Archeology, Museums and Haptics: TITA (Tangible Interactive Table for Archeology)

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The proliferation of virtual museums, on line and built inside a museum's collections, stimulates new challenges for research and public education. This happens through multimodal applications and methods, such as augmented reality, virtual storytelling, virtual reality, computer graphics and haptic applications. This paper discusses a haptic approach with a hybrid solution, able to virtualize tangible objects in a physical space and digital models in a cyber space. The main goal of this approach is to propose alternative ways to experience an object, an artifact, a site or an entire collection. In particular, the hands-on experience is very important, for having tangible feedback from objects and to generate a visual narrative, by touching and combining physical/virtual interaction simultaneously, to customize the visit according to the experience and empathy generated by the unique artifacts. The Tangible Interactive Table for Archeology (TITA) is a open-source prototype of a digital-haptic device, designed for museums and in general for the digital communication of archaeological artifacts, monuments and sites. The intention is to lower the bar of entry for this type of technology in the cultural heritage community, to enable further research and exploration of its affordances, by initiating a community open design project, which provides the digital fabrication files and specifications to produce, test, extend and hybridize such a device, and mechanisms for sharing mutual hardware and software development projects. Such efforts to combine virtual reality and tangible 3d printed artifacts, also entails a rethinking of the production pipeline of digitally reconstructing 3d environments and their constituent elements, where 3d digital models need to be at turns both "light-weight", visually accurate yet low-poly for real-time, game engine applications, and high-fidelity and well formed as 3d printed artifacts.

• Human Centered Computing→Haptic Devices • Human Centered Computing→Visualization • Human Centered Computing→Virtual Reality • Human Centered Computing→Collaborative Interaction • Applied Computing→Interactive Learning Environments • Applied Computing→Arts and Humanities.

Additional Key Words and Phrases: Open-source design, digital fabrication, tangible user interface, interactive tabletop, DIY, maker space, cultural heritage, digital humanities, archeology, museum exhibition, computer vision

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INTRODUCTION

The proliferation of virtual museums, on line and built inside a museum's collections, stimulates new challenges for research and public education. This happens through multimodal applications and methods, such as augmented reality, virtual storytelling, virtual reality, computer graphics and haptic applications. This paper discusses a haptic approach with a hybrid solution, able to virtualize tangible objects in a physical space and digital models in a cyber space. This is the main goal of the TITA project (Tangible Interactive Table for Archeology), a collaborative research project entirely designed and produced at Duke University thanks to the sponsorship of Duke Digital Initiative (DDI). The Tangible Interactive Table for Archeology is a prototype of a digital-haptic device designed for museums and in general for the digital communication of archaeological artifacts, monuments and

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sites. This project is part of a larger international initiative of collaboration between Duke and several Italian public and philanthropic institutions for the creation of a Virtual Museum of the Roman city of Regium Lepidi (I-III cent. AD), now Reggio Emilia (Italy). Improvement and standardization of TITA will allow us, in the future, to extend the current system to different kinds of applications and digital content. The main goal of this approach is to propose alternative ways to experience an object, an artifact, a site or an entire collection. For example, archaeological museums need to re-contextualize objects and their space/time relationship otherwise they are not understandable. In particular, the hands-on experience is very important, for having tangible feedback from objects and to generate a visual narrative, by touching and combining physical/digital interaction simultaneously.

The success of hands-on sessions in several prominent museums, such as the Louvre and the British Museum, for example, show the importance of creating a visual and tangible narrative focusing on specific objects. In this way the targeted audience is able to generate its own narrative and to customize the visit according to the experience/empathy generated by the unique artifacts. The Chess Project (Cultural Heritage Experiences through Socio-personal Interactions and Storytelling), at the Acropolis Museum of Athens, for instance, was entirely designed for the creation of a visual narrative and storytelling linked with specific sculptures (Korai) and artifacts, and it is a very successful example of museum digital narrative [Katifori et al. 2014].

TITA

The Tangible Interactive Table for Archeology (TITA) is an open-source hardware design of a digital-haptic (touch) device, intended for museums, and in general for the digital communication of archeological artifacts, monuments and sites, and art objects broadly. The aim is for the table to provide a unique and engaging interface between the museum visitor, and the breadth of digital content, modeled artifacts and virtual environments, being collected, hypothesized, and communicated by archeologists and other researchers, using the intrinsic affordances provided through interacting with physical objects and touch-based engagement [Kirsh 2010] (Fig. 1)(Fig. 2).

TITA is being developed as a very versatile platform and once deployed, it could work with different digital content (not just archeology). The haptic/multitouch surface, associated signage and tangible objects, could be easily swapped out for other exhibition materials, and thus has broad applicability for the presentation of educational, curatorial or entertainment content, across disciplines. Furthermore, as an open making project, where all digital fabrication files are shared with the museum, academic and hobbyist communities, it offers the potential for community testing of the platform, refinement, extensibility, mutation and dispersal.

Fig. 1. Approaching table, vertical display augments tabletop interaction.

Fig. 2. Tangible/multi-touch interaction surface, tangible trays and illuminated signage.

Within the museum setting, tabletop-based tangible interaction is not new [Hornecker 2005][Patten et al. 2006][Shaer and Hornecker 2010]. Such projects are usually developed on specialized, often prohibitively costly, commercial hardware (infrared optical tracking displays such as the Microsoft PixelSense [Pixelsense 2016], Multitaction MT Cell [Multitaction 2016] or commercial tangible interaction tables such as Reactable [Reactable 2016]), or are produced as "one-off" projects, with custom display and cabinet designs and unique tracking configurations. Custom projects leverage highly specialized design, fabrication, technology integration and programming skills, and access to workshop space and a wide range of tools and equipment, which are often unavailable to many exhibition development groups and cultural heritage research laboratories. Such lack of access to this technology has limited the exploration of tangible interfaces and their affordances in the digital humanities and cultural heritage communities.

