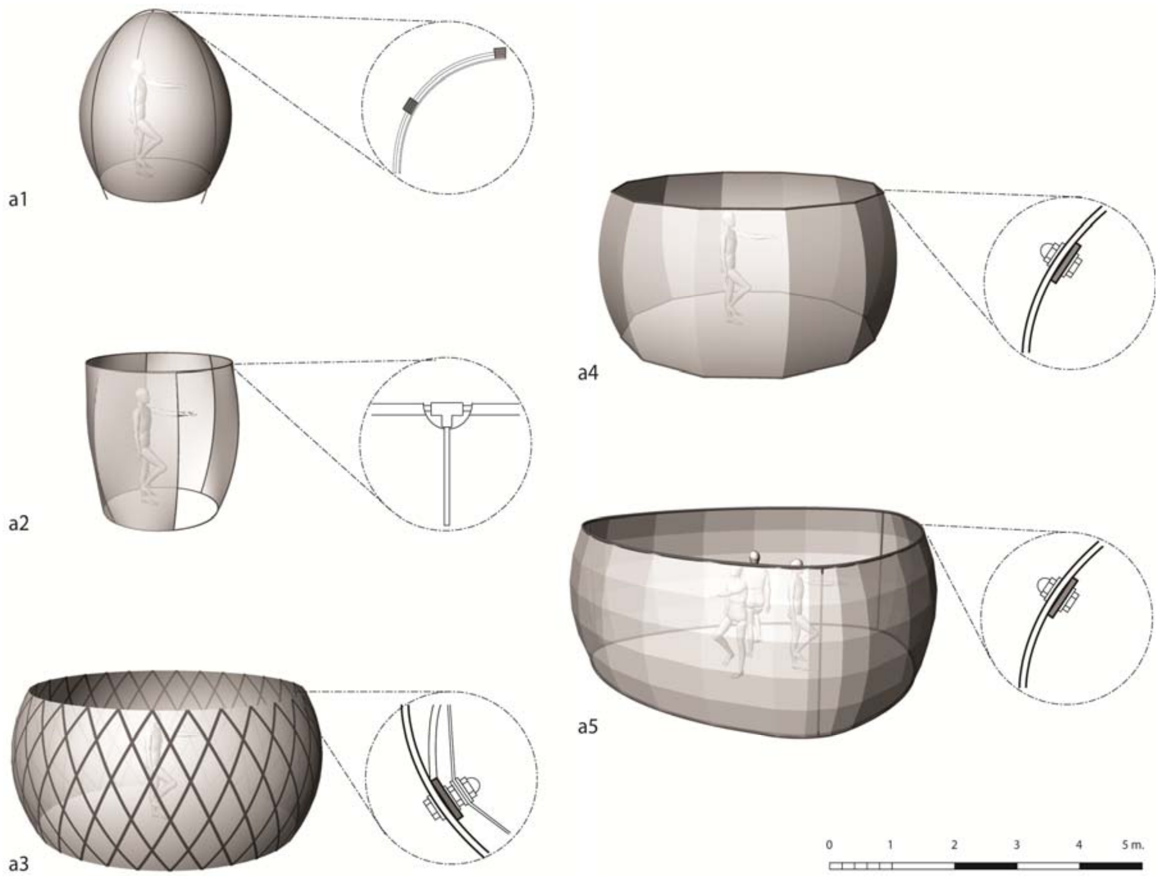

Figure 3. Immersive Textile skin alternatives

In addition, we have developed two alternative setups that combine textile structures, projections and the Kinect motion sensor (Figure 4). The number of projections can be adjusted according to budget requirements. Alternatives a4 and a5 can be used with back or front projections whereas alternatives a1 and a2 are designed to work with back projections. Alternative a3 support only front (inside-out) projections.

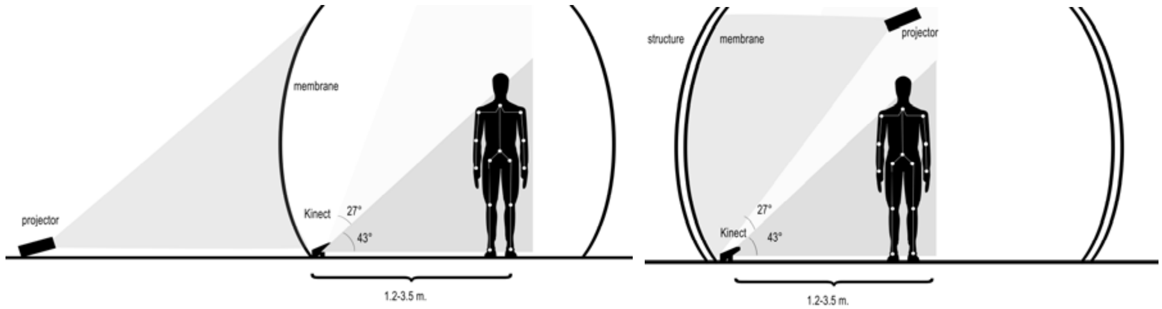

Figure 4. Two alternative setups of portable immersive environments that combine textile structures, projections and the Kinect sensor.

