

Exploring the Potential of 3D Visualization Techniques for Usage in Collaborative Design

W. W. Wits¹, F. Noël², C. Masclét²

¹ Faculty of Engineering Technology, University of Twente, Enschede, The Netherlands

w.w.wits@utwente.nl

² G-SCOP Laboratory, Grenoble, France

frederic.noel@g-scop.inpg.fr, cedric.masclét@g-scop.eu

Abstract

Best practice for collaborative design demands good interaction between its collaborators. The capacity to share common knowledge about design models at hand is a basic requirement. With current advancing technologies gathering collective knowledge is more straightforward, as the dialog between experts can be supported better. The potential for 3D visualization techniques to become the right support tool for collaborative design is explored. Special attention is put on the possible usage for remote collaboration. The opportunities for current state-of-the-art visualization techniques from stereoscopic vision to holographic displays are researched. A classification of the various systems is explored with respect to their tangible usage for augmented reality. Appropriate interaction methods can be selected based on the usage scenario.

Keywords:

Tangible interaction, Collaborative design, Virtual mockup interaction, Augmented reality, 3D autostereoscopic display, Virtual reality

1 INTRODUCTION

This paper is a positioning paper to investigate the use and perception of 3D visualization techniques for collaborative design including remote interaction. To boost the information exchange and collaboration between design team members, clear communication plays a vital role. 3D visualization techniques support design teams in their collaborative work, due to their capability to comprehensively present the artifacts being designed. This, in turn, makes product models more tangible and increases product awareness, stimulating better mutual communication.

On the consumer market today, one can already buy 3D systems ranging from stereoscopic systems (usually involving special glasses) to autostereoscopic systems, also known as auto 3D displays. Examples of the former are, for instance, anaglyphic imagery, polarized imagery or alternating imagery. For each of these techniques special glasses are required. Examples of the latter systems are holographic imagery or lenticular lenses. For these systems no optical aids are required. Currently many companies are announcing that they will have autostereoscopic displays on the market in the near future.

Any such system may support a design team locally; however, for remote collaborative design support multiple systems should interact through a network. This research envisions a system that enables the connection of local 3D visualization techniques to a global platform, thus supporting a design team with specialists at different geographical locations. On this platform, design team members can work conjointly and simultaneously on their design, independent of their location. Such a platform could lessen the amount of travel, increase productivity and ultimately speed up the product design process.

As the use and perception differs for the various visualization techniques, this must be well understood first in order to strengthen the mutual communication. As mentioned some techniques require optical aids, whereas

others lack the ability to provide an independent view of the design artifact to each group member. This might cause a lack of clarity when collaborating, especially when you are on a remote location. Interaction techniques need to be researched as well, as these may also differ for the various visualization techniques. Altogether, the potential of 3D visualization for collaborative design is explored.

1.1 Research goal

This research aims to advance the current state-of-the-art in collaborative design support with the use of an interconnected 3D visualization platform. Using the internet or other frameworks, interaction between engineers and designers should not be limited to a specific location. An essential aspect of the research will be to develop a platform that is able to join multiple visualization devices at different geographical locations. As aforementioned, next to the technological aspects, a clear understanding about the use and perception of 3D visualization techniques for members of a design team needs to be gathered. This knowledge will enable the exploration of the full potential of such interconnected visualization techniques.

The impact of new interaction modes for collaborative design must be investigated. For instance, depending on the scenario or product to be designed, what would be the best combination of interconnected visualization techniques and their associated manipulation facilities? Studies about the trends in digital design studios are already rising up. For instance, Van Doorn and Horvath [1] are especially focusing on the possible scenarios for the entire design process. They involve different interacting technologies according to their level of maturity.

This study will provide guidelines for potential users about what visualization systems to procure. Finally, this research should give us an answer up to what level of collaboration – even at remote locations – can be

strengthened by the environment and whether we continue to need traditional local design meetings.

1.2 Research approach of this study

To better understand the usage, possibilities and (in)conveniences for design teams working on a platform with multiple viewing stations, several 3D visualization techniques are compared. This paper presents a bottom-up approach as shown in Figure 1, where: (1) a design artifact is displayed on a specific 3D system, (2) the perception of the design artifact is studied and (3) model interaction methods are researched. These issues require a complete qualification of the holistic process with respect to tangibility and acceptability for collaborative design.



