Integrating Physical, Digital, and Virtual Modeling Environments in a Collaborative Design Thinking Tool

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Abstract. Design thinking is a creative process that requires brainstorming techniques that take place in a physical environment. However, such physical interactions are not possible in remote environments. In this paper, we propose a software tool for design thinking that bridges the gap between physical, digital, and virtual modeling environments. We describe and evaluate a virtual storyboarding application that enables remote collaborative design thinking in 3D and the conversion of these 3D models into 2D digital models. To evaluate the approach, we conducted an experiment with students and were able to derive directions for further research in this area.

Keywords: Design Thinking · 3D · Virtual · Modeling and Conceptual Modeling

1 Introduction

In times of fierce competition and ever-changing environments, companies must continually develop new and innovative solutions to survive on the market. One possibility to support innovation is the use of *Design Thinking* [10]. Design Thinking combines knowledge from design, social sciences, engineering, and management. It creates innovative ideas, systems, and services using multidisciplinary collaboration and iterative improvement techniques [12]. Traditionally, design thinking requires people to be in the same place, working with pen and paper and communicating in face-to-face conversations to share their knowledge [20]. However, as a result of the COVID-19 pandemic, more and more work is being done remotely. A recent Gartner survey[1] revealed that many enterprises will move considerable parts of their previously on-site workforce to a permanently remote work-model. This makes knowledge sharing in innovation processes more challenging. Remote working has been shown to reduce the process of tacit knowledge transfer between collaborators [4]. This is largely due to people working remotely and the lack of face-to-face interaction in shared work environments.

Since Design Thinking is a highly creative process, the seamless exchange of information between physical, digital, and virtual modeling environments is desirable to keep up with new work demands.

[1] Gartner study by Justin Lavelle – https://rb.gy/iwsmlf, last accessed: 13.03.2023

Transferring physical Design Thinking models to digital formats, e.g. using whiteboards and storyboards, has been explored before [14,24]. In addition, approaches for Design Thinking using digital formats have been proposed [2], as well as ideas for working fully immersed in virtual 3D environments [22]. However, the integration of physical, digital, and virtual modeling environments for Design Thinking has so far not been achieved. The availability of such an approach would however facilitate the exchange of design information in hybrid work scenarios where some actors work remotely and others are physically present.

Therefore, we propose in the following a concept and prototypical implementation of a new modeling tool for the Design Thinking approach called "Storyboarding". Thereby, we aim to narrow the gap between traditional physical, digital, and virtual Design Thinking approaches. Three research questions guided our investigation, which are informed by design-science research (DSR) oriented methods, e.g. [17]. These are: **RQ1**: "What are the requirements for a software application that supports Design Thinking and that enables narrowing the gap between physical, digital, and virtual modeling environments?", **RQ2**: "What would a software tool look like that would meet these requirements?" and **RQ3**: "What are the results of evaluating the usefulness and usability of the implemented prototype?".

The remainder of this paper is structured as follows. Section 2 briefly discusses the foundations of Design Thinking and related prior work. Section 3 presents the research methodology, followed by the objectives of the solution and the requirements for the approach in Section 4. The realization of the prototype according to these requirements will be described in Section 5. After a demonstration and an initial evaluation in Section 6, the paper ends with the discussion and conclusion in Section 7.

2 Foundations and Related Work

In this section, we briefly present the foundations and the related work for *Design Thinking*, *Physical and Digital Design Thinking Approaches*, and *Design Thinking in virtual modeling environments.*

2.1 Design Thinking

According to Herbert Simon, the design process is a rational set of procedures that respond to a well-defined problem [19]. Design is thus an important activity as it creates solutions and appropriate structures for previously unsolved problems or new solutions to problems that were previously solved in other ways [1].

The user-centered method *Design Thinking* adopts this approach of design. *Design Thinking* typically reverts to an iterative five-step process, which systematizes the procedure of design until a solution is found. A commonly used scheme was developed at Stanford University and includes the following steps: 1. "(Re-)Design the Problem", 2. "Needfinding & Synthesis", 3. "Ideate", 4. "Prototype", and 5. "Test" [3]. Further, Design Thinking promotes the use of interdisciplinary teams for enhancing the overall creative performance and environment [20].

