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Artefacts Supporting Distributed Design Collaboration

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Abstract
This study addresses the mechanisms by which collaboration environments affect design teams' collaboration via shared artefacts. We collected data by observing design teams consisting of experts and decision makers. The teams utilized (1) a state-of-the-art web conferencing collaboration environment and (2) a three-dimensional virtual world in their collaboration. Our analysis reveals the virtual worlds' potential to foster the use of pictorial documents as design teams' shared artefacts. In addition, our study embraces the web conferencing tool's potential to nourish interaction on the basis of written artefacts. The findings contribute towards distributed design research, describing the role of design artefacts, and describing ways, how different collaboration environments can support distributed design teamwork.

Keywords: Design artefacts, distributed design, virtual worlds

1. Introduction
Current trends of globalization and evolving collaboration technologies are transforming design teamwork from collocated to distributed interaction. This transformation requires an understanding of the operations, tools, and practices that support distributed design collaboration.

Several studies highlight the role of artefacts in design collaboration [3], [4], [10]. Artefacts refer to documents, such as drawn sketches, images, textual documents, three-dimensional models or prototypes, used during the design process. Shared artefacts are suggested to contribute to mutual understanding within team collaboration [15]. Artefacts foster knowledge transfer by supporting the building of a common ground among diverse team members [3]. Artefacts can also conscript team members towards mutual interaction [10], [11]. The essence of artefacts is also studied in ICT mediated, distributed collaboration [4], [17].

This paper presents the results of an empirical study that focuses on the transformative impact of collaboration technology environments on the distributed design teams‘ activities. We observed distributed innovation and design teams in a global manufacturing corporation. These teams interacted in two collaboration environments. One of them was a traditional web conferencing tool, while the other was a novel three-dimensional virtual world collaboration space. Previous research has discovered the potential of virtual worlds' contributions towards team creativity [1] and collaborative design activities [21].

Collaboration environments impact distributed teams' group processes and work outcomes [9]. Therefore, it is relevant to ask how different collaboration environments can foster distributed design collaboration. Only few empirical studies address real-life distributed design teams that utilize various artefacts to support their collaboration. More research is also needed to examine emergent collaboration technologies' support of design collaboration. Therefore, our paper addresses the following research questions:

> *What types of artefacts can be used to support distributed design interaction?*
>
> *How do virtual worlds and concurrent web conferencing environments differ in terms of artefact manifestation during distributed design collaboration?*

We define design thinking in the context of our study. Next, we discuss the essence of artefacts in a design process. Then, we outline differences that emerge within collaboration environment genres that can be used in design collaboration. Finally, we present and discuss the results of our study, assessing their implications from the perspectives of theoretical concepts and design practices.

2. Theoretical points of departure

Design thinking can be referred to as an analytic process that engages its attendees in experimenting, creating and prototyping models, gathering feedback and redesigning [18]. Design thinking embeds the practices of inventing, creating and implementing artefacts, thereby integrating and transforming heterogeneous and uncertain domains of knowledge [4]. Therefore, design thinking is considered a design paradigm [6], [7].

2.1 Artefacts

The role of artefacts has been highlighted in the context of design [3], [10]. Artefacts are objects that represent an individual's or a team's knowledge. These representations may concern physical objects, processes and people or other features of an activity environment. In a design context, the artefacts as representations of design knowledge are referred to as design artefacts [16]. Design artefacts serve a variety of important roles: they provide an external representation of the information in a designer's mind, are central to communication, and allow designers to see and reinterpret the design [19].

Typical design artefacts include sketches [10], images, documents, and other types of documentation. Instead of remaining static and unaltered, design arte-

facts may develop and change during the design process. Design typically begins with a series of sketches and later includes more structured drawings, such as plans and sections [19]. Especially in the later phases of design process, these artefacts can be digital, such as 3D models and electronic repositories [20].

Given design artefacts' representative and signifying nature, artefacts by themselves are incomplete embodiments of knowledge. When artefacts are used to support conversation, it *might be* possible that they transmit some shared understanding of a design situation [16]. Therefore, in addition to the design artefacts themselves, the mechanics of interaction that occur and are embraced by the artefacts are equally important [20].

2.2 Collaboration environments in design interaction

In distributed design settings, the presentation of design artefacts is supported by collaboration environments. Collaboration environments themselves can be seen as platforms for technological artefacts [17]. In addition, artefacts such as whiteboards and interactive walls have been noted to integrate physical and digital interaction in both collocated and distributed settings [12].

