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REVIEWS

Collaborative Design

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Abstract | Global cooperation is a reality for most engineering design teams today, and even though the core group is co-located, they are forced to cooperate with subcontractors or experts with complementary knowledge and skills. The design process can be seen as an integration of a technical, cognitive and social process, and such process is clearly multidisciplinary. This review presents research challenges and emerging directions for future research and focuses on interpersonal communication in collaborative design—small teams of interdisciplinary stakeholders who work jointly toward a common goal that would not otherwise be accomplished by the individual participants themselves.

1 Introduction

Global collaboration is a reality for most companies today, with multidisciplinary teams working in parallel and independently to develop products with limited resources and shorter and leaner design cycles. Some of the challenges include aspects such as differences in language, culture, education, and government regulations, and that the team works across different time zones around the world. To support collaborative design, methods and technologies should not only strengthen the capacity of individual specialists, but also increase the capacity of participants to interact with one another and take advantage of the group's integrated knowledge and abilities.

The underlying problem is that engineering design is fundamentally a socio-technical activity, since design activities involve immense communication and interaction among individuals and groups in generally complex social settings. Social activity cannot be separated from the technical results, they are intertwined:

> "*… meetings that produce the specifications; the discussions around rough calculations and sketches that create understandings among the participants; the arguments about interpreting test results and prototype qualities that contribute to 'feel' and 'intuition' about aspects of the design; and the debates about whether the design is 'done', if the specifications have been 'met', and if the result is 'good'…*"[1]

Hence, a design process is seen as an integration of a technical, cognitive and social process.[2] As Larsson points out, "*the social character of design activity is not separated from the technical results*",[3, p.153]. This process is much easier to perform in a co-located team. Although the local team often does not have the right competences, knowledge or abilities to accomplish a certain task, its members are forced to work with one another. The level of involvement and interaction among participants in a collective project can be quite different. Researchers attempt to differentiate between different types of collaboration, the most common used in research include collaboration, cooperation and coordination:

- *Coordination* is the most basic level and includes the organisation of resources or elements, usually within a complex body or activity. Often it is performed in a large community with multiple and even competing goals.
- *Cooperation* is the process of working together with shared resources and sometimes shared methods. This often includes the subdivision of tasks that are developed in smaller teams and later integrated. MacGreggor[4] highlights that "*Co-operation is the overall process of working together, which includes other elements such as collaborative actions, which may change over time*".
- *Collaboration* is the action of working with someone to produce or create something,

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usually involving the parties to achieve a common goal or interest that the individuals would be incapable of accomplishing alone.

Both collocated and distributed design goes through cycles of collaborative and individual work, depending on the project context. The concept of *True Collaboration*[3] was introduced to distinguish when diversity and competences of the whole team can be utilized, and where team members can *think together* rather than merely exchange information and opinions, and divide work.

Lu et al.[5] summarise the distinguishing characteristics of working together, as shown in Table 1.

Lu et al. use the following definition of Collaborative Engineering: it "*facilitates the communal establishment of technical agreements among a team of interdisciplinary stakeholders, who work jointly toward a common goal with limited resources or conflicting interests*".[5, p.617]. It is important to highlight that collaborative teams often have conflicting interests (based on personal interests, different strategies from the companies involved, etc.).

CSCW (Computer Supported Collaborative Work) is a scientific discipline that allows people from a variety of different disciplines to come together and discuss issues without any common ground, except for the very vague idea that it is somehow about using computers to support activities of people working together.[7] The CSCW discipline is socially-oriented rather than technology driven.

In design, collaboration is used to enhance knowledge within the team, where the participants involved need to interact and share knowledge with others. This is considered vital to most companies, but also very difficult. Alan Mulally, Director of Engineering for Boeing's 777 project, which consisted of 5,000 Boeing engineers and thousands more who worked in Boeing's supplier companies, described the problem of communication as follows:

> "*The biggest problem with communication is the illusion that it has occurred. We think when we express ourselves that, because we generally understand what we think, the person that we're expressing it to generally understands it in the same way. When you're creating something, you have to recognize that it's the interaction that will allow everybody to come to a fundamental understanding of what it's supposed to do, how it's going to be made. We should always be striving to have an environment that allows those interactions to happen.*"[6, p.6]

Knowledge sharing and communication are essential to collaborative projects, though this is not easy to achieve even in a co-located project. The aim of this review is to highlight the differences between working in a co-located design project and that in a distributed team. The review focuses on interpersonal communication in collaborative design—for small teams of interdisciplinary stakeholders, who work jointly toward a common goal that could not be accomplished by the individual participants themselves. Finally, the review presents research challenges and emerging directions for future research.