2.2 Physical and Digital Design Thinking Approaches

Design Thinking is traditionally conducted *physically* with people working together at the same location. Common techniques include *Mindmapping* with whiteboards, or *Storyboarding*, where scenes of future scenarios are visually or haptically depicted, e.g., using paper figures [20].

For enabling the transformation of these physical techniques to digital formats, several ideas have been proposed in the past. Wenzel et al. [24] presented an approach for transforming physical whiteboards into digital *Tele-Boards* by taking photos of the original whiteboards and transforming them with the help of a web-based procedure into digital replications. Miron et al. [14] presented the *Scene2Model* approach for the automatic transformation of haptic storyboards into diagrammatic models and their deployment in a computer-aided design environment. By tagging the storyboard figures with visual markers, the system is able to transform the arrangement of the physical figures into corresponding digital 2D models. In addition, there are several commercial collaborative whiteboard and Design Thinking tools available[2].

2.3 Design Thinking in Virtual Modeling Environments

We refer to digital Design Thinking approaches that use three-dimensional modeling environments as "Design Thinking in virtual modeling environments". Rive and Karmokar [18] presented a collaborative Design Thinking approach in virtual worlds by using *Second Life* [13]. Thereby, users can meet as avatars in a virtual world and work collaboratively on their ideas in different setups. Further, Vogel et al. [22] presented a virtual reality (VR) application that allows users to create Design Thinking storyboards of prototypes by collaboratively arranging virtual objects. Due to the high immersion through virtual reality, this approach aims to deliver an experience as close as possible to the traditional physical Design Thinking approach. However, this approach is based exclusively on virtual reality and does not provide an interface to digital or physical modeling.

In summary, several proposals for digital and virtual Design Thinking approaches have been made in the past. However, to the best of our knowledge, a virtual Design Thinking approach that bridges the gap between physical, digital, and virtual modeling environments has not yet been described in research or practice. Therefore, we will address this research gap through the design, development, and initial evaluation of a new virtual storyboarding modeling tool.

3 Methodology and Research Design

For the development of our approach, we revert to Design Science Research (DSR) and follow the procedure by Peffers et al. [17]. In the following, we outline the six steps of the design procedure.

[2] See for example: Invision, SprintBase, Stormboard, Userforge, Smaply

The problem of the project has already been formulated in the introduction (Step 1). In *Objectives of a Solution*, we derive the requirements for our artifact by analyzing related work in the area of traditional, digital, and virtual Design Thinking (Step 2). The *Design & Development* phase (Step 3) includes decisions on the design of the artifact and a first implementation of a prototype to ensure the technical feasibility. In the *Demonstration* phase (Step 4) we describe the demonstration and evaluation of the artifact by reverting to a group of students. This includes a first quantitative evaluation of the usability by conducting a SUMI questionnaire [9] (Step 5). The *Communication* phase (Step 6) corresponds to the publication of the findings for the academic community and industry by means of this paper.

4 Objectives of a Solution

The objective of this work is to produce a new IT-artifact in the form of a software application for the problem domain [8,11] and contribute to the scientific knowledge base on how to solve upcoming problems in a remote working model [7,16]. Thereby, we aim to bridge the gap between traditional physical, digital, and virtual Design Thinking. To identify the different requirements for the design and functionality of the Design Thinking tool, we examined existing approaches in physical, digital, and virtual Design Thinking.

To develop the specific requirements for our artifact, we reviewed the literature on design thinking to first derive general Design Thinking requirements (DR) [19,1,20]. In a second step, we screened the literature for physical and digital Design Thinking modeling approaches [14,24,18]. In a third step, we reviewed the existing approaches in virtual Design Thinking [22], followed by the conception of a suitable state-of-the-art technology stack for implementing a storyboarding prototype.

