The Loom: Interactive Weaving through a Tangible Installation with Digital Feedback

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Abstract. The design of hybrid interactions, which involve both tangible and digital aspects, is a recent trend in interactive systems for cultural heritage because it adds physicality to the interaction and affords sociality of experience. The paper presents the approach for the design, prototyping and evaluation of an interactive loom at an industrial museum with which visitors can experiment and play to gain awareness about the weaving process. The system comprises of a small-scale (shoebox-sized), simplified loom replica made of wood that is connected through appropriate (Arduino) sensors to an interactive application (Unity) that digitally recreates and enhances the outcomes of user interaction onto a multitouch screen. We found that hybrid interaction is important for educational reasons because it supports constructivist learning, which favors exploration, active learning and experimentation over passive consumption of information. Also, the approach is suitable for engaging younger people, who often do not find much interest in museum visits.

Keywords: tangible interaction, physical interaction, hybrid interaction, loom, interactive weaving, cultural heritage, museum, Arduino, Unity.

1 Introduction

A recent trend in museum installations is the use of hybrid approaches that combine tangible interactions with digital content. Traditionally, museum visits have been enriched with augmented content that presents additional information about the exhibits or the related context through static or mobile digital devices, such as audio guides, info kiosks, multitouch tables or mobile apps. However, the overuse of such solutions might lead to a disassociation between the actual artifacts and the digital content, divert visitor attention from the 'actual' exhibition, and leave less room for reflection [1]. A notable path to avoid the aforementioned issues and still retain the benefits of enhancing a museum visit with useful content is the use of tangible interactive artifacts that are linked with digital information. This approach, if properly designed, can lead to more playful and thus engaging experiences, and increase social enjoyment and sharing. Although it is usually not feasible to let users touch and experiment with the original exhibits, it is

however possible to construct physical replicas or simplified models and enhance them with digital / interactive affordances to offer a more holistic experience.

The design of usable and effective hybrid physical / digital artifacts for museum visitors is an issue that needs further research and experimentation. As a design task, it is quite complex and requires a lot of testing and reiterations. It involves a number of experts from various fields, it needs the active participation and feedback from a range of users, and, most important, one has to focus not only on the usability of the physical parts and the digital components, but also of the system as a whole; there has to be a good interplay between the physical and digital content that positively contributes to the user experience. Currently there are no generalized design patterns, approaches or guidelines to be found for this type of installations. Thus, there is a need for study of the design process and of the effect of successful paradigms to help shed more light on the prospects and pitfalls of this design field.

Fig. 1. Left: the hybrid (digital and physical) prototype of the loom. Right: The homepage of the multimedia interface of the system.

In this paper, we present the design, implementation and early evaluation of a hybrid interactive installation at an industrial museum, focusing on the design process and the lessons learned. The aim of our research is twofold: a) to design an effective solution for the interactive and embodied understanding of the operation of a loom in a museum and, b) to reflect on the design process used and critically review the design of such systems. The implemented system is comprised of a simplified small-scale model of a loom and a multi-touch screen presenting related digital content[1]. Visitors of the museum can experiment, play and gain awareness about the weaving process through interacting with the loom model whilst observing the results of their actions on screen. Additionally, a multimedia interface presents information about the loom exhibits of the museum and the textile industry (Figure 1). The installation is designed to be placed next to an actual loom, which is a permanent exhibit of the industrial museum. The main motivation behind our work was the fact that visitors, especially younger ones, tend to spend little time in examining the complex machines presented in the museum.

[1] A video presentation of the design process and system is available at: https://www.youtube.com/watch?v=TPBCTI9GX5w

We examined whether their engagement with an interactive replica that lets users actively experiment and learn about their operation and usage, positively affected the user experience.