2 Collaborative Design

Research relating to collaborative design is done in the engineering design domain as well as more computer focused domains such as **CSCW**.

In the following section, some of the most important technologies for collaborative design are presented.

2.1 *The golden standard—face to face meetings*

Presence is the feeling of being together that comes from interactions among people in a physical, face to face meeting. Interactions includes *gaze* (what you are looking at), *gestures* (non verbal communication using hands and body), *facial expressions* (non verbal communication using muscles in the face), *turn taking* (a process by which people in a conversation decide who is to speak next).

Side conversation is a parallel communication that occurs in a meeting where several parallel threads are discussed at the same time.

Many researchers imply that the golden standard for collaborative work is the face-to-face meeting,[8] since it leads to a natural communication with a higher media richness that is not limited by technology. **Presence**,[9] gaze, gestures,[10] facial expressions,[11] turn taking,[12] and **side conversations**[13] flow naturally through the whole meeting. It is also possible to interact naturally and uncontrived with design artefacts like sketches, documents and physical prototypes. The physical meeting also improves social bonding through activities like informal communication,[14] side-conversations,[13] touching each other, and eating and drinking together, building trust[15] and creating a shared understanding. Physical presence also symbolises a commitment to the meeting.

Table 1: Characteristics of different levels of cooperation (from Lu et al.[5]).

	Stakeholder	Resource	Goal	Task structure
Coordination	Large community	Limited and exchanged	Multiple and Competing	Pre defined, same layer in hierarchy, uni-direction
Cooperation	Mid-size Group	Limited and Shared	Multiple & Private	Pre-defined, across layers in hierarchy, bi-direction
Collaboration	Small team	Limited Shared Complementary	Single & Common	Unified, non-hierarchical, multi direction

Therefore, research in collaborative work has focused on recreating the physical meeting with as high a quality as possible. Videoconferencing is often implemented to solve the problem of the distributed team, and has been available in the research lab since 1930. There has been a massive collaborative effort by the research community to develop better collaboration tools, such as high end collaboration studios with very high resolution video, **telepresence**, and virtual and **mixed reality** tools. Despite these efforts, collaborative projects in industry are often limited to **H.323** or desktop based videoconferencing, where video quality is low due to bandwidth restrictions and poor **interoperability** between videoconferencing systems.

Often, collaborative sessions are restricted to telephone conferencing combined with a shared application, such as *Adobe Connect Pro*, *WebEx* or similar solutions. This type of collaboration is often not adapted to the real needs of the collaborators. Modern conferencing tools can technically transmit high quality audio and video, but their implementation in meeting spaces is often difficult. For example, a natural and high-quality audio experience is critical to achieve a fluid meeting and a sense of truly *being there.* In real world scenarios, audio quality is often substandard, and acoustic feedback, bad automixing, delays, and bad **lip sync** transform meetings that would be very easy to perform face to face into a frustrating experience.

Further, the tools are not designed to replicate actual engineering design sessions. Most telepresence tools seek to replicate the physical boardroom meeting by using conferencing rooms, where the local and remote room blends together into a shared space with half of the table represented by the telepresence system. However, this type of setup is far from the work practice in a creative collaborative session, which may look chaotic from a bystanders' view. In a typical design meeting, the participants interact with whiteboards, sketches, laptops, printed documents (that are shared among the participants and can be annotated) as well as physical prototypes.

Hence, the physical meeting has obviously a lot of advantages. Still, it is of course not possible to conduct all meetings physically, especially if the design team is spread across the world. There is also a vision that distributed meetings can be better than physical, co-located meetings. Holland and Stornetta[17] introduced the notion of "*Beyond being there*", where collaborative tools provide something better than just "*being there*" (e.g. recreating the physical meeting).

2.2 *Enabling distributed collaborative design*

Systems for collaboration are often categorised according to the time and location matrix[18,19] using the distinction between same time (synchronous) and different time (asynchronous), and between same place (face-to-face, i.e. co-located) and different place (distributed), see Figure 1. The ability to move between these spaces is also important, such as the usage of a team room

Telepresence tries to enrich communication to allow people to feel as if they were present at a place other than their true location.