Partially mitigating this problem, numerous open-source software projects have been developed in the last fifteen years, which provide the communications and interface protocols (TUIO/OSC [TUIO 2016][Kaltenbrunner et al. 2005], for example) and computer-vision frameworks (Reactivision [reacTIVision 2016][Kaltenbrunner and Bencina. 2007], CCV [CCV 2016] and Bullseye [Klokmose et al. 2014]), to support tabletop-based tangible tracking, interactivity and experimentation. Such initiatives are mature enough to be considered standard tools for the interaction design communities. Game engines such as Unity3D or Unreal Engine, or software development frameworks such as Qt, Processing, OpenFrameworks, Touch Designer and Max/MSP, among others, provide TUIO/OSC client interfaces to receive and use the multi-touch, fiducial marker or shape tracking information for the unique applications being developed. Utilization of these open-source projects has allowed numerous communities to develop and experiment with new modes of interactivity, without huge financial investment, or the development restrictions imposed when using closed, proprietary technologies.

The TITA project was initiated to provide an open-source hardware, software and enclosure design and set of equipment specifications and instructions for building a tangible interaction device, without the need to start from scratch, in order to greater leverage preexisting NUI (natural user interface) software development. In many ways, it is just the start of a community effort to design, engineer and develop a range of open-source hardware projects, which explore and support emerging tangible interaction paradigms in the cultural heritage and digital humanities space.

As a general philosophy, TITA is being engineered for ease of fabrication and low-cost, specifying manufacturing techniques, materials and software that would be readily available to your average "digital maker" (assuming someone has access to a laser cutter or CNC router, 3d printer and basic hand and electronics tools). The initial prototype was sized, based upon the cutting bed of the digital fabrication technology used in our research laboratory, a laser cutter (an Epilog Fusion, with a 32" x 20" bed). The same basic design could be scaled up parametrically, depending upon the availability of more sizable fabrication tools (especially CNC routers) in order to accommodate a table with a larger interactive surface.

All fabrication materials used in the design can be obtained from local "big-box" home improvement stores, excepting the electronic components, touch surface material and projection mirror(s), which are specified from a list of online-vendors. The targeted fabrication cost, including the computer, projector and tracking camera(s), excluding labor or "sweat equity", is currently approximately one third that of a commercial tangible display, which can be further significantly reduced through the repurposing of pre-existing equipment or fabrication materials.

In the long-term, the TITA project is being developed to support a broad range of applications and permutations. A future iteration will be mobile, self-contained and lightweight, allowing the table to be easily moved into varied environments, from museum and gallery settings, to public lobbies and the classroom/laboratory. The initial prototype is designed to be a finished, visually attractive museum interface and display -- while it is not “portable” (it’s the size and heft of a lightweight, short podium), it can be easily disassembled into component parts, and packed into a small volume for shipping.

In a general sense, the project offers numerous opportunities for researchers, students, designers and interested makers to participate in an active collaborative design project, which crosses multiple domains—archeology/art and the digital communication of its artifacts, software engineering, computer vision techniques, digital design and fabrication technologies, open source communities, etc. – and thus represents the type of interdisciplinary collaborative effort that is the hallmark of the emerging maker culture and new models of 21st century engaged learning and research [Williams et al. 2012].

STATE OF THE ART

As previously mentioned, there are currently a number of commercial, optical-based tangible interaction displays and tables. Additionally, there has been research and development with tangible object tracking using standard projected capacitive-touch displays (PCT, the most common touch technology). There are a number of groups that have developed tangible tracking systems with PCTs, which use passive spatial tags (a unique touch pattern), or actively modulated, time-base, touch frequency tags (using embedded, powered microcircuits in objects, which allows actuated touches) [Yu et. al. 2011]. A related project uses PCTs and a microcircuit-enabled tangible, additionally integrating an optical sensor and active communication (Bluetooth) between the tangible and the tracking computer, to provide accurate, very low latency tracking [Voelker et al. 2015].

Vision-based, markerless tracking of physical objects using 3d (RGBD) techniques, enabled via depth cameras, have been used actively since Intel’s Project Oasis (2011) [Project Oasis 2011] and the release of the Microsoft Kinect and the associated KinectFusion project [Izadi et al. 2011] . Non-3d image-based object tracking has been prevalent for augmented reality (AR) applications, using commercial AR toolkits such as Vuforia, Metaio (acquired by Apple), and Wikitude, or open-source projects such as ARToolkit. Such techniques inherently have difficulty with variable light conditions (especially in low-light museum spaces) and object occlusion (where objects overlap or hands hide objects).

Interesting emerging projects using active real-time 3d scanning of physical objects and the environment, to provide enhanced augmented reality experiences (and potential tangible interactivity) include Microsoft’s Project Hololens [Project Hololens 2016] (which incorporates an “augmented-reality computer”, heads-up display, cameras, and specialized circuitry into a set of visor glasses) and Google’s Project Tango [Project Tango 2016] (which enables similar AR interactivity using Android-based mobile devices).

The increased use of 3d computer game engines to drive digital representations of hypothesized and real artifacts and sites, has allowed cultural heritage researchers to more easily explore, visualize and communicate their work in diverse ways using virtual reality (VR) technology. In many cases, projects can be developed generally in these environments, and then deployed to one or multiple specific interaction/display platforms which best suit the content represented and exhibition experience desired. The emergent widespread use of personal VR devices such the Oculus Rift headset, Google Cardboard and similar devices, enable incredible stereoscopic first-person immersion and interactivity in simulated environments. Desktop-enhanced VR systems, such as the zSpace, permit a more social display and interaction space, especially facilitating interacting with object-scale elements [zSpace 2016].

In collaborative virtual environments (CVEs), where multiple coexistent users experience a space together, there has been some difficulty developing easy-to-use and intuitive mechanisms for navigating through a virtual world, and interacting with its objects. As most VR technologies do not typically engage the users sense of tactility and touch, interface design researchers have opportunistically explored the use of tabletop-based tangible navigation controls and object manipulation with tangible props incorporated with large vertical displays or CAVE systems [Kim et al. 2006]. This is particularly important in the more social environment of a museum, where users may be disinclined to isolate themselves with a head-mounted display, or spend time learning the interaction vocabulary of a game controller, stylus and the like. Most current VR platforms typically do not engage the user's haptic faculties. The hope is to develop interaction schemes that leverage comfort with using physical props in a communal setting, similar to the common social practice of playing a board game with tangible tokens, or the parallel and cooperative activities that occur while experimenting with toys in a sandbox. In this case though, the milieu is a shared virtual space, with a collaborative interaction/control surface and a variety of both tabletop and heads-up visual output displays.