2 Related Work

The physicality of a museum visiting experience is considered a major issue. Visitors want to be able to stand close and study important exhibits with attention in order to reflect on the emotional, socio-economic and contextual conditions of their creation. Of course, it is not common practice to allow users to touch or use the real artifacts that are often sensitive to damage, wear and tear. It is however possible to construct accurate physical replicas and enhance them with digital / interactive affordances to offer a more holistic and experiential visit. This approach has been adopted by various museums and exhibitions. For example, the Prado Museum in Mardrid, Spain, offers a touchable exhibition of paintings from Da Vinci and other famous artists, which all visitors – including the blind and the visually impaired - can touch and sense in a new way [3]. Another example is the work of Anagnostakis et al. [4] who create 3D printed replicas of Cycladic figurines that are enhanced with Arduino sensors to let blind users touch and feel the replicas in order to hear respective audio descriptions.

Furthermore, the public exhibition of artwork and its placement on display is a wider issue that has been extensively discussed in the area of curatorship and museums from many perspectives such as fidelity of reproduction [5]; visitor perception and issues of authentic objects vs. replicas [6]. In the cases where the original object may not be touched or it is not available, it has been suggested that "3D multi-visualization augments the perception of physical characteristics of the artifacts allowing a more embodied experience with these objects" [7].

Modern science museums usually contain several tangible interactive installations, that let users actively play and experiment with scientific concepts [8]. This approach follows the constructivist perspective, which favors exploration, active learning and experimentation over passive consumption of information. Several studies in science museums have shown that the augmentation of physical experiments with digital content leads to significant conceptual gains. For example, in [9], an exhibit device called Be the Path, which consists of two fixed metal spheres (one foot apart) with wires connecting them to a battery and a light bulb, was digitally augmented to illustrate electrical conductivity and the flow of electricity through circuits. Visitors attempt different configurations to complete the circuit—by using their body to close the gap between the metal spheres—and light the bulb by touching the metal spheres. Their embodied interaction with the device and the augmented illustration of electrons' flow around the circuit enhances visitor understanding and learning. Currently, we are witnessing interesting novel approaches that combine tangible artifacts and digital content for science learning like the work in [10] which developed a tangible museum exhibit for exploring bio-design by utilizing active and concrete tangible tokens to allow visitors to experience a playful biodesign activity through complex interactivity with digital biological creations.

A similar approach can be applied in museums exhibiting complex devices or processes related to technology and industry. In these cases, the aim is not only to observe the physical artifacts (e.g. machines of the past), but also to be able to actively use them and understand their operation. For example, in the Tower of London visitors can interact with a half-sized replica of a cannon in a hybrid tangible-digital environment [11].

3 Iterative Design Approach

Our work focused on an industrial museum[2] that includes many exhibits of machinery and small industry. To increase visitor understanding and engagement, it is important not only to present the original machines but also to illustrate or convey their internal structure as well as the human operation. In order to approach these goals for the visitor experience, we sought to identify new ways of interaction that were not merely digital but would afford user operations onto a physical loom model (thus afford embodied user interactions with the model). In addition, we had to avoid a toy-like experience, therefore we decided to enhance the outcome of user interaction with the loom by displaying it onto an interactive multi-touch surface with the idea that this surface would also allow users to search for more information about the interactive exhibit as well as pursue explanations to possible queries.