5 Prototype Development and Preliminary Tests: Experiences, Observations and Findings

The development of low-cost immersive environments that support gesture-based interfaces is a complex and challenging task because it involves integration and testing a wide range of technologies and architectural concepts. These technologies and concepts have to be individually reliable: the gesture-based interface should function properly and be usable; the proposed architecture structure should be inviting and structurally sound; and, moreover, the immersive projections should be seamless and free from distortions.

Among the technologies, designing gesture-based systems stands out as challenging task. We chose Kinect motion sensor as a basis for our research because of its availability and low cost, but Kinect is not designed as a "CAVE specific input device". Further experimentation is definitely needed for exploring the opportunities of integrating Kinect into immersive spaces.

Kinect interface development inevitably involves mapping certain gestures to certain functionalities; which in itself is a separate design process. There is no standard gesture language in existence yet, but there are various systems and technologies that have implemented gesture-based interfaces.

In this context, we have collected a set of gestures for basic interaction functionalities based on various gesture-based libraries (Xbox 360, Microsoft Surface, Apple Multi touch Systems and GestureWorks Open Source Gesture Libraries) with the purpose of using them as a basis for interactions that will take place in our low-cost immersive space (Figure 5).

Of course, like many other experimental gesture-based realization, a brief (automated) introduction session was needed to inform the users about the use conventions and gestures. At this point, we faced an important question regarding the memorability of gestures in relation to the perceived acceptability of them (acceptability here refers to the users' self declared willingness to an individual gesture in the future).

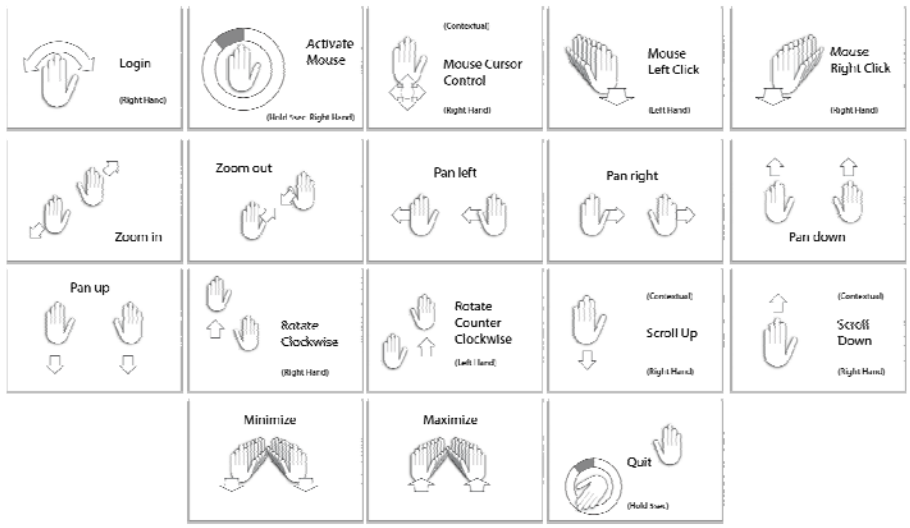

Figure 5. A collection of two handed gestures for basic interface functionalities based on Xbox 360, Microsoft Surface, Apple Systems and GestureWorks Libraries.

With this motivation, we have initiated an (ongoing) short experiment with students, faculty and staff members of Sint-Lucas School of Architecture to test the "memorability" and "perceived acceptability" of the gesture set by presenting the illustrations depicting these gestures to subjects (15 seconds each) and asking them to report what they remember (these illustrations were shuffled after each experiment for minimizing primacy and recency effects). These reports are ranked by the experimenter as: remembers (3), partially remembers (2) and forgets (1).

Moreover, right after the presentation, we asked them whether they would like to use each gesture in the future. At the time of paper submission, 15 people have taken the experiment. The initial results of this experiment show that users were able to remember at least 79.55 percent of the gestures (Figure 6).

