

The Impact of Virtual Environments on Design Collaboration

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Abstract. With recent developments in communication and information technology there has been increasing research into the role and the impact of computer media in collaborative design. This paper presents a case study that compares two designers collaborating in three different types of virtual environments with face to face (FTF) collaboration. The aim of the study is to identify similarities and differences between remote locations in order to have a better understanding of the impact of different virtual environments on design collaboration. Our results show that the architects had different designing behaviour depending on the type of external representation: they developed more design concepts, and had more design iterations through analysis-synthesis-evaluation while designing FTF and in a remote sketching environment; while the same architects focused on one design concept and making the design when designing in 3D virtual worlds.

Keywords. Collaborative design; virtual environments; remote sketching; 3D virtual worlds; face to face collaboration.

Introduction

Recent developments in virtual environments and the availability of high bandwidth networks have the potential to bring significant changes in the way that design related professionals collaborate and design. While these developments have led to important advances in the enabling technologies required to support changes in practices, there is still insufficient evidence about how this compares to the way designers collaborate in their normal working environments. Research into the impact of the technology on collaborative design can lead to a more critical understanding of how collaborative design can be facilitated. This understanding includes various factors including the role that communication media play, the use of physical materials and computer tools and the way people communicate verbally and non verbally (Munkvold 2003).

In this research we investigated the effects of communication and information technologies on designers' representation and collaboration using protocol analysis. Protocol analysis has been accepted as a research technique allowing characterization of processes in designing (Cross and Cross 1996). Whilst previous studies usually focus on the protocols' verbal aspects (Akin 1986), later research acknowledges the importance of design drawing (Akin and Lin 1995) together with design thinking which can be interpreted through verbal descriptions (Suwa and Tversky 1997; Suwa et al. 1998; Stempfle and Badke-Schaub 2002). We can understand how virtual environments impact on designers' focus during the design session by gathering information about their communication and behaviour.

Studying collaborative design

In order to understand the impact of virtual environments on collaborative design, we first need to have data that characterizes collaborative design activity without the technology i.e. face to face designing. We considered that the change in the collaborative technologies should be incremental, moving from the technology already in use (pen-based shared- whiteboard applications) to the use of augmented virtual worlds. With these ideas in mind, an experimental study with different design settings was developed in order to study the impact of virtual environments on design collaboration:

- Base line study (co-present): A collaborative design process in which designers work face to face (FTF) with traditional materials;
- Comparison study (remote): A collaborative design process in which designers use three different collaborative technologies with full communication channels (video and audio); a remote sketching application, a 3D virtual world and a 3D virtual world with sketching.

Baseline study

In the baseline study, we studied two architects collaborating on a design task in face to face. They were provided design brief, site plans, drawing materials (pen-paper) and a collage of photos showing the existing building on the site and the neighbouring buildings. They were asked to finalize the design task in half an hour. Figure 1 shows the baseline study, two designers are collaborating.

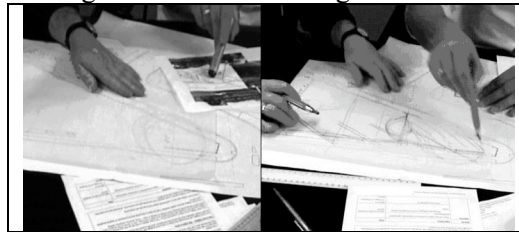


Figure 1 Baseline study, face to face design session

Comparison study

In the comparison study, the same architects were given different tasks of similar complexity in each setting. In order to simulate high bandwidth audio and video, the designers are located in the same room and can talk to each other, but can only see each other via a webcam. In the comparison study, the designers collaborated in three different environments as shown in Figure 2.