Mixed reality denotes technology that mixes real and virtual objects. This can be preformed by *Augmented reality*, which enhances reality with virtual objects (typically using a using a semi transparent head mounted display), or *Augmented Virtuality*, where real objects are merged in a virtual world.

H.323 is a videoconferencing standard defined by ITU (International Telecommunication Union)—United Nations specialized agency for information and communication technologies.

Interoperability is the ability of systems from different vendors to provide services to, and accept services from other systems, to operate together effectively. This is done by using videoconferencing standards defined by ITU.

Lip sync is a term for audio/video synchronization, and refers to the fact that visual lip movements of a speaker must match the sound of the spoken words. A misalignment (skew) of audio and video of less than 20 milliseconds (ms) is considered imperceptible. A skew of 80 ms is deemed acceptable for most observers.[16]

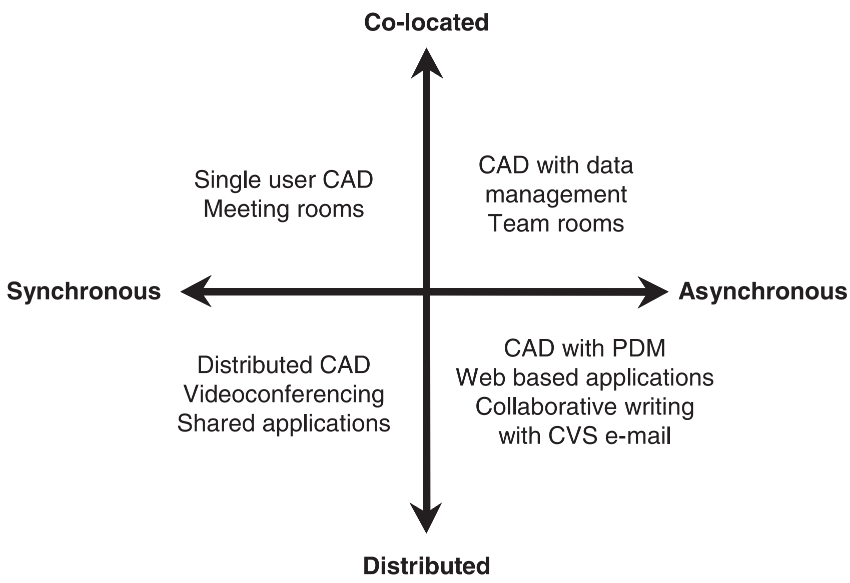

Figure 1: Use of collaborative design tools across time and space.

where the members have the possibility to leave artefacts (whiteboards, documents, prototypes) from a synchronous meeting into a team-room that acts as a collective memory for the team, and helps them update the team when they enter the room again.

Synchronous distributed tools for communication between persons are often referred to as telecollaboration or tele-mediated communication, and can support different modalities, from telephone to advanced, multiuser, virtual-reality conferencing using **haptics**, high quality video, **spatialized audio** etc. The most common telecollaboration tools can be divided into the following sub groups (for a more detailed review see Wolff et al.[20]).

Haptics include any form of interaction involving touch. For collaborative work, this is often done by applying forces, vibrations, or motions to the user to enhance presence and to manipulate or control virtual or physical objects.

Spatialized audio is a way to create a 3D-sound environment to intentionally exploit sound localization, so that users can instinctively detect where a person is located in the 3D-space.

