Collaborative design: Evolution of project's information and role of the graphic interactions

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Faced with challenges of new collaborative and digital design processes, it is necessary to understand how to support architectural design to articulate the information from the collaborative ideation (first creative moments of idea deployment) to the digital design phases that follow (such as BIM models specifications).

The study presented here lies within the fields of design theory and computational design as our research question is to analyze collaborative design processes to qualify the evolution of the information characterizing the project and the design activities generating this evolution, notably through the role of graphic interactions.

To achieve this goal, we changed the paradigm by considering the designers as transmitters of information, and the information as the heart of our questioning.

As result, we highlighted some typical design activities to characterize the project, recurrent associations of information and finally the importance of graphical traces as a support of this characterization.

Motivation

Background

The current modes of design show little articulation between their multiple actors, called to manage the increasing complexity of building projects. Building information modeling (BIM) technologies and integrated processes are seen today as the promising path to increase exchanges between

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actors and to improve the buildings' performances [1], [2]. If it undoubtedly brings benefits during the implementation phases, this digital approach for information sharing is not really adapted to ideation phases, creative moments of idea generation and deployment.

Thus, it is essential to address the issue of the transition from architectural design to BIM by integrating the collaborative, contextualized and designer-oriented processes. This involves tracking, collecting and articulating information from the collaborative ideation.

These questions relate to the fields of design theory and computational design, addressing the notions of design activities, external representations and graphical traces.

Existing research

Many researchers have already studied design theory.

Since 1990, Gero has been studying reflective practices in design and has developed a situated Function-Behaviour-Structure ontology model [3], [4], [5]. In the wake of Schön [6], he integrated the notion of situation and separated reflective practices into two types of reflection, self-reflection or reflection with the environment. This model will also allow the development of a situated Function-Behaviour-Structure co-design model [7].

Design thinking is also discussed in recent studies by Gero and Milovanovic, who go as far as defining a framework of analyses which includes design cognition, design physiology and design neurocognition [8].

Collaborative design activities have also been widely studied by Falzon, Darses, Détienne and Visser [9], [10] from the point of view of ergonomic cognitive psychology, developing several recommendations for collaborative design assistance.

Thereby, there are already many analyses on the collaborative design activity but they often focus on the actor. It is thus important to emphasize that in our study we did a change of paradigm by considering the designers as transmitters of information and the information as the heart of our questioning.

We also consider that the media, *i.e.* the mediator objects between the designer and the design activity [11], [12], are specifically chosen by the designers [13] and that they are combined with each other, forming patterns [14]. By pattern we refer to a recurrent association of media used in combination with each other. We therefore analyzed patterns within the usage of media. We thus differ from Yu and Gero [15] who studied patterns in the

designer's activity by observing sequences of moves in the Function-Behaviour-Structure ontology.

Aim

Faced with the challenges outlined above, our study aims to understand how to assist architectural ideation by collecting and articulating projects' information. To do so, we seek to understand how precisely this information appears, evolves and is shared.

We therefore analyze:

- what information is generated and shared, and by which media;
- whether patterns emerge in the media usage;
- and what role graphic interactions play in the evolution of this information.

Method

Environment

Our study takes place in the very particular context of Liege University's Architecture and Building Engineering Master's educational design workshop.

This workshop reproduces similar conditions to architectural competitions and presents the opportunity to observe an integrated collaborative design process consisting, in this case, in the realization of a 7000m2 musical complex with various functions (two concert halls, artists' spaces, restaurant with production kitchen, etc). We are studying this process in its entirety, *i. e.* over a period of 14 weeks long The observed design is thus analogous to an agency process.

The attending subjects form 6 teams of 3 to 4 actors, each team designing a unique project of the music complex. We are therefore studying 6 different processes in parallel.

These 20 subjects are all expert designers. They differ from novice designers by their global approach of the project, more focused on the solution space than on the problem space [16], [17], [18].

In addition, these 6 teams of expert designers interact during review sessions of the projects with 2 senior architects and 2 engineers, all having long-term professional and agency experience.

In this type of process, there are two typologies of design:

- the design which we will call "long design", which combines individual and collective design activities spread over several days in various work environments;
- the design which we will call "episodic", which constitutes short design moments, sorts of episodes of design conversations, for the instantaneous resolution of a problem, involving all the actors on a given focus, *i.e.* a discussion subject.