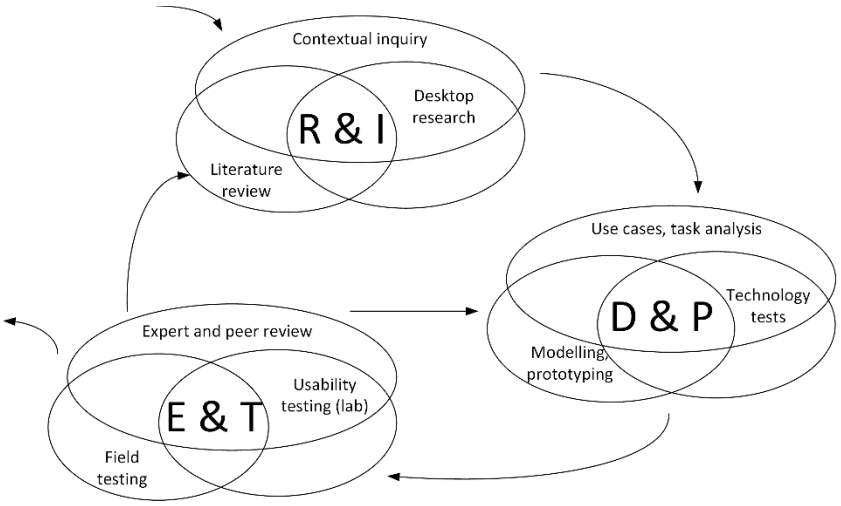

Fig. 2. The iterative design approach followed.

In order to elaborate and refine these basic ideas and framing into a working prototype, we followed an iterative design approach that includes several design methods in context and close cooperation with museum curators and other experts, as well as visitor

[2] Industrial museum of Hermoupolis, Syros island, Greece: http://www.ketepo.gr/en/

observation and interviews. The iterative design approach followed for the development of the interactive exhibit of the loom can be described with the following intertwined phases (Figure 2):

Research and inquiry (R&I). This includes various methods and activities with most important those of contextual inquiry, desktop research and literature review. Contextual inquiry is the most important activity because it helps the design team to gain understanding about the particular situation, context, people, place, exhibits, etc. Desktop research and literature reviews complement contextual inquiry with information and knowledge about trends and developments in similar contexts, worldwide.

Design and prototyping (D&P). This includes several activities that largely depend on the project at hand. For this project we focused on use cases, scenarios and task analysis, since the visitors had to be able to make use of the loom replica without prior knowledge of operation. Furthermore, we conducted several technology tests of microprocessors, sensors, conductors, and their connectivity to a computer system in general and a 3D visualization engine in particular. In addition, consecutive modelling and prototyping of the loom artefact and the interactive application took place.

Evaluation and testing (E&T). This phase includes several evaluation and testing activities that generally occurred in the classroom, in the lab and in the field. In the classroom, expert and peer review took place by other students, tutors, domain and technology experts with earlier models and prototypes. In the lab, usability was the main focus of the tests, in order to ensure that the system could be used by peers and other students. Field studies took place in the museum with the working prototype and the participation of real users.

We have followed this generic approach in several design projects interactive systems for cultural heritage like [4] [12] [13]. These projects explore the use of contemporary interaction technology to convey cultural heritage and to be applied in museums and other cultural sites. The projects stem from an interaction design & engineering studio course and are carried out by students at their final year of study in cooperation with cultural heritage professionals and sites. In these projects, we follow a problem-based [15], studio-centred [16] approach to interaction design and learning which lasts for an academic semester that is reviewed by tutors twice a week in co-located meetings as well with intermediate reports and online cooperation tools.

3.1 Research and Inquiry

Contextual inquiry. The concept of contextual inquiry typically refers to a focused interview with the client in the workplace, during working hours [14]. We have conducted contextual inquiries inside the museum with two museum curators and one marine engineers (who is domain expert knowledgeable of the machines exhibited at the museum). We also conducted two contextual inquiries with two loom weavers who owned looms and showed us the weaving process (some photos from contextual research are depicted in Figure 3). Furthermore, we undertook several sessions of observations of museum visitors (including children) and a semi-structured interview with a teacher of a primary school to explore the design space and identify requirements. The main outcomes of this contextual research gave us further detail of requirements (and

ideas and provided information for design decisions mainly about the space where the machine was located and the size of the machine as well as how the visitors would approach the interactive exhibit.

Desktop research. Desktop research is about finding relevant information over the web, especially on videos of similar systems or projects, open access/source software that can be downloaded and tested, open designs of loom models, etc. Desktop research is important to avoid re-inventions that others may be providing with rights of free use or reproduction. We did not find we did not find any project similar to our one, but we did find useful material , such as videos about how to operate a loom, as well as about connecting microcontroller sensors to physical models.