Three recent research projects are worth mentioning which begin to articulate a range of tangible interaction potentials that we are hoping to explore, synthesize and extend with TITA. Interesting work regarding VR navigation and object manipulation with tangibles by Wu and Reilley, highlights the interface difficulties in CVEs, suggesting a top-down tabletop map interface with tangible token avatars, which control the camera's point-of-view for a set of upright immersive displays [Wu et al. 2011], and discusses a mechanism for linking physical tabletop objects with objects in the virtual world (and the relevant design considerations), based in relation to previous NUI precedents.

The Mapping Place project [Chu et al. 2015] is a recent cultural heritage museum project which explores the cultural differences in relation to mapping and storytelling between Western and African cultures—it creates an immersive collaborative storytelling experience using a tabletop-based tangible interface, that tracks manipulated cultural artifacts, and displays digital imagery on the tabletop and projected surfaces of the surrounding walls. They describe their design process and situate the project effectively within the history of the interactive museum, exhibition and collaborative learning/storytelling space, and specifically articulate the development of a nodal user-interface based upon a tangible-object linked menuing system, allowing the users to dynamically construct, illustrate and archive cooperative stories.

The Belongings project [Muntean et al. 2015] is another designed tangible interaction museum experience which explicitly explores the curation and presentation of archaeological fragments, via a hands-on, touch-based engagement with physical reproductions of the artifacts themselves, and extensively describes the exhibition design process and use of multimodal interactive media engagements to provide a rich contextualization for the objects.

THE SYSTEM

The majority of tangible interactive tables use a pc-based camera imaging system which tracks, in two dimensions, fingertips and physical markers illuminated via infrared light, as they occur on top of a piece of acrylic (or glass). The system rear or front projects a visible-light displayed image onto a translucent, diffusive projectable surface, co-planar with the tabletop (or it potentially incorporates an TFT LCD panel, instead of using a projector). There are various permutations to this strategy, and their uses, benefits and drawbacks are well documented in assorted projects in the NUI (natural user interface) communities [Schöning et al. 2010][NUIGroup 2016]. TITA uses a common technique called rear diffuse illumination (rear DI) for its first prototype, mounting a mini-pc, portable projector, infrared sensitive camera and infrared LED light array within the cabinet, using standard acrylic and a diffusive material for the interaction and image surface. A rear DI table was initially designed because of the ease of fabrication, ability to accommodate fiducial markers, and relative low cost. Further iterations of the design may explore other techniques and modalities. For the TITA Regium Lepidi project (see below), we have initially used the Reactivision computer-vision framework for tracking, Unity3D for application development, and Touchscript for TUIO multi-touch and marker support within Unity3D.

The basic internal structure of the table is composed of two major components— a tenon/dowel-joined 1/2" (12mm) plywood frame (lower and upper sections) and 4 x 3/8" (9mm) threaded metal rods, each located at a corner. The rods are load bearing and provide an armature for adjustable projector, mirror, infrared lighting and camera mounting shelves (Fig. 3).

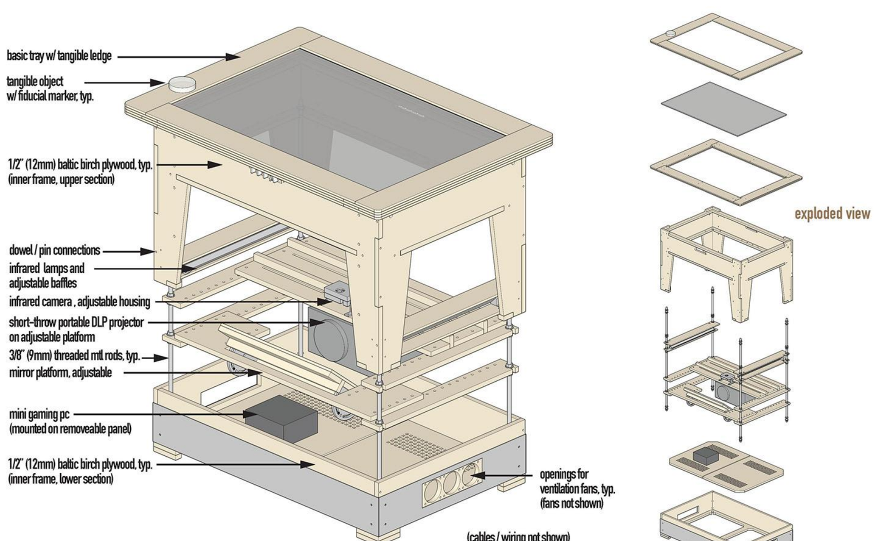

Fig. 3. Basic internal structure/configuration, exploded view.

The internal frame bolts together with the metal rods to form an adjustable assembly, which is wrapped and laterally stiffened by exterior veneer panels, made from cabinet-grade, finished ¼" plywood (other materials, such as opaque acrylic or metal sheets may be used, if sufficiently rigid) (Fig. 4). The plywood interior frame provides pre-drilled screw holes for the exterior panels, and receiving locations for bolted accessories, signage, lighting, and internal wiring and ventilation fans. All plywood pieces can be fabricated with a laser cutter or CNC router. The metal rods can be cut to length with a hand hacksaw. Connections and fastenings are made with bolts, washers and nuts, glued dowels, or screws (Fig. 5)(Fig. 6)(Fig. 7)(Fig. 8).

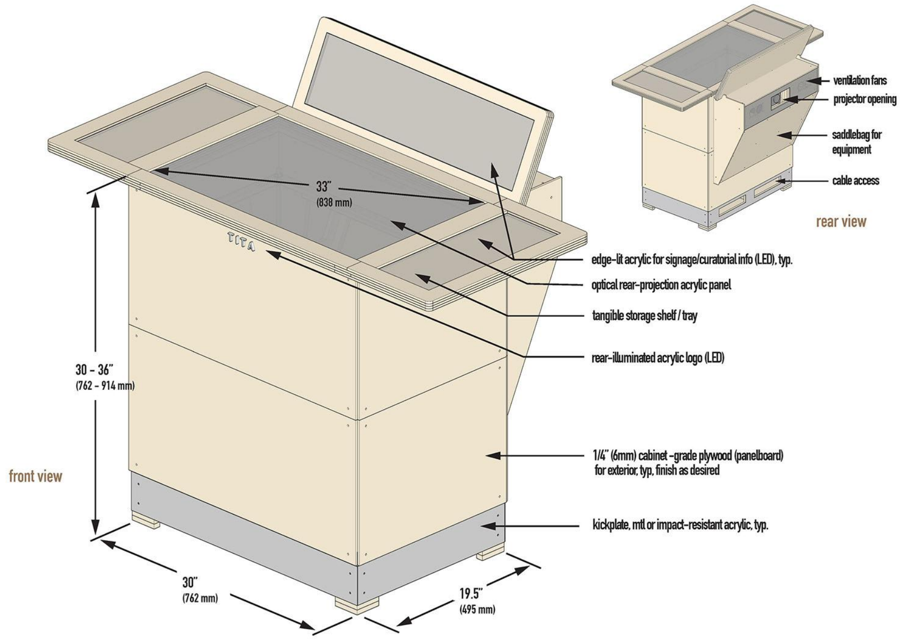

Fig. 4. Assembled exterior view, w/tangible tray, signage and saddlebag.