Several previous studies have discussed asynchronous collaboration environments and synchronous teleconferencing tools used by collaborative design teams. We outline the collaboration environment's role in distributed design interactions as twofold: First, the environment should support the creativity and common ground-building necessary for the design team's work by fostering shared, dynamic acts and members' re-representation of those acts [8]. Second, the collaboration environment should foster shared understanding among the team members [4], [16].

As an emerging option for concurrent web-conferencing systems, three-dimensional virtual worlds are a recent advance for distributed team collaboration [2]. In virtual worlds, the team members are able to signal their non-verbal behavior to others [5]. Design teams can also utilize the virtual worlds' potential to change the user's frame of reference: for instance, virtual models of designed buildings allow distributed team members and clients to experience and troubleshoot a future building already in the design phase [2], [8]. The virtual world's potential for different design purposes is previously highlighted [6], for example, to foster team creativity [1].

3. Data and Methods

3.1 Data collection

We conducted an in-depth qualitative case study within a global manufacturing and maintenance company. We studied 14 interaction sessions of teams and dyads, composed of experts and corporate decision-makers. The participants collaborated in design context by identifying and presenting problems, ideating solutions, and making decisions. Altogether, 36 attendees from six countries participated the interaction sessions.

Nine interaction sessions used a traditional web conferencing environment (MS Lync). The web conferencing tool includes functionalities such as application and desktop sharing, joint control and co-editing of content, annotation, and chat. Five interaction sessions used a three-dimensional virtual world collabo-

ration space (offered by Immersive Terf, Inc.). The virtual world allows users to co-create the collaboration space by adding displays for documents, web pages, whiteboards, and furniture. The participants are allowed to have self-representation through their avatars in the space and to navigate and negotiate the space similar to the way they would in a physical space.

We selected these environments because they are representative examples of their collaboration technology genres. Because the web conferencing tool is widely adopted outside and within our case corporation, it was embedded in the corporation's daily work practice and did not require learning for the users. The virtual world was new to the participants, requiring learning and transformation of their work practices. The participants did not receive any pre-training for the collaboration. However, an experienced facilitator provided technical *ad hoc* assistance for them during the interaction sessions.

We observed and recorded each team's interaction sessions. The duration of the sessions varied from 40 min to nearly 2 hours. We used these interaction sessions as units of our analysis. Data analysis was undertaken iteratively, following an abductive approach.

In both collaboration environments, we collected data from three sources. We (1) observed and recorded the design interaction sessions in both collaboration environments. After the interaction sessions, we conducted (2) a post-experimental survey that was administered to the team members. We also collected (3) data from the corporate innovation processing system related to the specific cases we studied. In addition to the primary data sources, we collected corroborating data from informal interviews and observations of meetings that the corporate innovation department team attended. The entire data collection period lasted 18 months.

3.2 Data analysis

We employed a qualitative multi-method analysis towards the data. The analysis proceeded as follows. First, one of the research team members transcribed the interaction sessions from recordings. He also segmented the transcriptions into turns, i.e., action switches between the participants.

Thereafter, we reviewed the recordings and transcriptions to identify documents that were both present in the visual communication channel and referred to in the auditory communication channel. If the document was manifested in visual and auditory communication and was a focus of team interaction, we labeled it a shared design artefact.

As a researchers' joint effort, the documents were classified according to their types. For example all technical drawings representing different objects that were used in different interaction sessions were labeled "technical drawings". However, drawings of the designed objects' form and models were separated from technical drawings because of their different contents and purposes of use.

As a result of the analysis, we produced a list of different artefacts that manifested during the design interaction sessions. For each artefact, we summarized (1) a typical phase of design interaction in which the artefact manifests, (2) an

activity to which the artefact was typically related, and (3) the collaboration systems within which the artefact manifested. When we found more than a single option within any of the phases – for instance, an artefact was used in two types of activities or in both collaboration environments – we listed all options.

Finally, we reviewed the classified artefacts for both collaboration environments' interaction sessions. As a result, we discovered repeating incidents that were characteristic of only one of the two collaboration environments.

4. Results

4.1 Shared documents as artefacts in distributed design collaboration

The team members utilized a great variety of documents as artefacts to support their distributed design interaction. These artefacts are depicted below. The documents are grouped according to our classifications. Table 1 presents artefacts that were typically composed of pictorial content. Table 2 lists the artefacts that were a combination of pictorial and written content. Finally, Table 3 presents artefacts with only written content.