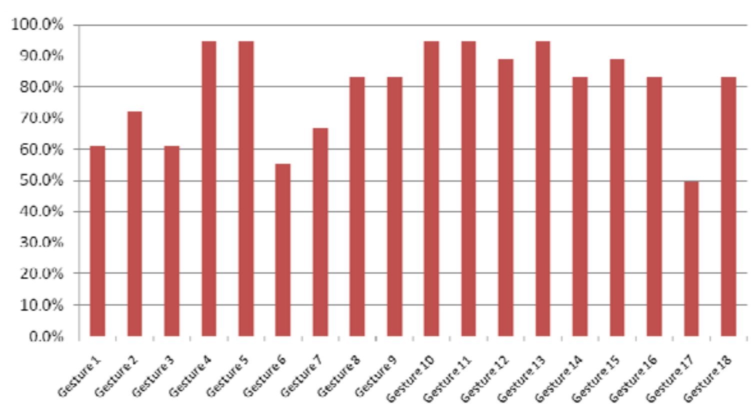

Figure 6. Testing memorability of the gestures: Average memorability of the gestures right after the experiment.

These results are encouraging for the future use of gesture-based interfaces with the proposed set of gestures, but the experiment needs to be extended further.

Our other observations show that some of the common gestures like zoom in and zoom out scored surprisingly low in the memorability test. This may be due to the difficulty in users' translating finger gestures into hand gestures. We also noted that gestures that relate to real life (like pan left, right, up and down) were the most memorable ones.

The preliminary analysis results show no correlation between the "perceived acceptability" of the gestures and the "memorability" of them but more tests should be conducted to come to a concrete conclusion. Furthermore, during these tests we observed that besides many other individual factors, the participants' acquaintance with multitouch devices (naturally) play an important role in their performances (this may be a subject of a future study).

Figure 7. Testing the usability of Kinect sensor, OpenNI framework and PrimeSense OpenNI-compliant component with a web-based virtual environment

As an attempt to test the usability of Kinect interfaces with web-based virtual environments, we have conducted a usability test with 11 users. This test involved a task-based analysis followed by a user satisfaction questionnaire and a short interview. The technology used in this test was based on OpenNI framework combined with PrimeSense OpenNI-compliant component. The interface that is tested is a web application hybrid that integrates a Mediawiki integrated google map with an information window and "layers" that can be turned on and off.

In the task analysis process, users were given basic tasks and were asked to perform them. These tasks included: launching a link, turning on and off a layer, launching an info box on a google map and reading a simple scrollable text box.

The evaluation results illustrate that the total amount of time spent to complete the whole set of tasks ranged from 37 seconds to 217 seconds with an average of 90.36 seconds. The same task set can be executed in 25 seconds with a mouse.

Moreover, we have recorded an average of 1.54 user errors per session (the whole task set). This is relatively high when considering the performance of off-the-shelf interfaces.

In addition, a system error was noted on one out of two task sessions, which also points out to the premature status of the Kinect sensor, OpenNI framework and PrimeSense OpenNI-compliant component. However, all the users were able to complete the tasks, a finding which suggests that the ***interface is effective but not so efficient***. We believe that the system errors can be decreased to a certain point by optimizing the response times and rates of the Kinect sensor.

Despite the system errors, more than 67 percent of the users strongly agreed that they were satisfied with the ease of completion and 59 percent were highly satisfied with the time it took to complete the tasks.

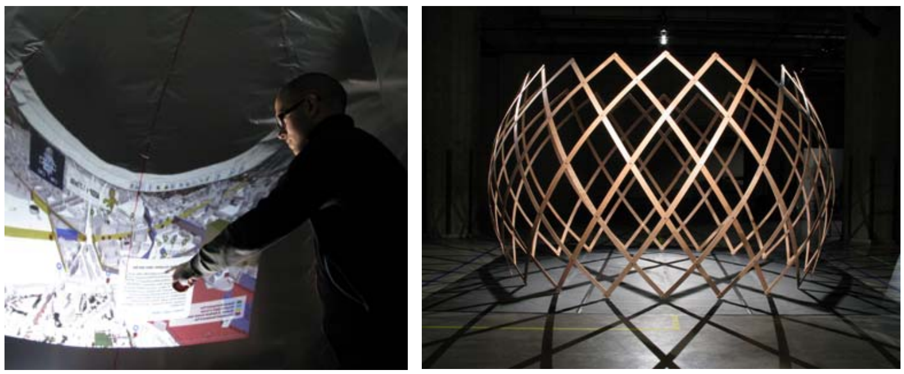

Figure 8. Preliminary implementations: Alternative a1 (on the left) and the structure of alternative a3 (on the right).

After testing gesture-based interfaces, we built two of the design alternatives that we have referenced in section 3 (alternatives a1 and a2) (Figure 8), and fully implemented alternative a2. The preliminary test results show that all of the alternatives are lightweight and can be erected with two people in less than 90 minutes. Moreover, the overall cost was less than 2500 Euros including the projection devices, a Kinect sensor, a high performance computer and other costs (this amount does not cover weather proofing and installation costs).

Our experiences with alternative a2 suggest that the Kinect sensor can work effectively in an immersive space, without the interference of the projection lights and reflections. This result comes from the powerful three dimensional scanner which can differentiate between the moving objects at different depths.