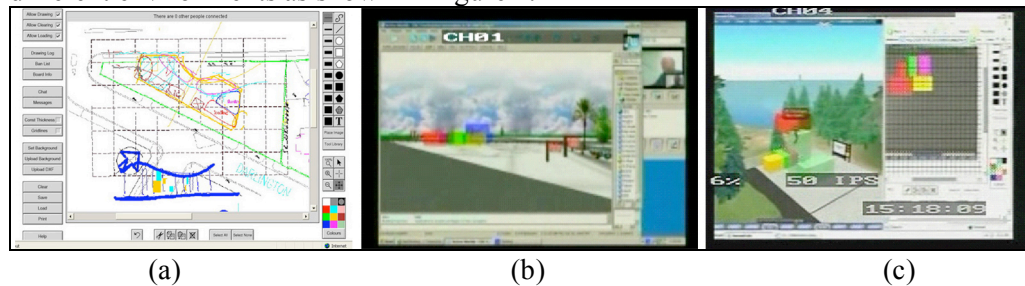


Figure 2 Comparison study, (a) RS-GroupBoard, (b)3D- Active Worlds, (c) 3DS- DesignWorld

- Remote sketching (RS): In remote sketching, the designers used a shared whiteboard application that is GroupBoard. One designer used a pen interface (Mimio) on a projection table, and other designer used a pen interface on a SmartBoard.
- 3D virtual world (3D): In 3D virtual world, the designers used a virtual world that is Active Worlds. A user is represented by a human-shaped character that is called an avatar in the 3D virtual world. By using the avatar, a user can build and navigate in Active Worlds using a library of building components and design elements.
- An augmented 3D virtual world with sketching (3DS): In this design session, the designers used a 3D virtual world (Second Life) and a sketching tool (GroupBoard) together. Similar to Active Worlds, designers are represented by avatars in SecondLife. Instead of using a variety of library objects, designers

create basic primitives, then copy, transfer and/or modify them to be a different object. In addition they have a choice of sketching on the shared white-board.

Each experimental session started with a training session followed by a 30 minute design session. In the training, designers were engaged in doing a tutorial in order to review and/or build their skills in using specific features of the applications. We recorded the designers' activities and communication in both studies with a surveillance DVR (digital video record) system (see Maher et al. 2005; see Gül and Maher 2006b, for more detail on experimental setup and procedure). Once the data collection is completed, the next step is to transcribe the protocol.

Video and verbal data coding

The data from the experiment includes a continuous stream of video and audio data that is segmented for coding and analysis. We divided the protocol into segments based on an interpretation of an event. Dwarakanath and Blessing (1996) state that an event could be defined as a segment of time which begins when a new portion of information is mentioned or discussed, and ends when another new portion of information is raised. This event definition is the most beneficial one for the study, since the occurrences of actions and intentions change quickly as architects draw/model and communicate interactively (see, Maher et al. 2006b for more detail about the segmentation)).

Coding scheme

We classified the verbal and visual information in the protocols into two categories: design process and design representation. These were further divided into subcategories. Table 1 shows the two categories and their subcategories.

The design process category includes generic design processes actions that are: set up goal, introduction of ideas, analyse problem, analyse solution, synthesis, clarify/restate and evaluate. The introduction of design ideas code also has two sub-codes that are change and progress. Those codes capture the differences in proposing design ideas in face to face and digital environments.

The design representation category has two subcategories: realization actions and perceptual focus, as shown in Table 1. The realization actions category shares characteristics of Kavakli and Gero's (Kavakli and Gero 2001) 'drawing actions' category and has Cardella et al's (Cardella et al. 2006) 'representation' category. The category looks at the interaction of the designers with the visual information that is a drawing in GroupBoard or a model in 3D virtual worlds. This subcategory has the following codes: write, create elements, continue elements, add elements, and delete elements. The perceptual focus subcategory has two codes: object/entity and spatial relationship, as shown in Table 1. This category looks at the visual information as well as the verbal information. When designers engage with the visual features of the design product that are size, shape, colour or texture, etc, it is coded as object/entities. When designers engage with the spatial relationships of the objects that include positions, locations, alignments, etc. it is coded as spatial relationship.