Table 1. Artefacts with pictorial contents

Artefact	**Collaboration system (WCT = web conferencing tool VW = virtual world)**	**Typical phase of the design thinking cycle**	**Example of a typical activity**
Sketches	VW	Beginning of the design thinking cycle: sketching the operating principles of a product.	Sketching an image that depicts operating principles of the designed product; pointing and annotating the sketch.
Mock-up images	VW	Typically in developed / progressed design interaction sessions.	Discussing and annotating a 3D CAD image of the product in its intended surroundings.
Animated video describing the intended functionality of the product	VW	End of the design thinking cycle / before the prototyping phase.	Describing the intended functionality of the product or the intended context in which the product would be used.
Technical drawings of the product	VW	Mostly in the sessions at the end of the design cycle.	Describing the expected functionality of the product or discussing the developed product's details.

Photographs and other fixed images	VW	Mostly in the sessions at the end of the design thinking cycle.	Viewing and pointing to the image that depicts a prototype of the designed product: discussions concerning certain details.

Table 2. Artefacts with combined text and image contents

Artefact	**Collaboration system (WCT / VW)**	**Typical phase of the design thinking cycle**	**Example of a typical activity**
Company's idea management system	WCT	Beginning of the design thinking cycle.	Presenting the object of the design activity in its original context within the idea management system.
Slideshow presentations of the idea / concept	WCT & VW	Beginning of the design thinking cycle.	A structured presentation of the idea that is being developed during the design thinking cycle.
Slideshow presentations of the designed product	WCT	In a couple of sessions, during which the designed product was proceeded at the end of design thinking cycle.	Presenting the designed product using a slideshow.

Table 3. Artefacts with written contents

Artefact	**Collaboration system (WCT / VW)**	**Typical phase of the design thinking cycle**	**Example of a typical activity**
Text on whiteboard	WCT & VW	Used in all except one session, various phases of design thinking cycle.	Writing and co-authoring text, pointing on certain text and referring to the text in speech.
Product's requirement specification document	WCT	Mostly in sessions at the end of the design thinking cycle	Primarily either negotiating a detail of the designed product or elaborating the contents of the document.

The following conclusions can be drawn based on the aforementioned results. First, artefacts with pictorial contents are used primarily in virtual worlds. In contrast, artefacts with written contents are favored in interaction sessions that occur via the web conferencing tool. According to previous studies (e.g., [5], [13]), this phenomenon relates to the virtual world's rich visual communication channel. The rich visual communication channel fosters presenting pictorial

contents. In contrast, in the web conferencing environment, the auditory communication channel is more central to communication: this might lead participants to embrace processing of auditory content in a written form.

Moreover, those artefacts that are combinations of written and pictorial contents are utilized in both collaboration environments. This might indicate the artefacts' applicability in different collaboration environments. On the other hand, users are able to utilize these, documents, being slideshows or extractions of an ICT tool, in various manners. For instance, the interaction can be nourished by the pictures or the text, depending on the context of collaboration.

Both collaboration environments embrace the use of artefacts in all phases of the design thinking cycle. The examples of typical activity indicate that participants in both collaboration environments engage in similar tasks; only the essence of the artefact that mediates the action is altered. For instance, planning and co-authoring tasks occur via sketches in a virtual world and via texts on whiteboard in the web conferencing environment.

Finally, the artefacts' content seems to develop in parallel with the progress of design thinking cycle [10], [11], [19]. This phenomenon occurs in both collaboration environments. However, the difference between written and pictorial contents remains. For example, sketches are used by project teams in virtual worlds during the initial phases of the design thinking cycle. Meanwhile, project teams that interact via the web conferencing tool use the whiteboard function for notes and other preliminary written contents in a similar way.

4.2 Differences between the collaboration environments

In addition to the aforementioned differences of the virtual worlds' priming effect on pictorial artefacts and the web conferencing tool's similar effect on written artefacts, our comparative analysis revealed two more differences between the collaboration environments. First, we outline the virtual world's potential to simultaneously act as a technological artefact and a platform for artefacts. Second, we discuss the virtual world's potential to process parallel artefacts.

4.2.1 Collaboration environment as an artefact

Existing studies report the use of virtual building models as boundary objects [8]. We observed a similar instance in this study in which the virtual world as a collaboration space supported collaboration around the team's shared artefacts.