Fig. 3. Left: Photograph of a piece of machinery from the industrial museum. Centre: Photograph of a loom from the industrial museum. Right: A woman illustrating the weaving process onto an operating loom.

Literature review. Literature review is about finding scientific papers about relevant and related topics. In the context of this project, we did not address this as a formal written report but as a collection of works that were related to hybrid interactive installations for cultural heritage. From the literature review, we identified the trend of making hybrid interactive installations for various purposes but we did not find any work on a project about interactive loom and weaving.

3.2 Incremental Modelling and Prototyping

Use cases and task analysis. There were many ideas about the use cases and scenarios, including: instructional avatar mediated interactions (to allow learning); game-like interactions in the form of assignments i.e. create a particular piece of (digital) garment or pattern; free exploration and creation of a garment pattern, intertwining of user actions with narratives about the cultural value of the loom or the textile industry, etc. From the very start of this project, a central question was the nature of the tasks and actions that the users would be able to perform with the interactive exhibit, and throughout the research and inquiry phase we kept exploring ideas. But, as the design proceeded we gradually developed the specification of use cases and tasks in the form of detailed task analyses which included pairs of user actions (with the loom model) and system responses (with the multitouch surface).

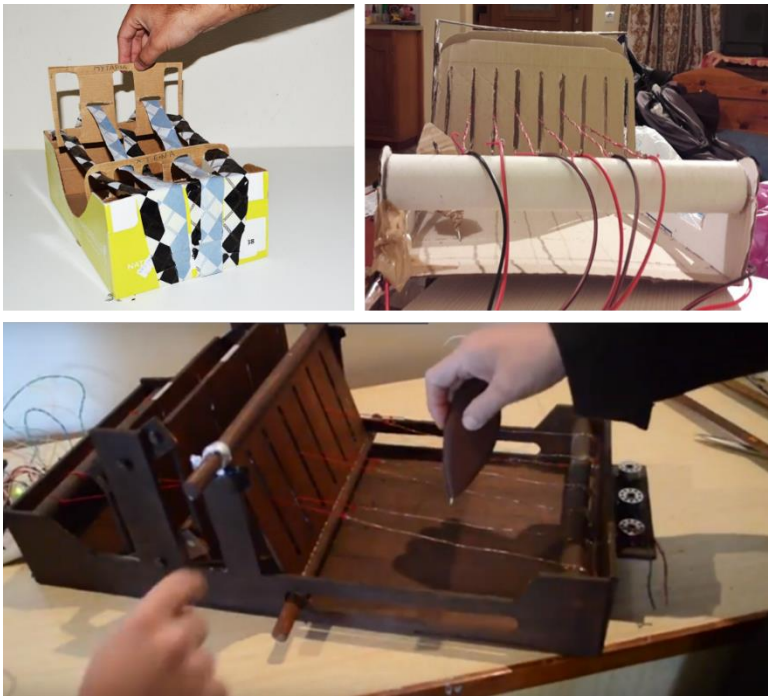

Fig. 4. Top left: The first model of the loom, made of cardboard and nylon (for strings). Top right: A subsequent model of the loom (cardboard and wire strings, with a comb) connected to Arduino sensors. Bottom: The final model of the loom made of wood and wire strings.

Technological tests. These tests were about the microcontrollers, sensors and their connectivity to the computer-based system; the creation of the digital loom model with animations and touch-based interactions; the implementation of an accompanying multimedia interface with additional information about the loom exhibits of the museum and the textile industry. Technological tests were carried out very early in the project since it was essential to realize the technical feasibility of ideas in the given timeframe.