Table 1 Coding scheme

Design Process	
SetUpGoal	Assigning task, planning the design actions
IntroductionOfIdeas: Progress Change	Proposing new ideas introducing a design idea, a continuous process introducing an alternative design idea
AnalyseProb	Analysing the problem space

AnalyseSol	Analysing design space, solution space
Synthesis	Synthesis the solution space
Clarify /restate an idea	...a concept previously introduced by another individual or by self and questions by others (Milne and Leifer 2000)
Evaluate	Evaluate a design solution
Design Representation	
<i>Realization actions</i>	
Write	Creating a written response or writing down ideas to be used later
Create elements	Engage with (creating/drawing) point, line, plane, volume or in 3D virtual world cloning, duplicating an object
Continue elements	Continuing sketching or modelling/ developing the same representation further (modifying, moving, transferring, grouping)
Add to elements	Returning to the previous element after engaging in a different activity or working on different part of the representation.
Delete elements	Erasing elements
<i>Perceptual focus</i>	
Object/ entity	Engage with visual features of elements; shape, size, dimensions, colour, texture, material,
Spatial relationships	Engage with spatial relation of elements; position, direction, alignment, x, y, z coordinates, being up, down, left or right

Analysis and interpretation of the results

We used software called INTERACT for our coding process. INTERACT gives us the total duration of an action in each category as well as how much time a designer spent on each action.

The percentages of time the designers spent on collaborative communication, comparing the co-present location with the remote locations: FTF versus RS, FTF versus 3D and FTF versus 3DS, are shown in Figure 3. The communication category durations are divided by the total time elapsed in each session, where duration percentages are obtained for each code. The design communication (desnCom) duration percentages are the highest in all environments, which are followed by communication about software features (ComTech) and awareness. Discussions that are related to software features (ComTech) are the second highest in remote sketching (RS) and in augmented 3D virtual world (3DS) as shown in Figure 3(a, c). This is because the designers spent time to save and upload images constantly in Groupboard, and discussed how to do things in DesignWorld. In addition, Figure 3(b) shows that awareness code is the second highest in 3D virtual world (3D) session where the designers discussed the location and the actions of each other.

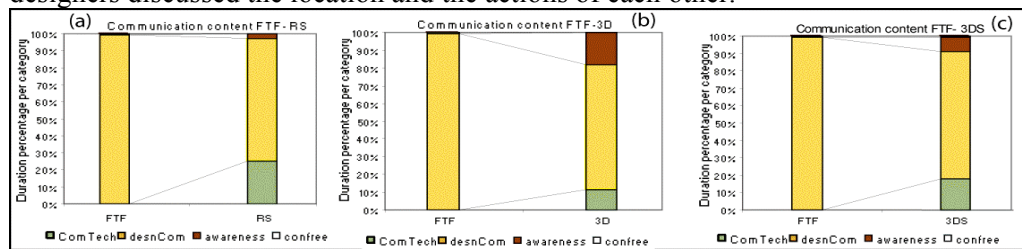


Figure 3 Communication content (a) FTF versus RS, (b) FTF versus 3D, (c) FTF versus 3DS

An analysis of the segment durations in each of the design sessions is shown in Table 2. Since we segmented the continuous stream of data according to a change in verbal or visual design externalization, and each session is the same length of time, the numbers of segments in each session give us information on how frequent the changes/ shifts occurred. In FTF, the mean duration of segments is the shortest (10 sec.) and the number of segment is the highest (190). On the other hand, the segment durations (the means are 11, 11 and 12) increase and the number of segments (190,

174 and 154) decreases in the virtual environments, as shown in Table 2. This shows that the designers have more attention shifts in face to face sketching (less time and more segments). The longest segment durations (44 sec and 1 min 22 sec) are observed in 3D virtual worlds where the designers spent time to elaborate the design model. Higher standard deviation values (7 and 8 sec) and the Kurtosis (8.95 and 26.37) measures in 3D virtual world sessions show this tendency. Skewness of segment durations for all sessions are positive.