To provide an example, the virtual world's interaction sessions begin as a situation in which the team members were gathered in the virtual lobby. In the lobby, the attendees were technically instructed how to operate in the virtual world, including speaking and hearing each other. The lobby space allowed participants to move their avatars, try to express different gestures and become familiar with the infrastructure of the virtual world. The virtual lobby space and technical facilitation intervention were used to create a training context and content (Figure 1). After the technical instructions, the facilitator invited the participants to go to a virtual meeting room that looked like a physical meeting room with a conference table and chairs (Figure 2).

Figure 1. Team members gather in a virtual lobby to check the functionality of technology artefacts

Figure 2. Attendees gather around the virtual meeting room's table

The transition from a virtual, open space to a meeting room repeatedly allowed the teams to experiment and try the boundaries of virtual world [13] in a way that is oriented towards work and collaboration. In other words, the changing virtual environment alters the stimuli that users receive from their environment, including the knowledge of expected behavior. The virtual world acts as an artefact that, by acting as a context for the design interaction, directs the users to new modes of operation.

4.2.2 Parallel processing of multiple artefacts

Within the virtual world interaction, the design team members were able to use and process several parallel artefacts. Typical parallel actions included uploading several images, documents and other visual artefacts relevant to their task on multiple display panels that surrounded the team in the virtual collaboration space. During the interaction, team members were able to switch their focus rapidly from one artefact to another and select the most relevant artefact to observe while they were listening to the ongoing discussion. Team members were able to share the audio and visual communication channels. Finally, team members were able to observe where a colleague's attention was directed through the colleague's avatar's gaze and proximity.

Figure 3 provides a snapshot of an interaction session in which several team members had uploaded boundary objects to display panels to support their collaborative discussion and observations. In the figure, the participant avatars (nr. 2 and 3) are engaged in observing the image, and one participant avatar (nr 1) directed his attention toward the technical drawing. During the ongoing discussion of ideas, they simultaneously used the product image, technical drawings, and layout CAD drawings while elaborating the product's technical details.

Figure 3. Manifestation of two parallel design boundary objects in a virtual world

5. Discussion and conclusions

Our study addresses distributed design collaboration within the context of design thinking. We present and discuss insights about how documents as shared design artefacts and collaboration environments that act as contexts for these artefacts can support distributed design interaction.

We discovered a variety of document artefacts that were used during the collaborative interaction of real-life design teams. We labeled these artefacts as pictorial or written or a combination of these forms. We found that in virtual world interaction sessions, pictorial artefacts were favored. Virtual worlds also allowed the processing of multiple, parallel artefacts simultaneously and were used to direct the design interaction by acting as a dynamic and altering context. In contrast, written artefacts were utilized extensively in web conferencing interaction sessions. Both collaboration environments supported various phases of the design thinking cycle.

Our findings contribute to research regarding distributed design collaboration. The different collaboration environment genres' tendency to prime different types of content might explain the hindrances encountered in computer-mediated design collaboration [14]. Our findings also expand the understanding of virtual worlds' potential to support design collaboration (see e.g., [13], [21]).

We connect the practical contribution of our study to the tool-to-task fit concept. When a design team intends to process pictorial contents, our results suggest the use of virtual world collaboration. When textual or spoken contents will be processed, the web conferencing tools might be a more suitable option. Finally, we encourage design team members to consider the appearance and form of their mutual artefacts when sharing knowledge or processing the artefacts' contents.

Because of the study's exploratory nature, the following limitations can be identified. First, because ours was a case study, it was impacted by the working practices of the case corporation, although we consider the case corporation a good representative of a global industry corporation. Moreover, our technological choices may have affected the results. Our selection of collaboration tools was guided by the wide adoption of web conferencing tools and previous research experience with the virtual world. However, rapidly developing technologies might embrace novel affordances for design interaction. We believe

that the results should be validated with a more extensive study that involves teams that are experienced in virtual world collaboration.

Distributed design collaboration is rapidly becoming a new standard for design interaction. This development calls for research into the interaction tools that support collaborative design activities and practices that are favorable towards collaborative design interaction. Based on this study's findings, we suggest future research efforts to examine these differences between collaboration environments that support distributed design interaction and to develop understanding concerning the role of design artefacts within distributed design collaboration. For instance, it would be valuable to discover understanding of artefact modalities that support various design thinking phases, or measure the effectiveness of shared artefacts. Equally, we are interested in the communication mechanisms by which visual content is processed within the different collaboration environments during design collaboration. Finally, we expect that empirical studies that compare virtual worlds and state-of-the-art collaboration environments will contribute to the development of emerging interaction and collaboration technologies.

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