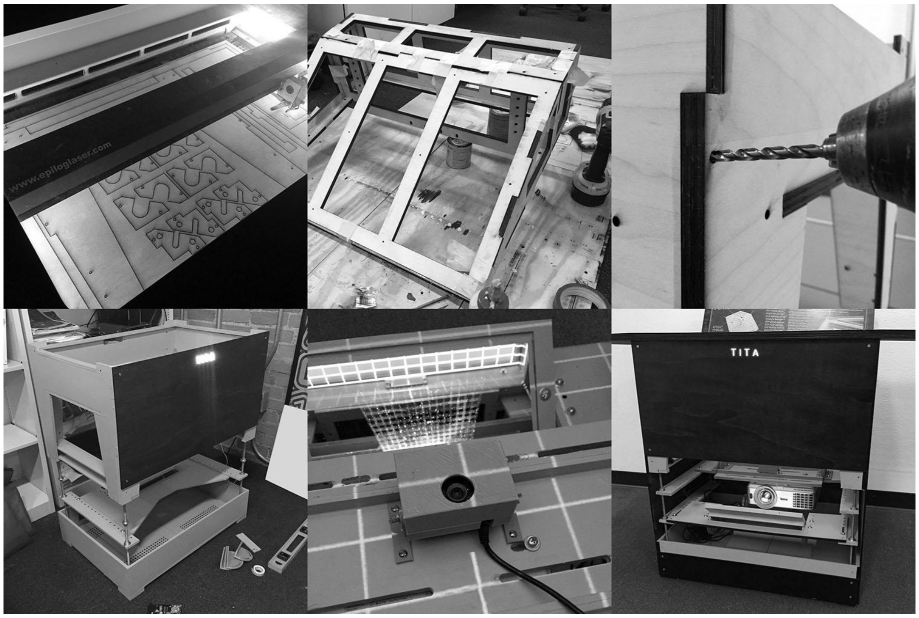

Fig. 5. Fabrication and assembly.

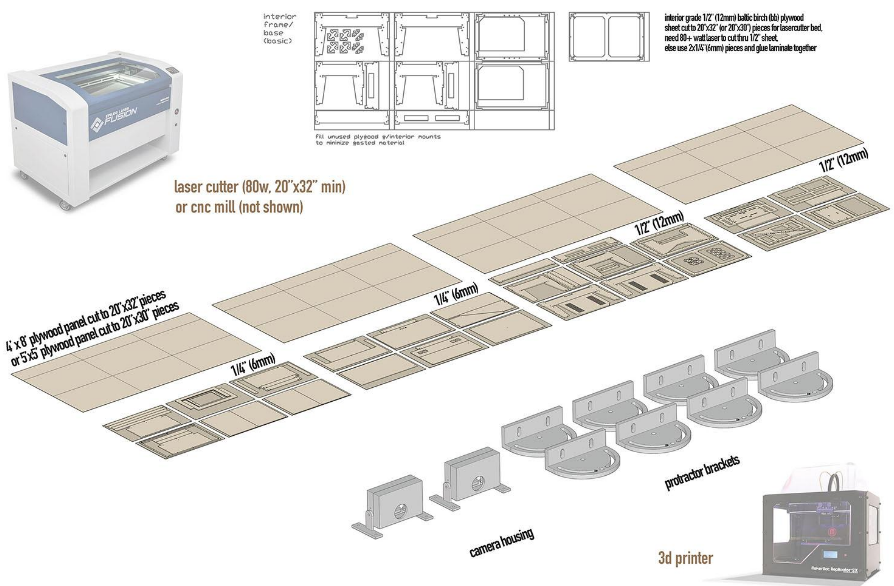

Fig. 6. Fabricated pieces, laser/cnc router cut or 3d printed.

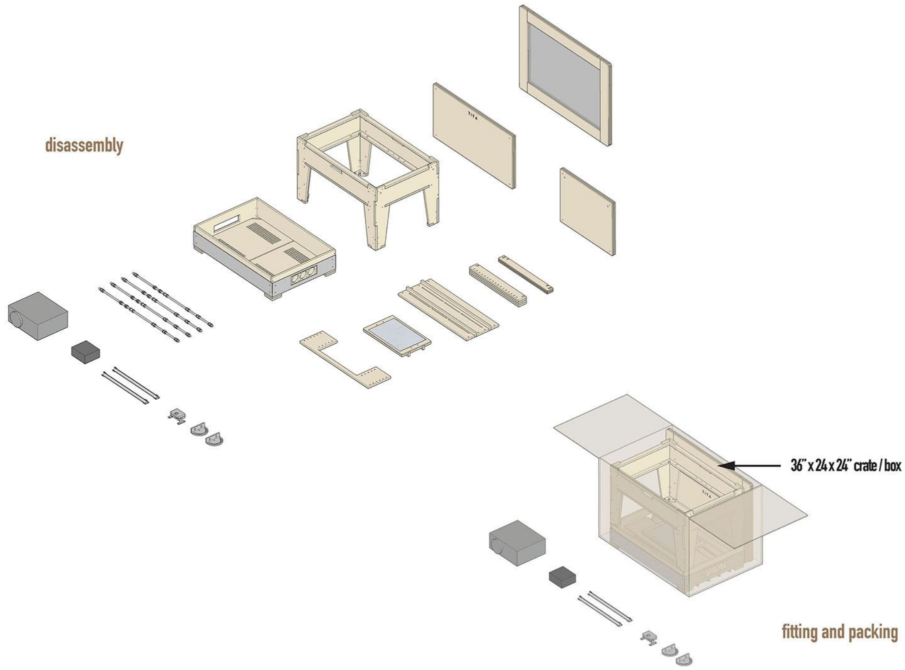

Fig. 7. Disassembly, fitting and packing in small crate.