- *Audio conferencing* is the basic form of synchronous communication and still the most used communication tool today, though it lacks many of the social cues available in face to face meetings such as gaze, gestures, expressions and body language.
- *Screen sharing* is often supported in most collaborative systems. Here, all users are forced to share the same view at the same time that is normally controlled by one user. Screen sharing is often combined with audio- or video-conferencing. This is normally adequate for presentations, but allows limited interaction for the participants.
- *Object sharing* allows the user to share documents (i.e. *Google Docs*) or shared 3D-models. Here, the main difference compared to screen-sharing is that each participant can have his/her own view and interactively interact with the object (i.e. browsing and writing at several places in a *Google Docs* document).
- *Video conferencing* provides a window into another place and is an increased improvement over audio-conferencing,[21] because it better supports facial cues, gestures and social presence. To not compromise the interactivity of the conversation, a frame rate of at least 20 fps and a delay of 80 ms is tolerable.[22] To read facial expressions and gestures, large video windows or even life-sized conferencing are preferred.[23]
- *Telepresence* tries to enrich the communication and seeks to replicate the physical meeting, i.e. using conferencing rooms where the local and remote room blend together into a shared environment, and the remote participant is displayed in real size. By sending more than the image of a person's upper body, a richer vocabulary of body language is used.[24] Most commercial systems use high frame rates, high resolution and large displays to improve communication. Most systems use one camera per site, though there are research systems that try to improve presence by using several cameras and more advanced visualisation technologies; examples of this include the office of the future vision[25] and other 3D-conferencing systems.[26] Many of the systems require proprietary installation and very high setup costs.
- *Mobile Telepresence* is to 'teleport' a person to a remote place,[27,28] often achieved by a telepresence robot allowing the remote user to move around in a remote environment. Other systems focus on how a user can be assisted from a remote site, providing a first person view from a remote operator.[29,30,31]
- *Collaborative mixed reality*[32] is an emerging area where few tools and applications have ever left the research labs and supported practical use in industry. The emergence of affordable technologies, such as Google Glasses and Microsoft HoloLense,[33] may change this.
- *Collaborative immersive virtual reality* systems, such as Cave systems and HMD (Head Mounted Displays) allow for the possibility of a shared object manipulation, communication of references and improve the spatial context. Wolff et al.[20] highlight the potential for natural collaboration, especially where users collaborate around shared information artefacts. Immersive display devices place a user in a spatial and social context, thus allowing natural first person observations of remote users, while interacting with objects. They all provide interesting advantages to existing collaborative systems, but also introduce problems for local interaction: "*Head Mounted Displays prevent easy access to standard design tools, such as paper documents, telephones, coffee, and other people in the room.*"[34] for many, essential tools for engineering work.

3 Challenges for Collaborative Design

The design process is often generalized and described as a linear process, starting from the identification of needs, followed by a progression into a clarification of the task, concept development and detail design. In reality, the process is more complex and intertwined, and seems more a matter of simultaneously developing and refining both the formulation of the problem and ideas for a solution. This is often done through a constant iteration of analysis, synthesis and evaluation between two notional design spaces, i.e. problem space and solution space.[35] This design process introduces some interesting challenges for distributed collaborative work.

A typical distributed design project is performed by a distributed, cross-disciplinary team that is forced to collaborate to solve a complex problem. The global team often consists of several small co-located teams, where each team contributes with their specific knowledge and capabilities. The collaborative design process has several phases that require different types of interaction between team and individual team members. Each of these phases creates different challenges for collaborative design; a simplified collaborative design process is described below and illustrated in Figure 2.

1. The early design stages often focus on creating a shared understanding and identifying the real problem.
2. The understanding of the problem is often intertwined with a creative exploration of the solution space, where the team proposes conceptual solutions.
3. After the initial design concepts and specifications are decided upon, the team dives into a refinement phase where detail design is developed. In this phase, the problem is often divided into subsystems, or modules developed in parallel by co-located teams. Throughout the detail design phase, as the design matures, more and more information can be shared and integrated through various support systems, such as CAE and **PDM**.
4. When a satisfactory detail design has been developed, the system must be integrated and the focus of the development should be on the integration of the subsystems. During this stage, change can be very difficult to manage, and adds a big overhead.
5. The final stage is an integrated review phase, where the complete product is refined, tested and evaluated.

The following sections present some of the important challenges for the right side of the collaborative design process (see Figure 2), and is focused on the highly interactive work in design meetings (synchronous work), and not the individual work or coordination done between meetings (asynchronous work). The left side is more focused on integrating PDM systems, **distributed CAE**, sharing of documents, **change management** and **knowledge management** (for an overview see[36, 37]).

3.1 *Creating a shared understanding*

The first stage of collaborative design (the first step in Figure 2) is to create a shared understanding of the problem. The team, in a collaborative design project, is normally quite heterogeneous, includes different competencies, skills and responsibilities, and therefore, views the problem differently,[38] without yet having achieved a ***common ground***.