Table 2 Statistics on duration of segments

	Mean	Std dev.	Kurtosis	Skewness	Min	Max	Seg.Number
FTF	00:00:10	00:00:05	0.38	0.61	00:00:02	00:00:26	190
RS	00:00:11	00:00:06	0.76	0.85	00:00:02	00:00:31	174
3D	00:00:11	00:00:07	8.95	2.40	00:00:02	00:00:44	154
3DS	00:00:12	00:00:08	26.37	3.73	00:00:02	00:01:22	154

The distribution of segment durations along the segment numbers in the design sessions is shown in Figure 4. Similar to what was shown in Table 2, the graph demonstrates that the segment durations are longer in virtual environments, and shorter in the FTF session. This suggests that designers had more new actions and shifted them quickly in FTF, but they spent more time on an action before they engaged in a new action in virtual environments. We could interpret that this consistent data showing longer segment duration in remote environments is due to: (1) the remote environments slow the designers down because they require more cognitive work and/or (2) the designers pursue each action in more detail in a digital representation in a remote environments.

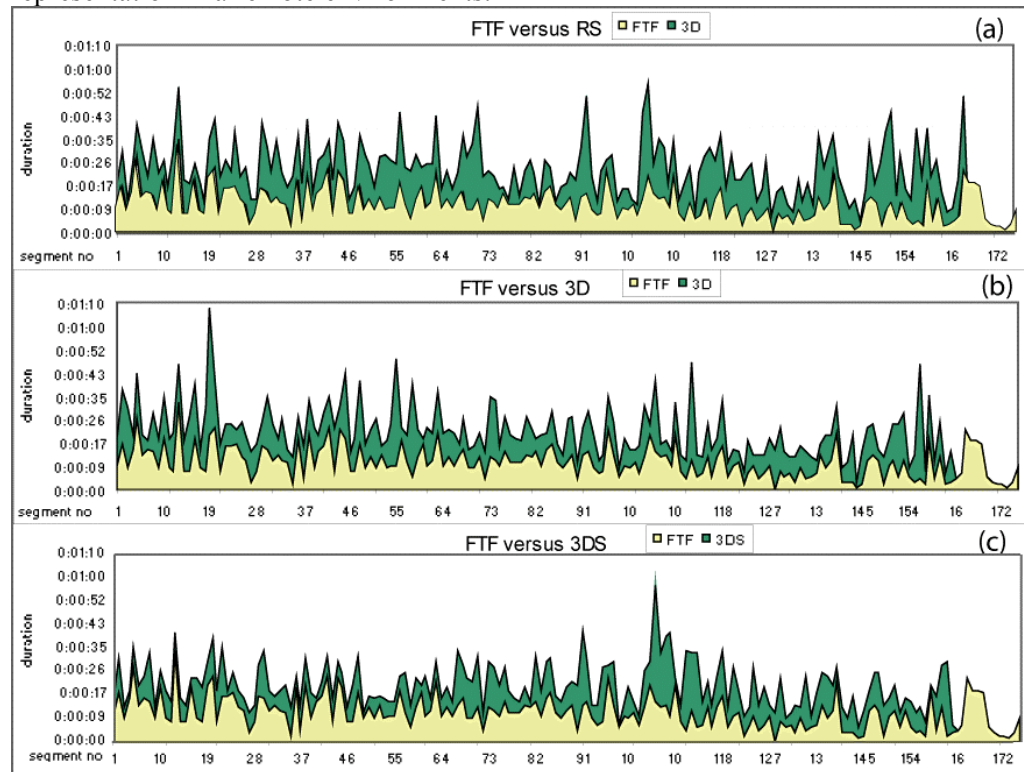


Figure 4 Distribution of the segment durations (a) FTF - RS, (b) FTF - 3D and (c) FTF - 3DS