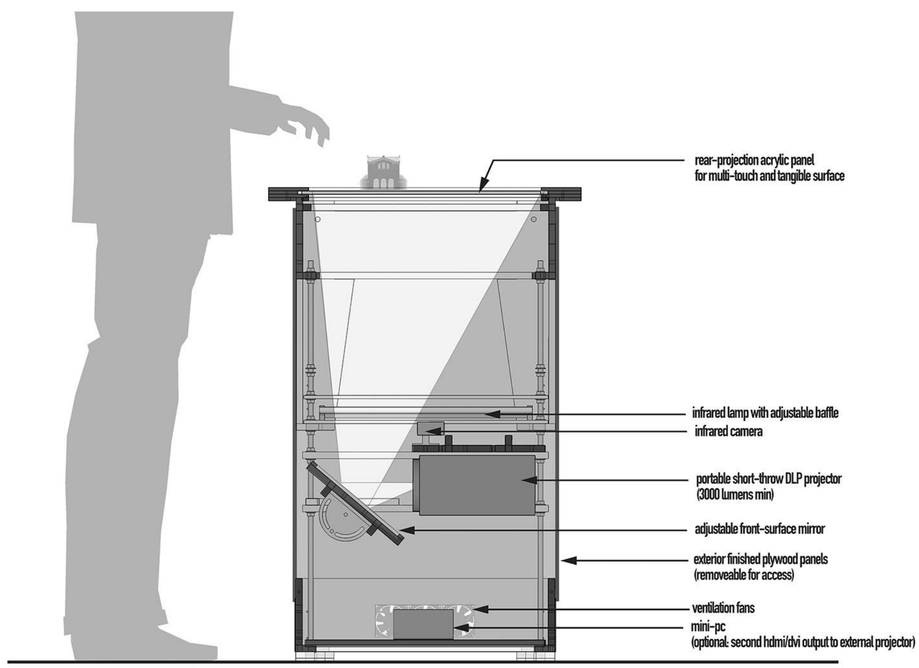

Fig. 8. Cross-section.

The table is engineered to be parametrically adjustable for a desired fabrication size, height and area of interactive surface, thus the interior structure needs to accommodate variability. The design also anticipates a range of equipment (assuming differing optical specifications for installed projectors and cameras). Adjusting the focal length and field of view, adding mirrors and additional infrared lights and cameras, is all accommodated with the rod armature and cabinet flexibility -- new mounting shelves and light modulating baffles may be added, which can be freely move up or down the rods by tuning anchoring nuts and washers. Components on the shelves can be slid back and forth in pre-cut tracks, or rotated via 3d printed protractor brackets, and then bolted securely when adjusted properly. Potential unforeseen customization and hybridization can be accommodated in this fashion.

Intrinsic to TITA's design is modularity of configuration. The system allows the selection and fabrication of one of a number of top tangible trays, or the addition of an equipment saddlebag, potentially adding locations for signage, illuminated tangible storage surfaces, a position for a vertical lcd display or forward-displaying projector. As new features are explored, the hope is to alter the basic frame to accommodate as many of them as possible (Fig. 9).

The function of the table is driven by a collection of small, lower-end consumer grade electrical equipment. The computer we selected is in a burgeoning class of PCs - mini-gaming computers (such as the inexpensive Valve Steam box), in this case a Gigabyte Brix gaming machine (GB-BXi7G3-760)(8GB/256GB SSD), with a 4-core CPU (Intel i7) and a dedicated NVidia GeForce GPU (760 GTX)(Fig. 10). The computer is a small form factor (SFF) computer (2.3" x 5" x 4.5", 59.6 x 128 x 115.4 mm), allowing flexible positioning in the cabinet, with reasonable power requirements (100W) and heat output. The multiple-core CPU provides the processing thread distribution, to accommodate both the computer vision tracking software and the 3d game engine running simultaneously, with adequate game engine frame rates at high visual fidelity, and generally low interaction latency. The dedicated GPU provides a number of video outputs for the internal projector, and multiple external projectors or displays.

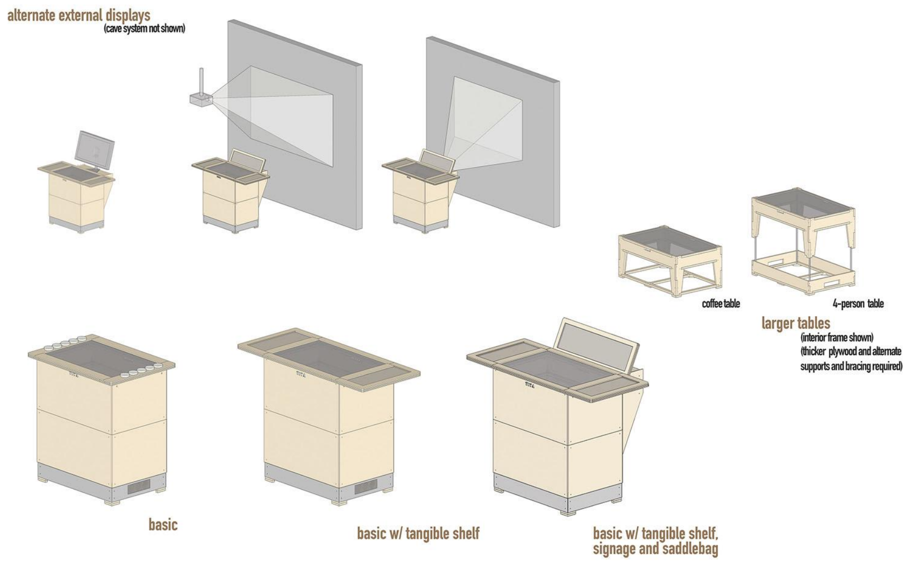

Fig. 9. Variability of design, parametric scaling.