The development of the common ground is called ***grounding*** and is achieved through interactions between the team members. A shared understanding does not imply a decision on which

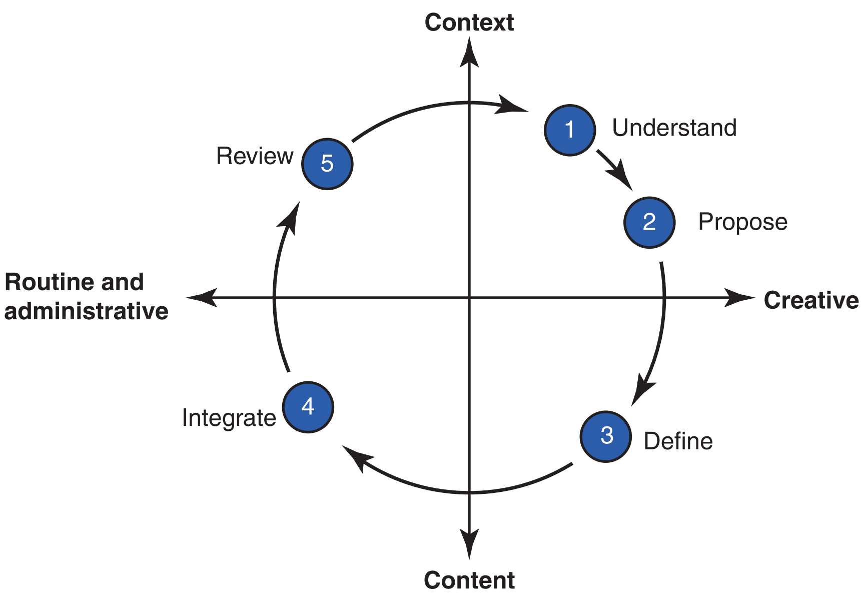

Figure 2: Different phases of collaborative design.

Distributed CAE (Computer Aided Engineering) includes tools for design and simulation that be accessed and modified by several users at the same time. In ordinary CAE-tools only one user can work on a specific object at a time.

Change management is used in collaborative design to highlight and evaluate the effect of a design change.

Knowledge management is the process of capturing, developing, sharing, and effectively using organizational knowledge within an organisation or sharing it with partners.

Common ground or mutual knowledge, mutual beliefs, and mutual assumptions are the foundations of which participants are mutually aware.[39] People with the same background and experience have a more developed common ground.

Grounding refers to the interactive process of making sure that what is communicated is also correctly understood.[39]

PDM (Product Data Management) systems are responsible for management and publication of product data within a company, and are also used for sharing product data with external stakeholders. Product data includes CAD-models (digital representations of physical objects), specifications, simulation models, documents and how objects are related to one another.

solution must be reached, but sets a common basis for the limits, rules and requirements that the product must fulfil. This understanding is not static and can be reassessed throughout the design process as new knowledge is acquired.[39] During this process, different views may arise to create a contrasted understanding[40] or ***equivocality***.

Equivocality refers to the extent that multiple and conflicting interpretations exist among project participants.[41]

To mitigate equivocality, a consensus must be formed through the exchange of subjective interpretations and a shared understanding, even though new information may actually increase rather than decrease equivocality.[42] In a collaborative design project this stage is critical, since a diverse team with little common understanding and agreement will come up with a wider set of ideas and concepts,[43] and differences in opinion are a source of inspiration.[44] The contrasting understanding has to develop into shared understanding; once the team determines the solution path, they have to then manage the conflicting constraints and decide the primary design intent for the product. Shared understanding is very closely tied to the informal communication, though shared understanding is often built up through the informal interactions among the team members.

Conjectures in design are often described as early stage ideas, opinions or conclusions formed on the basis of incomplete information.

3.2 *Informal communication*

The design process can be seen as an integration of technical, cognitive and social processes,[45] and relies on the communication and knowledge sharing among team members. During the daily work of a co-located team, communication is informal and ubiquitous, and has a major impact on the exchange of information in the project. It is easy to notice these quick, short meetings during the daily task.[14,46,47] These types of everyday interactions are crucial for a successful, co-located collaboration, because one can quickly and continuously share information, monitor progress, and learn about what others are doing.[47]

The ability to share information and solve problems quickly and unplanned is considered an important part of successful communication within organizations; a well-known phenomenon is that close physical proximity increases the probability of collaboration.[47] The greater the distance among people who have to communicate with each other, the less they communicate; therefore, much of the information exchange that takes place with a colleague on the same floor of a building and a distance of 30 meters is equivalent to being truly remote.[48] One concept that can be used to realise the benefits of collocation is **radical collocation** to maximise communication and information flow. In most industrial projects, this is not very practical; and is impossible in distributed projects.