The back projection technique was disturbing to the users due to the low quality of the transparent textile material that was used for testing. We partially solved this problem by tilting the image vertically while keeping the projection device parallel to the ground. Currently, we are testing other materials that are both transparent and support high quality back projection.

For warping, image correction and soft edge blending, we used immersive display designer demo software during the implementation process of alternative a2. By using this tool we were able to create a relatively acceptable immersive experience (Figure 9).

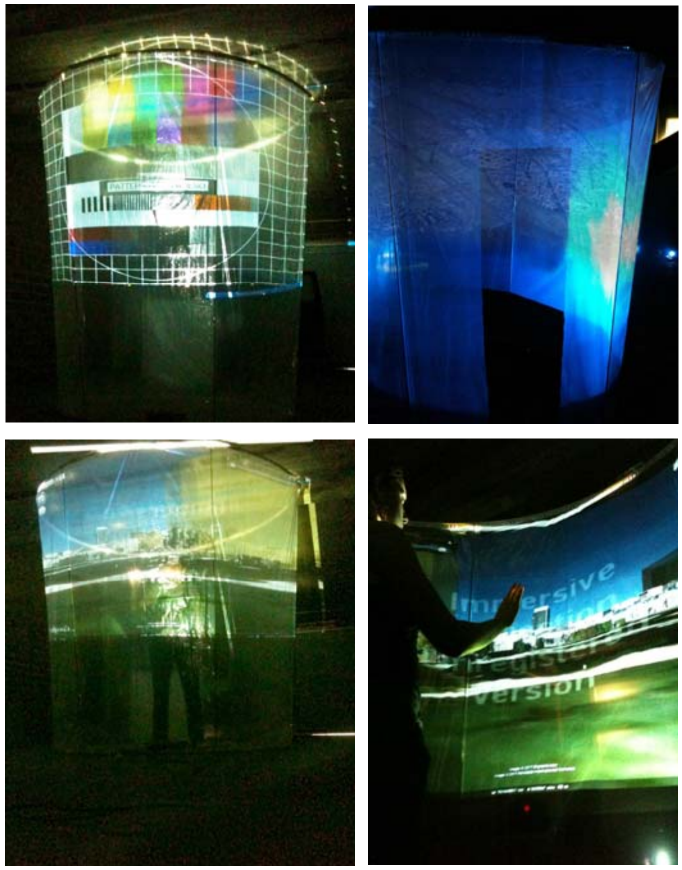

Figure 9. Implementation and preliminary testing of Alternative a2: calibration, image correction and interaction.

6 Conclusions and Future Recommendations

In this paper, we have reviewed a variety of methods, conceptual tools and materials related to textile tectonics and techniques which can be individually used or combined for the development and construction of portable immersive spaces. In addition, we have discussed the opportunities and challenges of using a low-cost gesture-based interface (Kinect) to support "touchless" interactions. We also presented five design alternatives of low-cost portable immersive spaces that we have synthesized from our background studies and shared observations from our prototype development, implementation and preliminary testing processes from three of these alternatives.

Our usability studies illustrated that Kinect as a gesture-based system is an effective tool when used with the OpenNI framework and PrimeSense OpenNI-compliant component. The experiences with the fully implemented alternative a2 suggest that the Kinect sensor can work ***effectively*** in an immersive space, without the interference of the projection lights and reflections. The test users were able to complete all of the tasks assigned to them.

On the other hand, the interface was not so ***efficient*** due to a high number of system errors which points out to the premature status of the OpenNI framework. However, despite the system errors, the majority of the users were ***satisfied*** with the ***ease of completion*** and ***the time it took to complete the given tasks***. This positivity can be attributed to the extraordinary experiences offered by gesture-based interactions.

We are currently testing the Microsoft Kinect SDK Beta which provides more opportunities for interface development and mapping. We will repeat the same test with this kit and compare the results in the future. With the Microsoft's SDK Alpha release, it is not hard to see that a huge number of applications will be available for designers and researchers soon.

The initial test results reported in this paper can be taken as a proof of concept for developing low-cost portable immersive spaces that combine Kinect gesture-based sensors, multiple projections and textile structures. It was possible to create an exciting immersive experience under 2500 EUR (~3580 USD). One of the biggest difficulties for the further development of low-cost outdoor versions of these spaces is weather proofing. Proper insulation, protection of electronics and making the structures wind-proof is expected to significantly increase this cost.

In conclusion, designing and testing gesture-based immersive spaces are complex and challenging tasks. This study can be taken as a report on work in progress, which may inspire future developments. We believe that gesture-based interfaces combined with immersive visualizations have enormous potentials and such immersive spaces can give way to new public environments for information sharing, communication and decision making.

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