Consecutive production of loom models and prototypes. From the beginning of the design phase it was clear to the design team that a simplified model of the loom would have to be constructed. To realize the form, materials and operation details of the loom model, a series of rough models were constructed (Figure 4). The main design decisions about the loom model construction were: (a) for reasons of convenience, speed and durability, the final model would be made of wood (instead of cardboard or a 3D printed model that were other alternatives); (b) the model would comprise of six string heddles and support three colors, (c) the user should use a simplified model of a loom comb, in the form of a pen-like interface, to touch the strings; beforehand, the user would have picked a color.

3.3 Evaluation

Expert and peer review. During the lifetime of the project, expert review of ideas, models and rough prototypes, took place on a weekly basis. Expert review was carried out by the course tutors in terms of comments and questions aimed at stimulating students' thinking and approach. Additionally, peer review took place in terms of constructive comments and ideas by other student teams. Furthermore, the process followed was inherently open to feedback from other domain experts since it included exploratory and confirmatory observation, interviews and contextual inquiries.

Fig. 5. Left: Peer review of the first sketches and model of the loom (classroom). Right: Field testing and evaluation at the museum, with users (school students).

Usability testing. As soon as a first working system was constructed, usability testing sessions were organized in the classroom and the computer lab (Figure 5). The participants were other students who played the role of museum visitors. The goals of the usability test were to identify qualitative and quantitative issues during instrumental (i.e. task-based) interactions. A total of 24 users (ages 15-48) were provided with particular tasks to carry out and they were observed during the process, while at the end they provided the team with their comments. The team also took notes of observed behaviors as well as spontaneous verbal comments. The main results of the usability test led to the following recommendations for changes and corrections to the design: (a) add textual labels onto the 3D model of the loom for clarity and learning; (b) improve readability of the user interface; (c) reduce information on each web page; (d) change the visual angle of the digital model of the loom to allow a better and more convenient view; (e) several minor corrections to the physical loom model, (f) adjust timings of responses between Arduino sensors and the digital loom model. These changes were included in the final version of the system.

Field testing and evaluation. The hybrid loom installation was setup in the industrial museum as a new interactive exhibit for several days. The installation was placed next to a real loom and it was also connected to a projector for visitors to see the output of the screen. Several visitors played with the interactive exhibit and provided positive comments. In addition, a field test was organized with the participation of 15 pupils during an educational visit. Pupils were asked to develop a simple (digital) garment pattern by making use of the physical model of the loom as their 'interface'. All pupils

expressed enthusiasm with the system and they provided comments mainly about possible future extensions (e.g. ‘more patterns’, ‘more colors’, ‘to add stamps’, ‘to print the pattern onto a t-shirt‘, etc.)

4 Discussion, Results and Lessons Learnt

Interaction design is inherently about the conceptualization and creation of new interactions and systems and requires creativity, making, research and thinking aiming at purposeful innovation from the customer/user perspective. Particularly in the field of cultural heritage, over the last few years we are witnessing an increasing number of ‘high-tech’ interactive systems (made up of various contemporary and emerging technologies, like mobile apps, interactive multi-touch public displays, online and mobile games, virtual/augmented reality systems, etc.) to the service of enhancing the user experience of visitors at museums, exhibitions, archaeological sites and various other places of cultural interest including cities and places with a historic or cultural tradition [17]. The design of these interactive systems is knowledge- and labor-intensive, and it may be characterized as a learning process for designers themselves, since they need to research and learn about new technologies, users and application contexts.

In this paper, we have outlined the design process and methods followed to develop an interactive exhibit of a loom that can be operated by museum visitors to create awareness about the weaving process. We have outlined the approach in practical terms and in the context of this particular project, in order to present a case study of interaction design methods for the domain of cultural heritage and interactive museum exhibits. From the beginning of this project, a number of design issues emerged and respective design decisions had to be made.