Radical collocation is gathering an entire project team in one room for the duration of the project,[49] often used to solve very important problems. These types of collaboration rooms are sometimes called war rooms.[50]

Kraut et al.[47] divided informal communication into four categories, based on the degree of pre-planning:

1. *Scheduled*: Conversations that are scheduled in advance by both parties.
2. *Intended*: Conversations that are not planned in advance, but sought out by one party.
3. *Opportunistic*: Conversations that are anticipated by one party, but occur by chance.
4. *Spontaneous*: Conversations that are unanticipated by either party.

The three last interactions are quite difficult to replicate in distributed settings. The rise of social media and instant messaging has greatly improved informal communication, where everyone has a mobile device that can be used to interact with a large community.

3.3 *Ideation and working with artefacts*

Once the team has reached a shared and initial understanding of the problem, the users' needs, and requirements, the teams enter a creative phase of proposing conceptual solutions—***conjectures*** or ideas that are presented, reviewed and evaluated during collaborative sessions[51] (second step in Figure 2).

The process of proposing and evaluating immature ideas is also used to strengthen the shared understanding of the problem, resulting in a co-evolution of the problem, and the solution.[52,53] These early creative stages are considered very difficult to perform in a distributed team, ideas and immature concepts are by their nature difficult to capture, visualize or communicate electronically.[54] Designers need something that can transform the internal mental representation into some form of external representations—as artefacts that can be communicated. In engineering design the most common artefacts are sketches and prototypes.

3.3.1 Sharing artefacts: During the project, sketches gradually evolve from simple sketches into more elaborate forms[55] during the project. Sketches are not only used for communication, they can also stimulate creativity, especially in the immediate idea generation process of the individual.[56,57] Early collaborative tools often included a shared whiteboard, but the awkwardness of sketching with a mouse rendered them almost useless. New systems and displays that support touch and pen interaction have changed this, with digital sketching now almost equivalent to traditional sketching and superior to traditional sketching in distributed settings in particular.[58]

However, prototypes are much more difficult to use in a distributed team. Prototyping plays an important role in the early phases of the product development process, and are seen as "*shared objects to think with*".[3] These shared objects are used to create a common understanding[59] and express the designers' ideas, examining design problems and evaluating solutions.[60,61] Shrage states, "*the value of prototypes resides less in the models themselves than in the interactions—the conversations, arguments, consultations, collaborations—they invite*".[62] Prototypes are often very crude and quick in the beginning, evolve and become more detailed over time.[63,64] IDEO follows the principle of three R's: *Rough* (focus on the most important aspects), *Rapid* (create many alternatives), and finally, *Right* (detailed prototypes with high fidelity).

Very few available tools can be used to create rough digital prototypes that can be used for the initial phases;[54] hence, today's distributed team is mostly limited to traditional CAD-models that can be shared. 3D-printing can be used somewhat to share prototypes in distributed teams, but requires CAD-models and takes time to design and print.

3.3.2 Ideation: Creative sessions also include a high level of interaction that is difficult to replicate in distributed meetings. In typical co-located creative sessions, several persons interact simultaneously with external representations—posting Post-Its and sketches on the whiteboard, annotating their own and others ideas, graphs, and notations. Post-Its (used for brainstorming) are clustered and moved around the whiteboard, sketches and additional documents are spread everywhere. The communication is hectic and individuals can change quickly between local conversations, and a consensus discussion of the general topic with the rest of the designers with several parallel discussions often occur.[65]

Several research prototypes have emerged to solve these issues, but very few have been commercialised and used in industry. Early prototypes such as the *Clearboard*[66] illustrated the importance of natural interfaces as well as of sharing of both the workspace and the interpersonal space (i.e. body language, facial expressions, gesture, gazes). The underlying concept for *Clearboard* was to stand on both sides of a transparent glass board used for sketching naturally, where you could also see the interactions from users on the other side. Although collaborative design is often done in a group session, *Clearboard* was designed as a one-to-one solution. *Roomware*[67] was an early concept that supported sketching on private and shared displays, annotation and clustering. The Distributed designers outpost[68] used a mixed media approach that included the support of physical Post-Its in distributed meetings with a sense of presence of remote users. Teamstorm[69] focused on transitioning between personal and group work.