Figure 1: Bottom-up analysis process.

For this study, based on a restricted range of technical devices, the available 3D visualization techniques were anaglyphic and alternating imagery as stereoscopic techniques and holographic imagery as an autostereoscopic technique. Other visualization techniques as CAVE-based 3D immersion or full immersion Head Mounted Displays (HMDs) were not tested in practice, due to cost and availability; however, they are considered from a theoretical point-of-view. To strengthen the perception and interaction with the artifact, a classical mouse, 3D mouse, haptic devices and data gloves are considered.

2 OVERVIEW OF SOME 3D VISUALIZATION TECHNIQUES

2.1 Anaglyphic imagery

Anaglyphic imagery has been used for more than a century. Even though it has been recently replaced by more competing technologies, it still stands as an easy and very affordable means of achieving stereoscopic vision. It relies on two views of complementary colors of the presented scene that are slightly offset. A pair of glasses with color filters causes the viewer to perceive the projected artifact in 3D, as each filter occludes one of the rendered images for one of the eyes. Various color schemes exist, but most commonly used color filters are red and cyan. Compared to old movies or antique still images, the computer has brought the possibility to provide animated scenes in real-time.

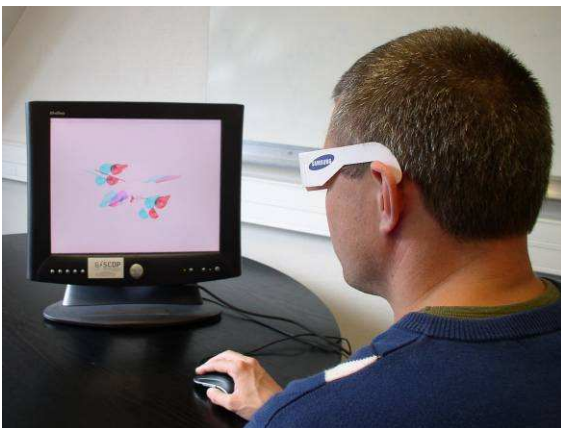


Figure 2: Product modeling using anaglyphic imagery on a classical computer display.

Figure 2 presents the usage of anaglyphic imagery on a classical computer display. The advantage of anaglyphic imagery is that no specific hardware is required. In fact, only a pair of color filtered glasses – costing less than 50 eurocents – is required. A normal desktop PC or laptop is able to render the images smoothly. Also, multiple experts may gather around a screen or projection wall and look at the same artifact simultaneously. The artifact can be manipulated by any input device connected to the computer. In Figure 2 a classical mouse is used. Disadvantages of anaglyphic imagery are the inability to use the full color spectrum and sometimes retinal rivalry causes discomfort for the viewer. Furthermore, the need for glasses make the swapping from the virtual to the real world uncomfortable because of the dual color filtering.

2.2 Alternating imagery

The second stereoscopic technique studied – alternating imagery – solves the previously mentioned disadvantages. Also, in this case, the computer renders two views: one for the left eye and one for the right eye. Both views are projected slightly offset on a screen with a beamer that alternates the projection of both images. In this case the user has to wear special glasses that are synchronized with the beamer to occlude one of images for one of the eyes. The 3D model is perceived in the same manner as the previous technique.



Figure 3: Product modeling using alternating imagery projected on a big screen.

Figure 3 presents the usage of alternating imagery using a Christie Mirage HD3 projector. This technique is more comfortable for the user as retinal rivalry does not occur. Also, the full color spectrum may be used. Figure 3 shows two designers in discussion in front of the 3D screen. In this case the image is manipulated by a 6D haptic arm. The presented airplane is the same virtual product model as the one presented in Figure 2.

Stereoscopic perception

Both stereoscopic techniques share the disadvantage that all users present in front of the screen see the same 3D view simultaneously regardless of their position in front of the screen. However, they perceive the projected 3D object at different locations in front of them. For instance, the designer on the right hand side in Figure 3 may be pointing at one of the engines; however, this will never be clear to the other designer on the left hand side. As features on the projected artifact cannot be pinpointed with an object outside the image, e.g. a finger or a stick, collaboration is hampered. Hence, to enable clear communication often an avatar representing a person's hand is introduced into the virtual scene. In other words,

there is a clear separation between the Virtual Reality (VR) world and the real world.