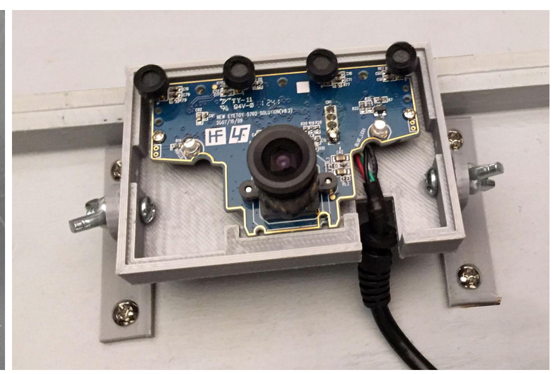

Fig. 10. Mini “gaming”computer (banana for scale).

Fig. 11. Infrared camera w/ 3d printed adjustable housing (top cover removed).

The specified internal digital projector is a short-throw DLP device (BenQ MW632ST WXGA, 3200 lumens, 0.72 – 0.87:1 throw ratio) - the short throw distance allows level internal mounting with only one front-surface mirror required to fold the image onto the horizontal tangible interaction surface at the top of the table. The infrared tracking camera is a modified, hackable game console camera (Playstation 3 USB Eye Camera, a common inexpensive camera often used for TUI tables), with an 850nm IR band-pass filter and lens kit (provided by Peau Productions), housed in a 3d-printed adjustable camera housing (Fig. 11). Infrared illumination is LED strip lighting, cut to size and mounted with two-sided tape in a cut aluminum channel with 3d printed brackets (Environmental Lights, 850 nm, 5050 60/m). Tangible tray and signage illumination is also LED strip lighting

(Environmental Lights, 3014 Side View, visible light, neutral white). A number of brushless DC fans, controlled with a simple potentiometer, provide adequate adjustable cabinet ventilation. The lighting and fans are all wired together in a very simple 12V DC circuit.

As mentioned, the tangible interaction surface is a translucent, diffusive rigid composite material, which can capture a projected image, yet allow infrared illuminated fingertips and fiducials to be seen through the surface, and tracked by the camera in the cabinet. The surface can be specified in a number of ways, depending upon the availability and cost of materials, and the aesthetic or functional properties desired. The simplest and most inexpensive option, for prototyping purposes, is to use an assembly, a piece of ¼" anti-glare optical acrylic, laser cut to size, covered with a sheet of thin-film drafting mylar. More expensive, specialized options may be used, which improve the quality of the projected image, the ease of tracking the fingertips or makers, or the aesthetic and tactile properties of the material itself. We have also used Acrylite optical rear-projection dark grey acrylic (7D006RP or 7D513), which was the original material used in the first generation of the Microsoft Surface 1.0 tangible tables (before they were re-branded Pixelsense). This acrylic floats the diffusive particles within the material of the sheet, and is a dark gray color, which increases the contrast of the projected image. The availability of this acrylic is limited, although the manufacturer offers a more available diffusive acrylic sheet that has similar optical properties, Acrylite Satinice (0D002DF colorless).

The final component of the table is the mirror—a first (front) surface optical quality mirror, suitable for folding the projected image (or varying the IR camera install), without any ghosting effects. This is mounted on a shelf, in a frame, which is adjustable via protractor brackets. This element, along with a customizable projector shelf and specific projector image adjustment, focus, zooming and keystoning options, allows the projected tabletop image to be positioned accurately.

DISTRIBUTION, INSTRUCTION AND DISCUSSION

[The project web page features fabrication and parametric design files, with accompanying instructions and equipment specifications, and project software templates and tutorials. These are linked and hosted via an open-source file/code management, distribution, version control, and fork-branch environment, such as Git (Github). Initial file formats for the fabrication files will include .dxf laser and CNC cutting files, and .stl files for 3d printing. We are looking into an open 3d CAD format to provide parametric variability (and potential scriptability) for the design files. The initial prototype was created in the proprietary 3d software Trimble (formerly Google) Sketchup, but we will be moving the design files natively to AutoCAD, with eventual distribution targeted toward a free open-source environment such as FreeCAD. Alternative simultaneous project/file hosting venues will be explored (with greater social networking/exposure potential), such as Instructables and Thingiverse. The website will feature future permutations of this design project, alternative community designed interfaces and software, and a user forum, and links to associated community/project pages (such as NUIgroup, OpenExhibits.org, TUIO.org, etc.)

All files for TITA are released under a Creative Commons Attribution-ShareAlike 4.0 International license.

TITA AND THE REGIUM@LEPIDI 2200 PROJECT

The Regium@Lepidi 2200 Project started in 2013 as a collaboration between the Duke Dig@Lab and the Lions Club Reggio Emilia Host-Città del Tricolore, Italy. The project aimed to study and virtually reconstruct the ancient Roman town of Regium Lepidi, 2200 years after its foundation. This initiative entailed the definition of new methodologies of digital documentation of the urban landscape as well as the implementation of a virtual environment, created for the general public within a museum setting, envisaging new perspectives on cultural heritage dissemination and virtual exhibit design.

The initial stage of the project involved data collection, GIS mapping and interpretation of the available archaeological documentation in order to draw up a potential urban layout relating to the roman phases of the city evolution. Vector features (points, lines and polygons) were traced after having digitized and georeferenced the drawings. A detailed Digital Terrain Model of the present landscape was also generated from LiDAR data. The ancient city ground was recreated by interpolating the points relating to roads and pavements findings, accidentally unearthed across the city during the postwar urban renewal. Among these are some of the finest domus mosaics ever found which are now preserved in the local archaeological museum.

Photogrammetric (computer vision) techniques have been employed to digitize a set of Roman artifacts, whereas the foundations of a monumental basilica – unearthed in the basement of the Credito Emiliano bank headquarters – was laser scanned. Digital models provided a basis for a virtual anastylosis of the architectural elements while the remaining foundations allowed some of the main forum buildings to be accurately located. Notwithstanding the work carried out on the site, lack of evidences for most of the other buildings present in Regium Lepidi, was one of the main issues faced for the comprehension of the ancient city plan.

Therefore, an evocative approach was adopted and procedural modeling for the urban area proved convenient in order to bridge the gap between scientific uncertainties and the need of a detailed 3D environment for a real-time simulation. GIS vector features that refer to the Roman street grid (centuriation) provided the input data for the procedural generation of the urban tissue in CityEngine, especially for residential blocks (insulae), while prominent buildings (temples, basilicas, theaters) were manually modeled. Specific urban scenarios were prepared in Unity 3D in order to be viewed through immersive virtual reality devices (Oculus Rift)-- stereo displays provided a virtual interactive environment, allowing the public to get a first-person view on speculative tableau, incorporating digital copies of the museum artifacts.