The design process actions are shown along the timeline of the sessions in Figure 5. Each horizontal bar shows the beginning of the sessions which are on the left and the durations of each operation. The numbers 1 and 2 indicate each designer's actions that are coded separately. In general, there is a similar pattern of design behaviour in all design environment. In the FTF session, the designers started with analysing the problem and setting up goals until they gathered enough knowledge about the problem space, and then, they proposed ideas and clarified them. Analysing the solution space, synthesis and evaluation of a design idea happened towards the second half of the session. We observe that the designers went back to the design brief many times and reviewed the specifications, and then iterated the process. We observed similar design process actions in the RS session, however the frequency of analysing the problem space and proposing ideas actions are less. In 3D virtual worlds, there are more setup goal actions and less frequent design process actions. The designers spent more time on task allocations as a consequence of the nature of creating objects in 3D virtual worlds. For example, when an object is selected by a designer, the other designer is not able to manipulate the objects' properties. This feature of the 3D modelling encourages the designers to communicate about 'who does what'.

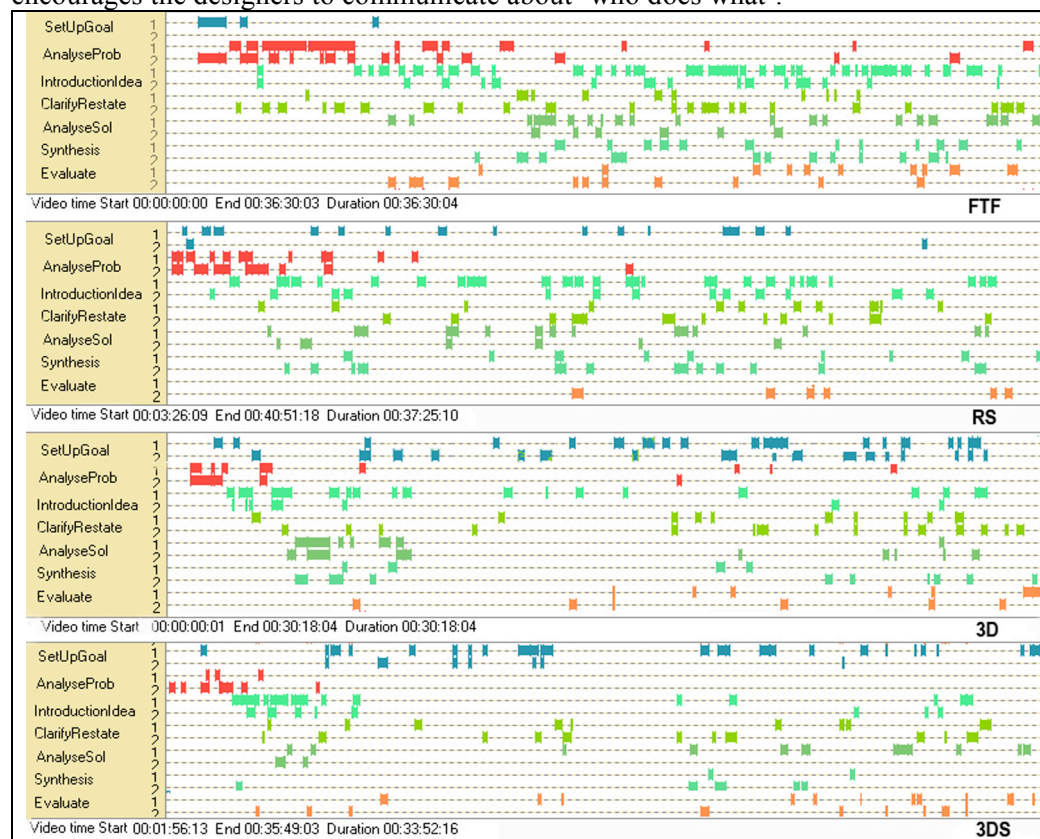


Figure 5 Design process actions over time

The duration percentages of the proposing design idea category actions of the designers in the four environments are shown in Figure 6. We observed that in FTF, the designers introduced more design ideas/concepts, and generated more alternatives. In RS, the designers developed more ideas/concepts and generated relatively fewer alternatives (Figure 6b). In 3D virtual environments, they introduced less design ideas/concepts. In 3DS they did not generate alternative design ideas/concepts, but instead they progressed and detailed one idea/concept (Figure 6c).