Although there are tools for virtual collaborative Design Thinking [22], we have not found an approach that provides an interface between traditional physical, digital, as well as virtual Design Thinking. Based on the collected information, five design requirements were derived as mandatory requirements for our Design Thinking artifact. Thereby, we answer the first research question (RQ1).

DR 1: Know-How – Users can apply the same Design Thinking methodology in virtual modeling environments that they are familiar with in the physical and the digital worlds [24,14]. This refers to the re-use of existing Design Thinking methodologies to facilitate the interaction for users.

DR 2: Collaboration – Users can collaborate in real-time with others in the same environment as if they were in the same location [22,23].

DR 3: 3D-based – Users can understand spatial relationships by perceiving, and interacting with the environment in three dimensions [5].

DR 4: Browser-based environment – Users can run the application in a browser on different mobile and desktop devices [24].

DR 5: Interoperability – The models created in remote and virtual Design Thinking are compatible with physical models by using a digital information exchange interface.

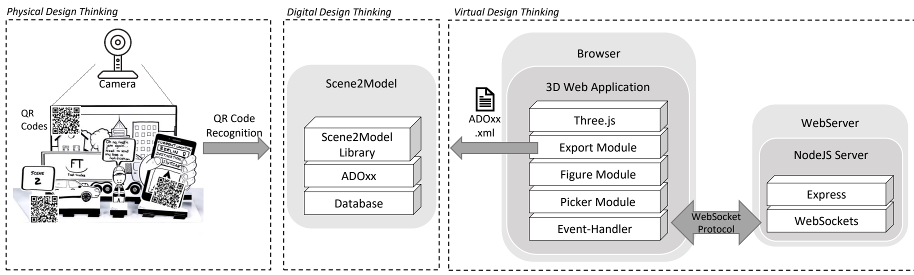

Fig. 1: Technical architecture of the modeling prototype.

5 Design and Development

In this section, we describe the development of our artifact in the form of a web-based modeling application according to the requirements listed above. Since our approach should enable the interoperability between physical, digital, and virtual systems, we decided to design a virtual *Storyboarding* tool that would be compatible with the Scene2Model modeling tool, which already bridges physical and digital storyboarding [14].

Our approach uses the graphics from SAP-Scenes[3]. Thereby, we meet the *Know-How* requirement, since the user does not have to learn a new methodology for using our modeling approach – see DR1.

According to the collaboration requirement (DR2), we foresee functionalities for sharing information about the scenes between different users. On a technical level, we added internal modules for handling the interaction with the Design Thinking figures – *Figure* and *Picker* module – see Figure 1. These modules then propagate the changes made by a user to the back-end server and back to the connected users. With this functionality, we ensure that all connected users can manipulate the same scene simultaneously as if they were interacting with paper figures in physical space.

For enabling users to gain a spatial understanding of the environment, the 3D JavaScript framework Three.JS[4] is used for the front-end web client, thus meeting the requirement of three-dimensional perception (DR3). The storyboard figures can be moved and rotated in all three axes during modeling, allowing the user to perceive the spatial relationships between the various objects.

The prototype architecture has been designed to be platform-independent (DR4). This means that the application will work on any device with browser support. In regard to the interoperability of our prototype (DR5), we developed an *Export Module* (see Figure 1) that allows the export of the virtually created models to the ADOxx-XML format [6]. This format is compatible with the 2D Design Thinking approach of *Scene2Model* [14]. This helps achieve the objective of easily sharing design information in hybrid work scenarios – see Figure 1.

[3] https://apphaus.sap.com/resource/scenes
[4] https://threejs.org/

6 Demonstration and Initial Evaluation

For the demonstration and evaluation of our artifact, we chose an *Ex Post, naturalistic* evaluation strategy according to the *DSR Evaluation Strategy Selection Framework* by Venable et al. [21]. In the first step, we assessed the *technical feasibility* in terms of the fulfillment of the previously derived design requirements by implementing a prototype. Next, we evaluated the *usability* of the user interface through a lab experiment and a standardized usability questionnaire.