In the case of TITA, the virtual reconstruction of the Roman Forum of Regium Lepidi constitutes the core digital content of the application and the 3D prints are related to the most important buildings of the Forum area.

The idea here is to engage the museum visitors to envision the Roman Forum as a reconstructable pattern/puzzle, and to approach critically the uncertainty of the virtual reconstruction as a simulation process. The haptic/multitouch action is collaborative and stimulates a multisensorial vision of the virtual models. The final goal is to arrange a holistic, spatial and architectural analysis of the Forum according to the relationships between tangible prints, digital models and topographic view of the city.

3D CONTENTS, MODELING AND PROCESSING

The fabrication of both the tangible (3d-printed) and virtual models for TITA entailed a complex workflow through a range of different software toolkits. Initially, we chose to reuse the available models that were created for the Oculus Rift virtual application (Forum@Lepidi). However, it was soon realized that a radical rethinking of the 3d contents was needed in order to disclose the entire potential of TITA. We decided to split the models into smaller architectural modules, in order to better address the specific goals of this experimental haptic platform. Indeed, the principal aim consists in making the users play with the ancient city topography by letting them reconfigure the building arrangement within the forum area (Fig. 12).

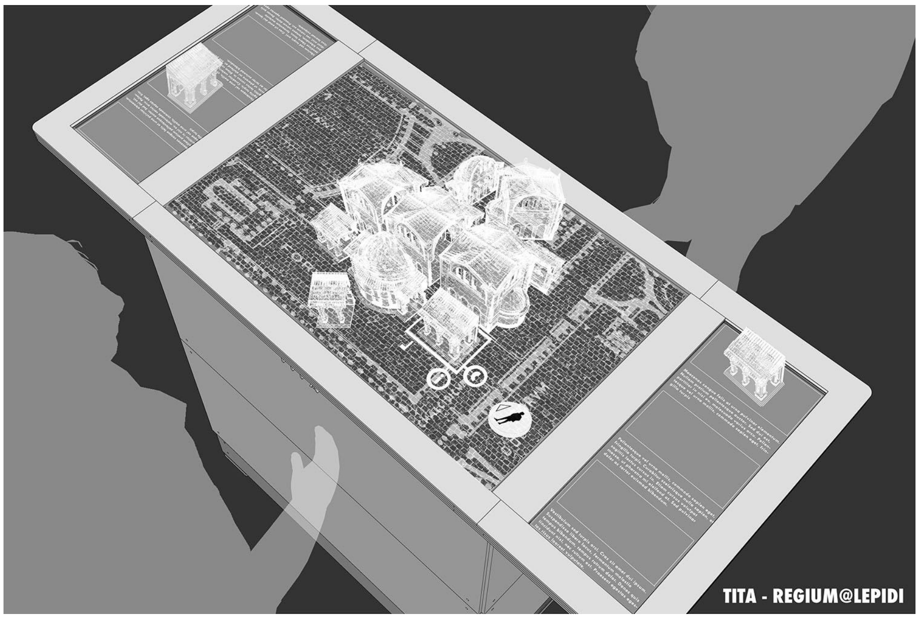

Fig. 12. 3d printed architectural joinable modules, configured as a museum exhibition game.

To accomplish this goal, the original models were segmented in joinable modules. These can be reassembled in a number of different ways in order to allow a wide range of variation. As a result, the basilica can now be constructed using multiple modular items rather than having it as a single piece. Doing so, the user can experiment with different configurations to fit the archaeological plan, according to various hypotheses. This also enables scholars to quickly visualize and reconsider their hypotheses in the light of new archaeological evidences.

Some of the original architectural fragments preserved in the museum were digitally recorded through photogrammetric techniques. The chosen method was Structure from Motion (SfM), via PhotoScan software, that generates 3D models by processing photos taken all around the object (Fig. 13). Once digitized, these elements were integrated in the reconstruction, after virtually restoring the missing parts (Fig. 14).

We chose the Unity game engine as a cross-platform environment to develop TITA's software components. Unity implements a real-time global illumination renderer that allows a very photorealistic yet interactive shading. Some graphic tricks were borrowed from the computer game design industry to overcome the limited number of polygons that can be managed by the GPU. Models were retopologized through resurfacing tools in order to produce uniform polygonal meshes. Subsequently they were optimized for real-time rendering, applying a polygon decimation algorithm. This led to the creation of several instances of a model at different polygonal resolution – namely

Levels of Detail (LODs) – that can be dynamically switched depending on camera range. The least detailed LOD is meant to be seen from a distant point of view, the most detailed one at close range.

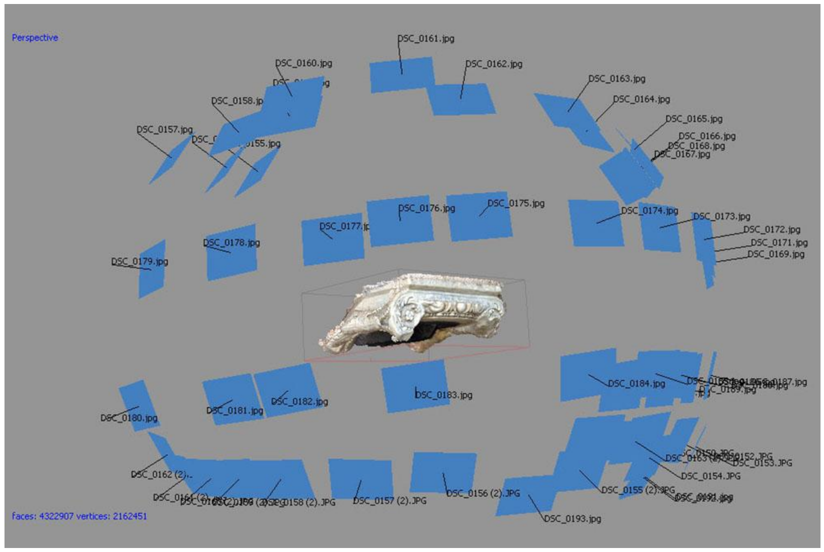

Fig. 13. Photogrammetric reconstruction of 3d artifact

Fig. 14. Virtual anastylosis of Claudian Temple

Parallax and normal map techniques were also adopted to preserve the architectural decoration integrity in very simple polygonal meshes. The minute geometric details were resumed from the highest detailed LOD to be mapped onto the surface of the simplified LODs. UV-unwrapping and render-to-texture procedures were used in order to generate a complete set of correlated textures, including normal and height maps (Fig. 15). The highest (undecimated) LOD was also used to produce 3d-printed scale replicas for TITA.