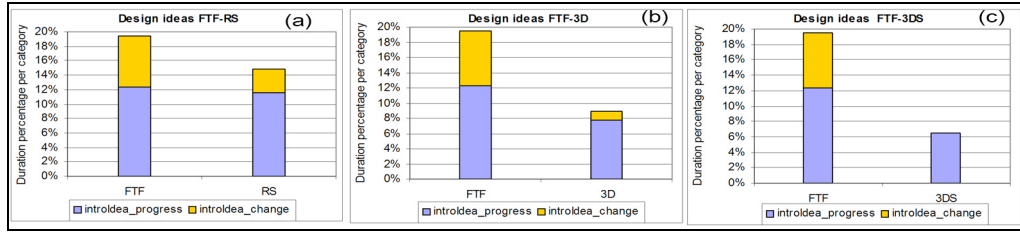


Figure 6 Introducing design ideas (a) FTF versus RS, (b) FTF versus 3D and (c) FTF versus 3DS

The duration percentages of realization actions of the designers over the four environments are shown in Figure 7. In the FTF session, write and create actions are higher where the designers spent some time analysing the specifications and generating design concepts/ideas, shown in Figure 7a. In 3D virtual worlds, the continue element action category is significantly high followed by create element and add element action categories, as shown in Figure 7b,c. This demonstrates that the designers engaged more with modifying/moving objects in 3D virtual worlds than with creating new objects. This is due to the nature of the 3D modelling where one simple click creates an object but then the user needs to move it to its place, and position, rotate or modify its properties. In contrast, in FTF the designers created and traced over the drawing. Our previous studies also showed similar modelling action cycles where designers inspect the representation, create, move and modify the design objects while in 3D virtual worlds (Maher et al. 2006a).

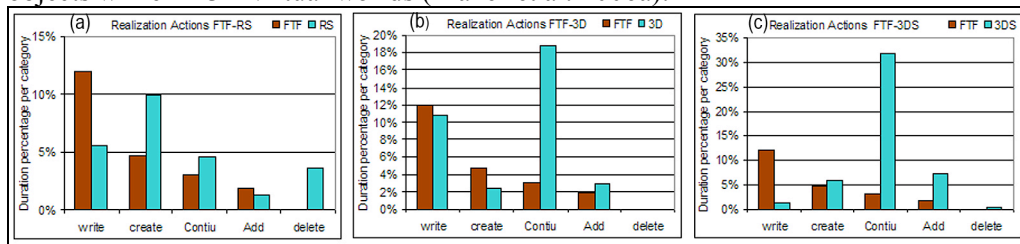


Figure 7 Realization actions (a) FTF versus RS, (b) FTF versus 3D and (c) FTF versus 3DS

Figure 8 shows the duration percentages of perceptual focus actions of the designers. The object/entity action is higher in FTF, and the spatial relation action is higher in 3DS. It can be observed that the designers engaged with the visual features of the objects in FTF, and while in 3D worlds they engaged with the spatial relationships of the design objects/elements.