6.1 Technical Feasibility

As defined in the second research question (RQ2), the goal of this work is to investigate how an implementation of a software application that allows the collaborative, remote creation of 3D virtual Storyboard models and transformation of these scene models into 2D representations which are compatible with a traditional pen-and-paper approach. Regarding the design requirements DR1, DR3, and DR4, we were able to realize the prototype using the technology stack described in Section 4. The collaboration requirement of DR2 is currently implemented in a rudimentary manner, lacking synchronization of all element attributes. This is due to the high implementation effort required to develop this functionality to meet the expectations of today's users, especially when compared to advanced commercial collaboration tools.

The functionality required by DR5, i.e., the transformation of virtual models to the digital platform Scene2Model [14], is implemented in a module for the export of the 3D scenes to the ADOxx-XML file format. The models created with our artifact were successfully imported as 2D models into the Scene2Model tool, which is also capable of importing pen-and-paper models.

In summary, the evaluation of the technical feasibility shows that the software prototype meets all design requirements and that all intended functionalities could be implemented. The only limitation so far is the collaboration functionality, which does not yet allow full synchronization between all clients.

6.2 Usability of the Artifact

For a first usability evaluation, the software prototype has been tested with users as part of an introductory course in business informatics at the University of Fribourg. The goal of this study was to assess various dimensions of usability and receive feedback for potential improvements. 20 volunteer students, all studying either management, economics, or business informatics in their first semester received an introduction to *Design Thinking* and *Storytelling*. None of them had prior knowledge of Design Thinking. First, the participants were divided into three groups and were given the task of modeling a use case with the storytelling approach using SAP-Scenes paper figures[5]. The focus for this use case was to elaborate on the question: "How do you imagine a normal working day to be?". To familiarize participants with the storyboarding approach, traditional paper-and-pencil modeling was used.

[5] https://apphaus.sap.com/resource/scenes

The participants were then divided into groups of two. All had access to a special browser-based web application for modeling the digital *storyboard* in the 3D environment of the prototype application. The participants had to answer the question: "How do you imagine the digital University of Fribourg in the future?". The participants had about 30 minutes to model their *storyboard* with the 3D modeling prototype. Screenshots of the modeling environment, as well as an XML export of the scene, had to be submitted for evaluation. Some examples of the study's outcome for the virtual approach are depicted in Figure 2.

Finally, the participants had to answer a standardized online SUMI questionnaire [9] for evaluating the prototype in terms of usability. We used the SUMI questionnaire because it is a well-accepted approach for evaluating the usability of a software prototype and freely available for academic purposes. In the following sections, we present the qualitative and quantitative results of the questionnaire.

6.3 Quantitative Results

In the quantitative part of the study, there were questions about *efficiency*, *affect*, *helpfulness*, *controlability*, and *learnability* of the artifact. From the 20 participants, there were 17 surveys that we could analyze. The mean value of the *efficiency* and the *affect* are with 46.59 and 46.29 respectively, clearly below 50 points. The *helpfulness*, *controllability* and *learnability* are 50.88, 50.18, and 50.94 points, each slightly above 50 points. With a *global usability score* of 47.94, the evaluation of the prototype is not extraordinary, since the usability is considered reasonable at an average of 50 out of 100 points.

However, the main focus of our user study was not the quantitative evaluation of our prototype. In the next section we will look at the qualitative part of the questionnaire.

6.4 Qualitative Results

The qualitative part of the questionnaire focused on the capabilities and limitations of the current prototype in order to identify potential drawbacks or problems and to improve these aspects in another DSR cycle.