Perhaps the first of these design issues was *about the most appropriate technologies and materials to be used*. Given the fact that the main concept (of the interactive loom exhibit) was identified through contextual research and inquiry, we had to identify the technology and materials that would transform the concept into a working system. The design-led approach allowed for use of applied research methods, as well as experimentation and incremental development from rough initial ideas to working solutions. In this project various iterations, models and prototypes were developed: for example, the loom model gradually evolved from a cardboard and nylon model into model made of wood (Figure 4). Overall, the interactive exhibit was developed with the adoption and integration of various technologies: Arduino, Unity, 3D Studio Max, Web technologies (HTML, CSS, Javascript), Creo Parametric. Thus, from the methodological perspective, *it is critical to rapidly make and test prototypes, experiment with technologies in order to ensure a working solution of a novel system*.

Another important design question was about the *purpose and goal of user interactions*, for which there were many initial ideas (presented in section 3.2. Use cases and task analysis). In general, there are many purposes and goals for interactive systems in cultural heritage from the user perspective, including [17]: play (game), virtual or physical exploration, presentation of digital content, user-generated content, simulation or operation, soundscapes, etc. The main focus and contribution of this work is the design

and development of *hybrid interactions with interactive exhibits, which involve both tangible and digital aspects*. This is an identified trend in interactive systems for cultural heritage that is expected to develop considerably in the next few years.

An essential aspect of the design approach was the *reflection on formative user testing and evaluation results before moving to the next phases of design and development*. Contemporary design thinking acknowledges the importance of getting timely feedback from various users and stakeholders in order to inform the design process [18]. During the lifetime of this project, there were many open sessions of user testing that occurred in the classroom, the lab, and the field (also outlined in Figure 5).

Regarding the *instrumental use* of the interactive exhibit, we have provided the user with a set of tasks that can be performed in order to either re-create a given textile pattern, or to create a new pattern from scratch. Certainly, there are many more options to user interactions and further extensions of the system, that can add more gamification (e.g. competition, score, leaderboard, sharing of results, etc.) and personalization elements (e.g. user identity, avatar, take-aways of creations, personalized help and adaptation of tasks to user pace or preferences, etc.). The results obtained from user and field testing were very encouraging. In the field testing, the *usability of the system was high*, since that users achieved in task performance with no supervision as well as to recover from errors. Also, *users showed much enthusiasm about the interactive exhibit* as it drew their attention immediately and they all expressed intense interest in play, exploration and interactive weaving. However, there is of course room for extension and improvement, since some participants expected a form of haptic feedback (onto the loom, rather than on the screen), while the need to look at both the prototype and screen resulted in discomfort / confusion for a few users. These issues will have to be addressed in future versions of the system.

One last important design issue was about the *location of the exhibit within the museum and its relationship to other exhibits*. This is an issue that also affects the cultural value and awareness created by the visit in general, therefore it was a joint decision with the curators of the museum. To allow for more in this respect, we have developed a multimedia web system that presented users with historic information, photographs and videos of interviews of loom weavers (Figure 1). During the field testing, several users did not explore the multimedia part of the application in favor of tangible interaction and creation of digital patterns. The multimedia subsystem needs to be better integrated into the primary task of interactive weaving in a gamified approach that will provide challenges and rewards.

5 Conclusion

We expect that the value of interactive exhibits for museums which offer hybrid interactions, i.e. of both tangible and digital nature, will be widely acknowledged in the next few years; especially in museums that are related to science, technology and industry, where the demonstration of exhibits and the active participation of visitors in learning programs is of the essence. The development of hybrid interactions is a creative process

with no standards or methods to be followed. Even the technology to be employed might be unknown to some extent to the design team.

In this paper, we have presented a design approach and a working interactive exhibit of an interactive loom that allows museum visitors to experiment and play by creating simple garment patterns to gain awareness about the weaving process. We envisage that the design approach presented can serve as a generic guide for other designers who aspire to develop novel, hybrid interfaces. In addition, the interactive exhibit of the loom might serve as an inspiring example or analogy for museum curators, technology designers and cultural professional experts to commission development of interactive exhibits of this sort for other science, technology and industrial museums.

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