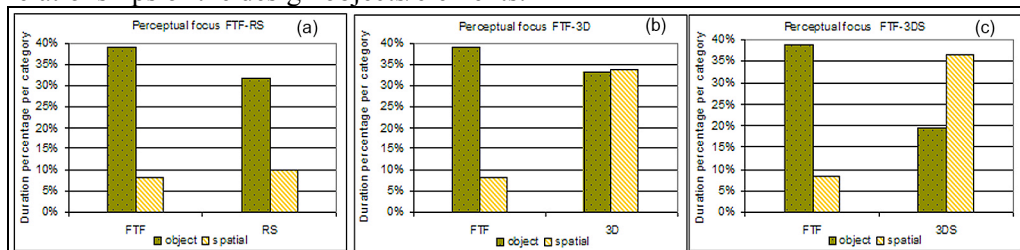


Figure 8 Perceptual focus (a) FTF versus RS, (b) FTF versus 3D and (c) FTF versus 3DS

The design process and realization action categories are shown along the timeline of the sessions in Figure 9. In FTF, the designers communicated the design ideas that are accompanied by the realization actions. This means they talked and drew at the same time in FTF, as shown in Figure 9. It can be seen that when the designers moved to the remote environments, the design process and representation actions showed a different pattern. The design process and the realization actions become separate actions. In particular, in the augmented 3D virtual world, the design process category was cut off in larger chunks and replaced with the representation actions as shown in Figure 9. Similar to what we demonstrated in Figure 5, in 3D virtual worlds, the designers had fewer discussions that are related to idea generation and design development, instead, they spent more time on the design objects and making the model.

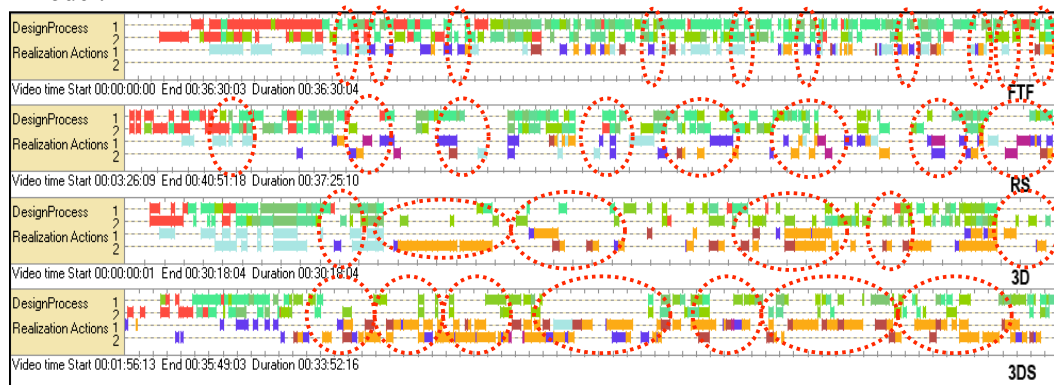


Figure 9 Communication content and realization actions:

Conclusions

Introducing new design media to team collaboration requires understanding what purpose they serve. A design environment could be useful for any design phase, however analysis of team collaboration process is required for understanding the impact of the new tools/environments. The case study described here characterizes and compares the design behaviour of two architects while collaborating using four different tools/media for designing.

We observed that the designers engage with different aspects of the design problem when they are sketching compared to when they are making 3D models, even when given a design task of the same level of complexity and abstraction. Our preliminary results show that there are differences in designing in a co-present sketch and a remote virtual environment. First, we characterise how the designers generate/develop design representations while in a shared 3D modelling environment. They quickly decide to pursue a concept/idea without having much problem definition (and redefinition) behaviour, and spend more time on the making the visual model of the design in the 3D modelling environment. In particular, they have longer model making actions that include engagement with the spatial relationships of the design objects in 3D modelling mode. Second, we characterise how the designers generate/develop design representations while in a shared 2D sketching environment. The designers focus on abstract representations of the design and iterate from synthesis to analysis more times while they are sketching. Third, they move/shift from one action to another very quickly, and generate more abstract design ideas when they are involved in FTF sketching.

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