The SUMI questionnaire rates statements with "agree", "undecided", or "disagree" to evaluate software functionality. Participants generally agreed on the software's main functions but noted unexpected behavior and inadequate handling of failures. Although users generally had positive opinions, many would not recommend the software to colleagues. Furthermore, the questionnaire asked

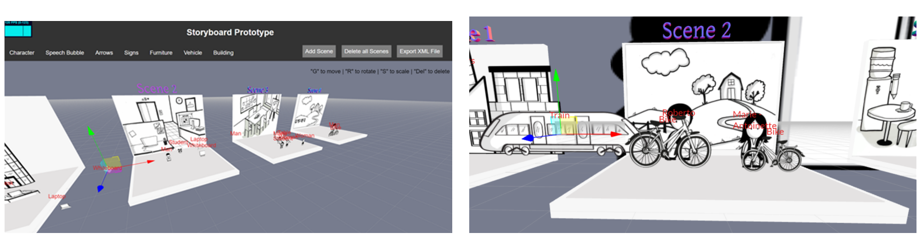

Fig. 2: Examples of the digital storyboards resulting from the case study. The storyboards have been created with the newly implemented modeling prototype.

open questions for the evaluation of the given topic. We will focus here on the two questions ´´What do you think is the best aspect of this software, and why?" and What do you think needs the most improvement, and why?"

Participants liked the prototype's simple interface, ability to have different views, faster arrangement of objects, and variety of objects with different attributes. However, some found interaction with the prototype challenging, including scrolling and keyboard events, cumbersome text entry, and difficulty scaling and moving objects. In addition, some users criticized the 3D environment because objects are simply 2D images placed on a plane, making it difficult to place them in relation to each other. Finally, some participants noted that the *Drag&Drop* functionality does not work in the *Safari browser*.

After the testing, we asked participants to indicate their preference between the traditional storytelling approach and the current prototype on a flip chart. Out of 17 answers, 13 participants preferred the traditional approach, citing reasons such as ease of use, collaboration, and interaction. Only three participants preferred the prototype, noting its eco-friendliness or personal preference for digital solutions.

By evaluating our prototype as described in this section, we addressed the last research question (RQ3).

7 Discussion and Conclusion

Although remote work and collaboration has received a tremendous boost from the pandemic, the design challenges it poses have not yet been addressed in research. Considering that an interface between traditional Design Thinking and virtual Design Thinking is needed to overcome the challenges of remote collaboration, our research aims to fill this research gap and encourage other researchers in this area. Therefore, we have developed a virtual *Storyboarding* modeling prototype that enables 3D collaborative remote design thinking, as well as the transformation of these 3D models into a digital 2D model. This was the first step towards bridging the gap between traditional physical, digital and virtual Design Thinking modeling approaches. By deriving the requirements for such a tool and implementing a first prototype, we answered the first two research questions – RQ1 and RQ2.

We evaluated technical compliance with the design requirements and conducted a user study with 20 participants to answer research question RQ3. The results are encouraging and show the potential of the 3D tool.

However, this prototype has some limitations as it is still in early development with missing features and incompatibilities. The evaluation involved university participants, most of whom were between 20 and 30 years old and unfamiliar with Design Thinking and storyboarding, potentially introducing evaluation bias.

At this stage of prototyping, the goal was not to have a perfect solution for virtual Design Thinking, nor to evaluate the tool based on a potential customer group, but to find out if the modeling prototype had the potential to bring virtual and traditional Design Thinking closer together.

The contribution of this research is manifold. Firstly, the prototype can serve as a guide for users interested in virtual collaborative Design Thinking to overcome the challenges of working remotely. Second, the use case of remote collaborative Design Thinking can inspire solutions in other virtual collaboration domains. Finally, our evaluation can encourage further research in business informatics to bridge traditional pen-and-paper and virtual models.

In the future we plan to verify the requirements by collaborative designers, extend the prototype by enabling virtual- and augmented reality (VR/AR) functionalities, and improve real-time collaboration. This would be possible, by using a metamodeling platform that already supports a VR/AR technology stack such as introduced by Muff and Fill [15]. This may open up new possibilities for even more immersive collaboration and natural interaction, as well as easier adaptability through metamodeling capabilities. We also plan to conduct an evaluation with a larger group of users to get more concrete feedback.

8 Acknowledgment

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