Using a head tracking system both stereoscopic techniques can enable the viewer to virtually look around the artifact (the computer renders an updated view for the new head position). Obviously this works only for one person; the other users will perceive the same movement of the artifact(s) as the tracked viewer. As movement cannot be shared with these stereoscopic techniques, this may also disrupt clear communication.

2.3 Holographic imagery

Holographic imagery is an autostereoscopic technique; that is, neither special glasses nor any other optical aids are required to see the image in 3D. Also in this case, the computer renders different views for the left and right eyes, but they are displayed through a holographic optical element. This optical element reflects the computer generated images to a specific (narrow) viewing angle, separating the views for the left and right eyes, and thus producing a 3D image for the viewer. Recently, much progress has been made in this area [2-3] and promises new opportunities for collaborative design.



Figure 4: Product modeling using holographic imagery on a holographic optical plate [4].

Figure 4 presents the usage of holographic imagery. Again the same airplane is used as the virtual product model, only this time manipulated by a different haptic device (Phantom Omni). The advantage of this technique is that multiple viewing angles can be defined around the holographic element, which allows each viewer to look around the artifact individually by shifting the position of their head. The available views of the artifact depend on the number of reflected viewing angles.

Holographic perception

Perception of the image is determined by the viewer's position around the holographic optical element. However, features on the projected image can be pinpointed with an object outside the image and will be perceived by all viewers at the same location within the scene. As, in this case, there is no clear separation between the VR world and the real world, we will refer to this as Augmented Reality (AR). The concept of AR was first published by Feiner et al. in 1993 [5]. They differentiate AR from VR by "presenting a virtual world that enriches, rather than replaces, the real world."

Often AR is dedicated to improving (enriching) a desktop environment with a see-through HMD. Here, it is important that the user is provided with a tangible interface to this Mixed Reality (MR) [6]. In the presented case of

holographic AR this seems not to be an issue: the virtual model is already very tangible. Following our bottom-up approach of Figure 1, we must however still investigate how tangible input devices are in respect to the potential usage. Needless to say, tangibility only applies to local viewers. For design team members at a different geographical location, an avatar would need to be projected within the scene to show the remote interactions.

3 IMPACT ON COLLABORATIVE ACTIVITIES

3D visualization techniques combined with internet communication networks provide new opportunities for collaborative design. Here, cooperation refers to synchronous activities where one or more specialists must share some perspectives about a common artifact. With the development of network communication, remote interaction on various representations of artifacts is available. VR and AR devices, supporting this feature, can be combined to share models in remote locations. The current section discusses the differences between VR and AR technologies regarding their potential usage for remote cooperation. With respect to AR, we will focus our interest on new holographic technologies.

3.1 Perception with stereoscopic techniques

The difference between VR and AR technologies remains confusing in most cases. Here, we analyze how they differ in respect to user perception. Let us consider the perception of various 3D visualization systems. Most 3D displays are based on a "Trompe l'oeuil" technique. Two levels of techniques to produce 3D perception are identified, where 3D images are mapped onto a 2D screen.

The first 3D representations were provided by wireframe drawings (Necker cube) [7]. People are able to perceive a 3D structure rather than a collection of 2D segments, but static views are ambiguous because a depth cue is absent: dual interpretation is possible. Regarding the information required, the observer is sometimes confused. For instance, in Figure 5a it is clear that one cube is presented, however it is not clear which face of the cube is in front. Also, significant time of acclimation to learn the visual code and to build the interpretation scheme is observed.

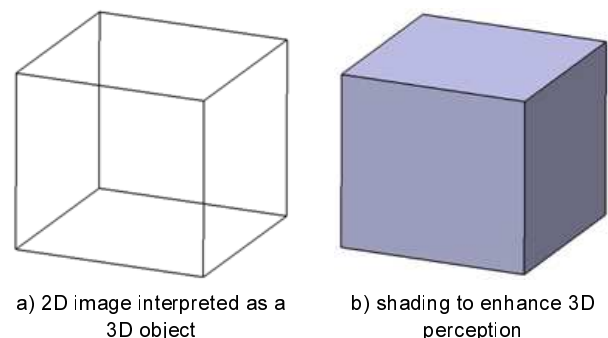


Figure 5: Using perspective to provide 3D perception.