Several recently introduced online technologies build on these ideas, for example *ConceptShare*, *Conceptboard*, *GroupMap* and *Murally* all provide support for creative phases. All tools provide a shared workspace (a drawing board where content can be displayed, similar to a pin board) and support annotation, commenting, and tracking. Some tools also provide support for voting and supporting process management (i.e. brainstorming, clustering, voting). These tools all have has the advantage of **session persistence**.[70] These tools do not allow sharing of the interpersonal space, and need to be complemented with some kind of videoconference to avoid losing much of the interaction.

Session persistence is a concept used to describe tools that can both be used synchronously and asynchronously, i.e. a shared whiteboard that can be continuously rearranged and updated throughout the project.

Another concept is to go *beyond being there,*[17] instead of trying to replicate the richness and variety of interaction in a physical meeting. There is the possibility to create tools that fulfil the need better than in co-located environments. For example, the **6-3-5** and similar methods such as *C-Sketch*,[57] *Chainstorm*[71] and *Brainsketching*[72] are much easier to adapt to distributed teams than traditional brainstorming, because the interaction between team members is very low.[73]

6-3-5 (also called Brainwriting) is a creative method, introduced by Rohrbach,[74] where participants first work individually, and then send their ideas to other participants who are free to get inspiration from these ideas, create variations or start new ones from the scratch.

4 Conclusions

This review focuses on the early design stages, where a team builds up a shared understanding, and creates and evolves ideas to explore different solution paths. If a distributed team really wants to collaborate together and utilize the competences of the whole team, they have to work very closely in synchronous design meetings. These design meetings have two main purposes—to create a shared understanding, and to propose new solutions on how to solve the identified problems. Creating this shared understanding is very difficult in distributed teams,[75,76] as it is dependent on close interaction among team members, not only verbally but through nuances, facial expressions, gestures and design artefacts. This understanding also develops slowly during the project, and is dependent on the informal communication carried out in-between design sessions. Creative phases where a team proposes conceptual solution ideas and further evaluates them into concepts are also quite difficult to support today.

For the early stages of design, some challenges for future work have been identified:

Vividness is the "representational richness of a mediated environment"[79] that is modelled by the amount of sensory information simultaneously presented to the users. It has two dimensions: breadth (i.e. visual, auditory, haptic, textual, graphical) and depth. Breadth refers to the number of sensory channels, and depth to the resolution in each of these channels.

- Enhancing *social presence* and **vividness** of distributed teams—the feeling of being together that comes from the interactions among people (gestures, embodiment, spoken word, eye gazing, etc.).
- Enhancing *informal communication* among remote team members, so that team members are aware of current activities, and are triggered to initiate both opportunistic and spontaneous conversations with remote team members.
- Enhancing the *sharing of artefacts*, enhancing interaction possibilities around shared design objects, similar to the usage of sketches and physical prototypes in co-located design meetings. The goal is to create artefacts that can be modified by all designers at the same time.
- Enhancing tools and methods for *distributed ideation.*
- *Enhancing the* ***quality of the experience***, a collaborative system should not intervene with the users task and enable flow[77,78]—when participants focus their full attention on the task, not hindered by the mediating tools and at the same time perceive a sense of control and great enjoyment.

Quality of the Experience is an effort to model, measure, and understand user experience.[80,81] It can be described as a user-centred measure for the characteristics of the sensations, perceptions, and opinions of people as they interact with their environments. These characteristics can be pleasing and enjoyable, or displeasing and frustrating.

Finally, future research will continue to try to replicate the golden standard—the advantages of the physical meeting in the virtual world, similar to the Star Trek Holodeck. Although some bits and pieces of the Holodeck have been realized today (in high end research prototypes), most of it is still in the realm of science fiction. The increasing development and miniaturization has led to a rebirth of the head-mounted technology and mixed reality systems. This, combined with advances in hologram technology[82,83] and commercial products such as *Oculus Rift*, *Sony Morpheus, Microsoft HoloLense*[33] create interesting possibilities for researchers to develop collaborative environments of the future.

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