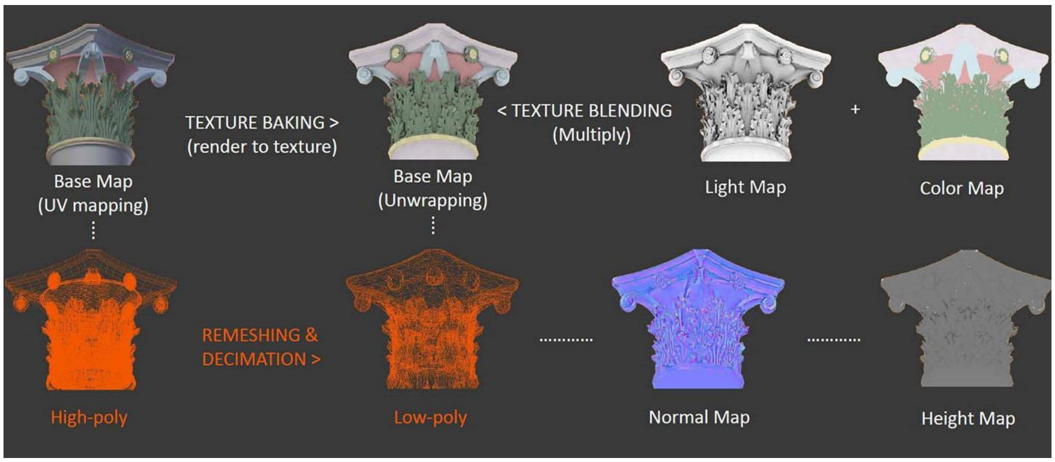

Fig. 15. 3d model meshing and texturing pipeline

The 3d-printed modules connect to each other like Lego pieces, providing the user with an immediate and tangible feedback about their affordances. At the same time, the virtual models change their configuration according to their movement as tangible pieces on a board. The most perceivable difference between the tangible replicas and their corresponding virtual models relates to perceptual aspects of inhabiting architectural space, the latter being rendered in a very photorealistic manner from a first-person viewpoint. After completing a certain configuration, the users can experience their newly generated architectures by walking through or flying over them.

The coexistence of the digital reconstructions alongside with the original artifacts on show in the museum allows the user to establish a visual bond between the surviving fragments and their lost architectural context. At the same time, the 3d-printed scale replicas provide an effective mean of interaction between the tangible content and its virtual projections.

CONCLUSIONS AND FUTURE DIRECTIONS

The development of haptic interfaces and augmented reality applications for museums can engage new types of interactions with users and visitors by involving them in collaborative experiences. This digital and simultaneous haptic interaction with real objects and virtual models develops an innovative approach to museum collections and to the archaeological contextualization of artifacts, architectural elements and topographic information. This kind of digital engagement is customizable and portable and in the future we can expect a "domestic/individual" use of these systems. Users could design and fabricate their own TITA for a personal game-like experience with the ability to change or provide new materials, or generate their own content.

The hands-on approach is a fundamental part of the museum experience, more specifically for archaeological objects which need a recontextualization of all the original object-environment affordances. TITA was intensively experimented with during undergraduate and graduate classes at Duke University, with the participation of many students and instructors. The first tests are very encouraging in terms of collaborative teamwork and visual and haptic interaction. The simultaneous and multisensorial activity of touching and manipulating empirical and virtual models apparently stimulates a stronger feedback in comparison with a pure visual engagement.

In the initial stage of design for the TITA project and its application at Regium Lepidi, we have identified a number of core tangible and multi-touch interactions that we will support in a Unity-based template, which will be broadly useful for future applications related to archaeology. Included in these are vertical display camera navigation using tangible tabletop avatars, linking physical objects with virtual objects (artifacts and architectures), avatar and object manipulation with context–based touch controls and menus, timeline controls, virtual object sectioning tools (to see inside them), curatorial text tools, and standard multi-touch interactions such as pinch/pull camera zooming and virtual object drag-and-drop, resize and rotate. These will lead to a museum application experience related to Regium Lepidi, encouraging visitors to speculatively reconstruct a Roman forum, based upon archeological evidence and typical period building typologies and configurations, using modular tangible building blocks (such portico, exedra, atrium or cross-vault pieces).

There are numerous projects, initiatives and emergent techniques in the tangible interaction space, which suggest interesting avenues of exploration for further development of TITA, and opportunistic use within cultural heritage applications generally. Again, the guiding approach would be to develop open-source hardware, software and design projects, which would be standardized, approachable and well documented, using maker technologies and inexpensive materials/equipment where possible, to further exploration within museums, cultural heritage laboratories, schools and your average makerspace.

Possible next steps for TITA includes investigating the use of tangible object tracking with consumer-grade capacitance touch displays, as previously mentioned, within an open design framework. Infrared, vision-based, projector-based systems still have some advantages, as it a very inexpensive, scalable technology, yet has drawbacks that include configuration complexity, light-sensitivity, potential interaction latency, and installation size.

Previous projects that incorporate micro-controllers into tangibles are promising (TUIC, PERCS, etc. [Yu el al. 2011] [Voelker et al. 2015]), though this would add an element of cost, complexity and maintenance that might prove problematic for the targeted user community. In this regard, the potential to use capacitance signature to identify and track an object on a PCT display is encouraging, especially considering various efforts to integrate capacitance filaments into the consumer 3d printing pipeline [Schmitz et al. 2015].

There are opportunities to use real-time, markerless, 3d object tracking, available via emerging AR platforms such as Project Tango, within a multi-display CVE VR environment. The integration of tabletop tangible projection mapping (using digital projectors to precisely place imagery on physical objects) is also very intriguing, especially in regard to layering meta information on tangible objects, and adding textural fidelity and dynamic animation [Dalsgaard and Halskov 2012][Halskov et al. 2014].

Generally, we are hoping to develop mechanisms to diagrammatically abstract these design projects, to be agnostic to specific hardware or software tools, but instead present general relationalities and design specifications and functions, which would be adaptable as specific applications and new technologies emerge.

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