It has been demonstrated that motion cues can partially solve this problem. Wherever the relative movement originates from – observer changing the motion of the artifact or observer moving around the virtual artifact – a slight change in the perspective angle of the observer gives sufficient information to clear-up any doubt on the spatial orientation. A depth cue occurs when the view is rotated. Nowadays, we can combine the rules of perspective projection established by "Renaissance"

painters and the capacity of computers and graphic cards to display the images real-time. Color, illumination, texture and shading effects all improve the 3D perception of the object, as illustrated in Figure 5b. Such rendering techniques experienced great improvements in recent years, in both the business and entertainment fields. They are now quite popular and accessible with medium range computers.

At the second level of 3D perception, the capacity to mislead the observer's brain is increased by proposing different images for each of the observer's eyes. The main point is that the two images remain 2D images and the brain is still in charge of building a 3D mental representation of the scene, but it does not have to interpret the visual code anymore. Stereoscopic technology was already established at the beginning of the 20th century. Once again computers are now able to animate the images, thus extending the misleading perception, as was shown in Sections 2.1 and 2.2.

Whatever the technology (anaglyph, alternation, etc.), 2D images are projected on a surface. Figure 6 illustrates the perception volume of the 3D scene on such a display. The images are projected onto the screen (usually a plane), while the perception of the object may be in front or even behind the screen. In any case, the perception will be in front of the observer and it will remain in the space between the observer and the far limit behind the screen. In addition, the maximum protrusion distance of the scene perceived in front of the screen, depends on the last real world visual reference between the observer and the screen. The mind perceives a 3D object but any additional visual reference between the observer and the projection screen changes the point of view and pushes the mental perception away from the observer. Hence, trying to grasp the object with your hand pushes the front perception of the object back towards the screen.

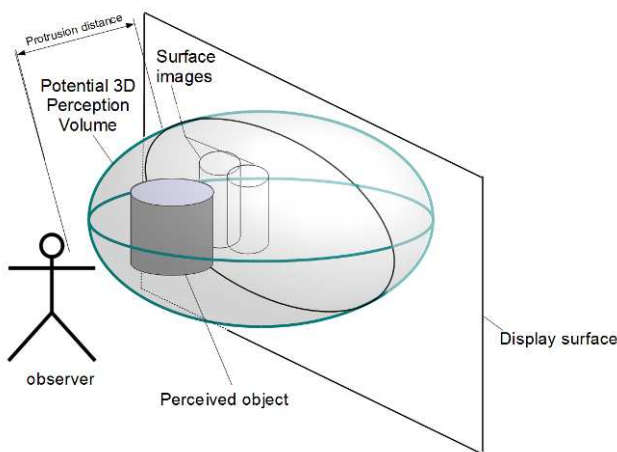


Figure 6: Perception of a 3D image projected using stereoscopic techniques.

In CAVE based VR systems, the observer is immersed between a set of projection walls. In this case, the previous perception is improved by the fact that images come from various directions simultaneously. This cancels any real world references from an optical point of view, fully immersing the user in the scene. With head tracking systems the projected views may also be adapted to the viewer's point of view. However, the principle remains the same: the observer can approach the object but he cannot touch it.

With both discussed levels of 3D techniques, the observer's brain is variably in charge of building the 3D scene. Most technical evolutions are directed to fool the

visual perception (sensitive stimulus) to enhance the cognitive interpretation. The hypothesis is that providing the most realistic view (eye stimulus) to the user helps him to increase consistency with his internal representation (what the brain knows it should look like). The second level of 3D perception opens collaborative activities to anyone not acquainted with 3D representations and their conventions.

3.2 Perception with autostereoscopic techniques

With AR technologies, the image is mixed with the real world. Some technologies that provide visualization for AR are: (1) by tracking the observation direction, a specific image may be mapped onto 3D glasses overlaying information upon the real world (HMD), or (2) with holographic technology an image can be constructed in 3D space, removing the previously necessary misleading of the brain's interpretation, as was shown in Section 2.3.

Holographic technologies are also not new; however, recent developments make them available with real-time 3D image processing [8]. In this case, the image is projected in 3D space and it is not a surface image in "Trompe l'oeuil" anymore. Figure 7 describes its installation and perception. The observer without any dedicated optical aids sees a 3D image. This time the perception zone is equal to the 3D location of the image and the observer may enter the 3D perception volume without interfering with the perception of the object as long as he does not interfere with the projected views.