The analysis of the evolution of information on a large scale, *i.e.* from week to week, to understand long design activities, has already been covered in a previous publication [13]. In this study, we seek to characterize specifically live information evolutions appearing in episodic design moments.

To study these moments of live episodic evolution across a 14-week continuous design process, we choose to focus our observations on the moments of review sessions. These are design moments [19] which offer the double advantage of being moments of explicit project characterization and of being easily time-taggable and instrumentable for data collection.

The discussions are supported by the graphic communication software SketSha (for Sketch Sharing). This software is based on the sharing, between several remote workstations, of various graphic documents such as plans, photos, texts, etc. These shared elements can then be annotated in real time with a digital pen [20], [21]. It is therefore a collective review tool allowing remote as well as co-presence review sessions [22].

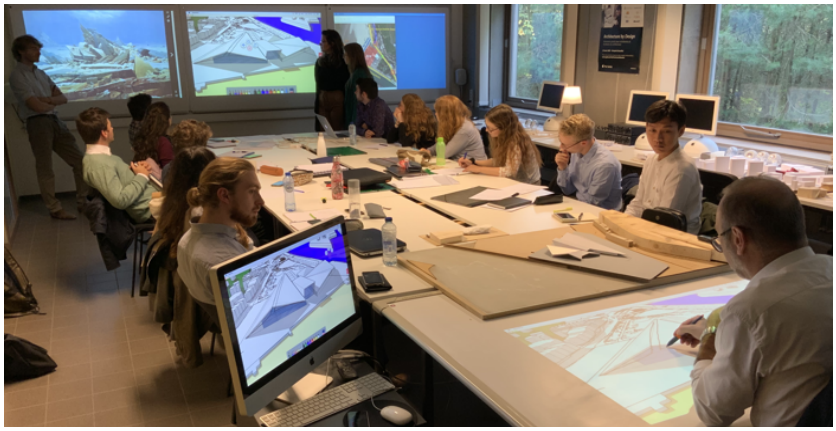

Fig 1. Critical review environment and SketSha software

In the present configuration, the review sessions took place face-to-face but also remotely due to the sanitary crisis. SketSha was therefore used both as a large graphic table supporting collaborative architectural drawing in co-presence (Fig. 1) and as a multimodal environment for remote collaboration

Data collection

We observe the project review sessions as non-participants in order to capture the documents used as well as the verbal and graphic interactions. For this purpose, we record the exchanges using a camera mounted on the ceiling, collecting the sound of the room and the image of SketSha (Fig. 2). This allows us to collect the necessary data without disrupting the subjects' design activities.

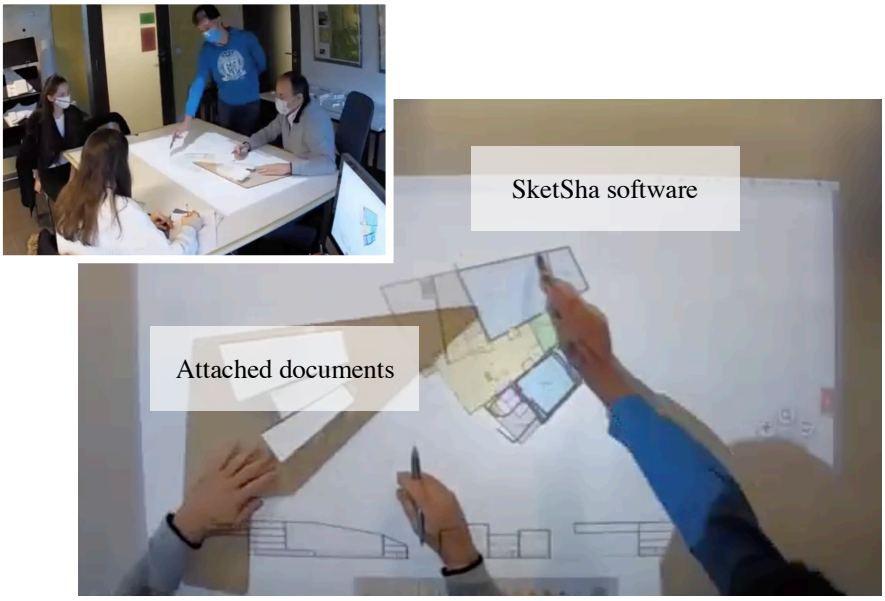

Fig 2. Experimental space – Camera shot

In terms of data corpus, this allows us to collate one hour of interaction for each of the 6 designer teams during 6 formal reviews, 3 of which presented episodic design sequences. We thus collect about 36 hours of verbal and graphic interactions.