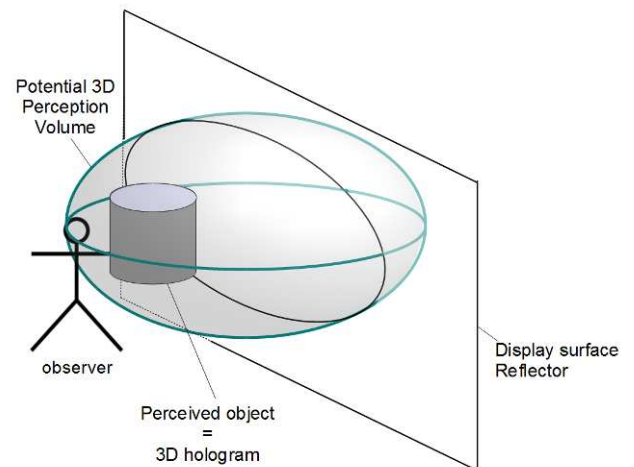


Figure 7: Perception of a 3D image projected using holographic (autostereoscopic) techniques.

AR, as part of MR environments, tries to hybrid real life artifacts with virtual artifacts [9]. However, the observer may face several perceptual issues. These have been analyzed theoretically in a study focusing on AR and MR [7]. Among the various issues described, the misperception of an object's location is a real concern whenever direct interaction is required. Mixing references from real and virtual worlds tends to mislead the observer. If AR is used in a way that overlays information onto a real scene, some shift between real and virtual objects is acceptable. Conversely, accuracy is critical when objects must come into contact with each other, especially when the real object is part of the observer's body that wants to interact with the scene.

Furthermore, not only the visual cues are involved in MR perception, it is also a great challenge to keep consistency between the visual sensations and others

Features	User benefit / discomfort	Stereoscopic	Autostereoscopic	
			Lenticular lens	Holographic
Visual aids	User has to wear special glasses	Yes	No	No
Depth resolution	Depth of the 3D view	Good	Limited	Good
Color resolution	Presentation of full color spectrum	Technology dependent	Good	Good
Continuous motion parallax	No discontinuity when moving around the screen	Only with head tracking (1 person only)	Not possible (lens dependent)	Possible (set-up dependent)
Direct interaction	User can directly interact with the 3D scene	Not possible	Not possible	Possible
Collaboration	Can user interact with team members	Not possible	Not possible	Possible

Table 1: Overview of features and user benefits for various 3D visualization techniques.

senses (e.g. tactile, audio, etc.) in order to avoid MR sickness [7, 10].

3.3 VR and AR interaction methods

Real manipulation of virtual artifacts provides an intrinsic way of interacting with the model. Mixing kinesthetic and visual modality to learn about and perceive the artifact will enhance the quality of acceptance by the actors. Kinesthetic feedback allows people to get information they would not have access to with visual means only, for instance, weight and gravity effects, dynamic properties of mechanisms (inertia), material properties (density, ductility, plasticity, etc.) or coarse textures.

Anticipating technological progress, we could even imagine the perception of temperature, fine texture, sensual or pain sensation. This kind of interaction will be very important for designers because it gives valuable information to understand and evaluate the design intention. It extends the concept of material utterance as defined by Dearden [11] for digital materials. With VR technologies, the observer cannot interact directly with the scene. The interaction must be handled by indirect input devices. Many devices are proposed from classical mice to haptic arms. The observer handles a device that does not belong to the scene and a virtual artifact must be mapped into the scene to localize this interaction. This avatar helps the observer to enter the scene, but he must renew his interpretation to achieve full interaction.

With AR technologies, the observer can interact directly with the scene. The perception does not change with respect to the position of external visual references as a hand or finger. It is truly AR since the produced image includes the real world. An avatar is not required within the scene and interactions can be applied directly to the 3D scene. Nevertheless, limitations exist that should be taken into account. Some specific studies have led to assess the use of holographic displays for the sake of product visualization [12]. The user perspective has been favored to obtain relevant quantitative observations. Logically, among the several heuristics taken into account, few elements gave evidence considering that the potential interaction with the virtual objects was satisfactory enough. Thus, such manipulation must be precisely foreseen to check for compatibility with the scenario and to choose the best interaction methods.

Table 1 presents an overview of the features and user benefit for various 3D visualization techniques that are discussed.

4 FUTURE SCENARIOS FOR HOLOGRAPHIC AR

AR not only gives the opportunity to deal with geometrical dimensions (releasing size constraints for instance). It also helps to enhance reality by overruling time constraints. The user has the power to represent what *has been* (visualizing the past), what *will be* (forecasting the future) and what *could be* (simulation). This offers new

opportunities in many situations. Hereafter 2 examples are given: remote surgery and cooperative product design.

Remote surgery

Imagine remote surgery: usually a surgeon must watch a screen where he perceives visual feedback of his actions; however, the actions are performed through actuators driven indirectly. Figure 8 shows a set-up where the visual cues are presented using stereoscopic techniques, and interaction and feedback is handled by two haptic devices. This virtual training set-up was developed by Vrest [13-14], which was formed as a result of a collaborative project between a local hospital and our research group.



Figure 8: Virtual surgical training.

A clear separation between both spaces (visualization and interaction) is required due to conflicting technology demands. For the surgeon this is inconvenient; he cannot mix real and virtual worlds directly, nor can he interact with another surgeon standing next or opposite of him.

Holographic AR technologies would allow the display and actions of the user to be integrated in the same space. This would require some devices to track the position of the hands and tools handled by the user, for instance with data gloves. However, in the end, the surgeon can focus on his actions directly. Moreover, his actions become much more tangible because they are clearly connected to his real world perception. Also, the glasses are redundant for holographic systems.

Cooperative product design

In the field of cooperative product design, communication between remote experts is vital. In this case, the use of holographic AR technologies will provide a more tangible system to simulate a co-located meeting. New visualization platforms must be envisioned, constructed and verified in this direction [15-16]. A holographic display for each expert on a remote location allows him to share

3D objects with other experts. This enhances the capacity of engineers to share their ideas and present their design models in 3D.

Every engineer may act directly on his own 3D virtual prototype for instance to annotate or to modify the product model real-time. The actions of the actors (hand movements, etc.) must also be tracked and dispatched as events on the shared 3D model. Design engineers in other locations can perceive the complete modification and all annotations of the model on a realistic perspective (real 3D) or they can participate as observers using a more "classical" 3D stereoscopic system. Actions of remote colleagues must be displayed as an avatar in their local scene.

Ultimately this could result in a new form of 3D video conferencing, where you would see your remote colleagues through a 3D screen and between the both of you the virtual model under discussion is presented. Such a 3D conference system is presented in Figure 9.



Figure 9: 3D video conferencing with distant colleagues [17].

In situations where the scene is complex, requiring accuracy and correctness, 3D allows the improvement of the job quality and provides a substantial gain in time [18]. Current AR technologies allow natural cooperation on the same virtual object for co-located observers. There is no need to digitize or re-create the contextual world. Human interactions are possible in a natural way with actors standing face-to-face or side-by-side. Real artifacts (professional tools, spare parts, missing parts from archaeological pieces, etc.) can be put into the AR scene to interact with virtual artifacts.

Breen et al. [19] demonstrated that in order to improve tangibility for designers, engineers or other actors, models pass from the real world to the virtual world or vice versa. For instance, a static capture of the real world is integrated into digital models or v.v. digital models are materialized with rapid prototyping tools. As these are all static representations, one step further would be to completely mix virtual and real worlds in a dynamic mode. This is what we envision to achieve with holographic AR technologies.

Additionally, on a platform, holographic AR technologies must be able to combine interactions from several remote persons. You can see the avatars of your colleagues and simultaneously you can work on the same scene. In any case, both scenarios benefit from more tangible (real world) interaction methods with the virtual scene.

5 CONCLUSIONS

Augmented reality nowadays already provides so many applications that it could become an essential technology to assist in future everyday life activities, as well as in many business fields. However its acceptance remains an open issue because, as any other tool, it expects the user to adapt to new constraints. Among the technological achievements, 3D visualization is a promising result. To effectively work with 3D visualization devices, they must allow realistic representation and tangible interaction. Holographic devices will be a key technology with respect to this goal.

This global discussion opens new research directions that will be followed by the authors of this paper. A major issue will be to characterize the level of tangibility of an interaction device with respect to a specific usage context. As a result of this research, clear indicators should be formalized to choose suitable collaboration techniques.

In the future, this would allow design teams to collaborate better among its members, even for distributed design teams. In the end, this will boost the performance and quality of work of entire teams.

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