The analysis of these design episodes is done by 15-second steps. We characterize the evolution of the information through a free description as well as through four criteria (developed in previous publications [23], [13]):

- The typology of the information mentioned (*e.g.* concept, facade or structure): classification of building's attributes constructed from the grounds up according to the Grounded Theory [24].
- The type of means of design used to generate this information (*e.g.* hand drawing, 3D CAD or prototype): type of instrumented action used to conceive the project and to produce the desired representation (design instruments are associated with a pattern of use and material or methodological resources).
- The type of external representation used to communicate this information (*e.g.* reference image, plan or perspective): possibilities of information figuration on visual documents.
- The presence or absence of a graphical trace materializing this information.

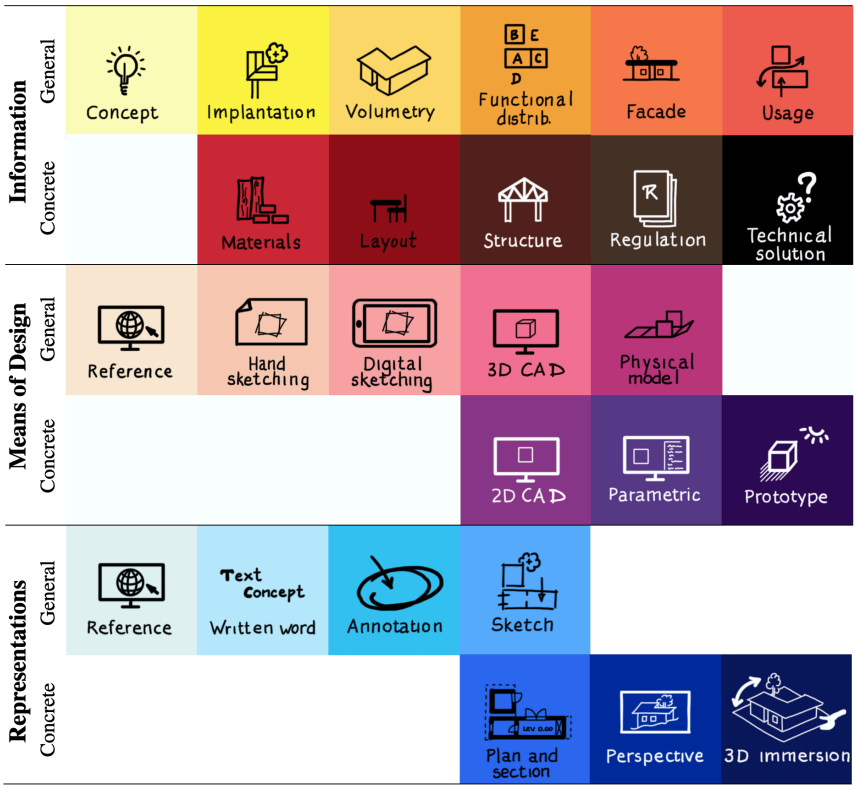

Fig 3. Diagram of the information, means and representation typologies

For example, when a designer, in the observed design episode, adds by drawing a water basin in the urban space on the layout plan, he evolves an "*implantation*" type of information through an instrumented activity of "*hand-sketching*" on an external representation classified as "*plan and section*".

The coding of these design moments is then imported into the data visualization software CommonTools [25], which allows the generation of several types of graphs such as, among others, timelines illustrating the evolution of the information.

This coding (Fig. 4) provides a reconstruction of the chaining of project information, and thus its evolution, during the 64 design episodes identified. As a result, in a longitudinal reading, for each team and for the three project review sessions observed, we can analyze the fluctuations in the information, means and representations used.

In addition, in a transversal reading, for each team of participants, each piece of project information expressed by a designer is characterized using the triplet of properties stated above (type of information, means and representation).

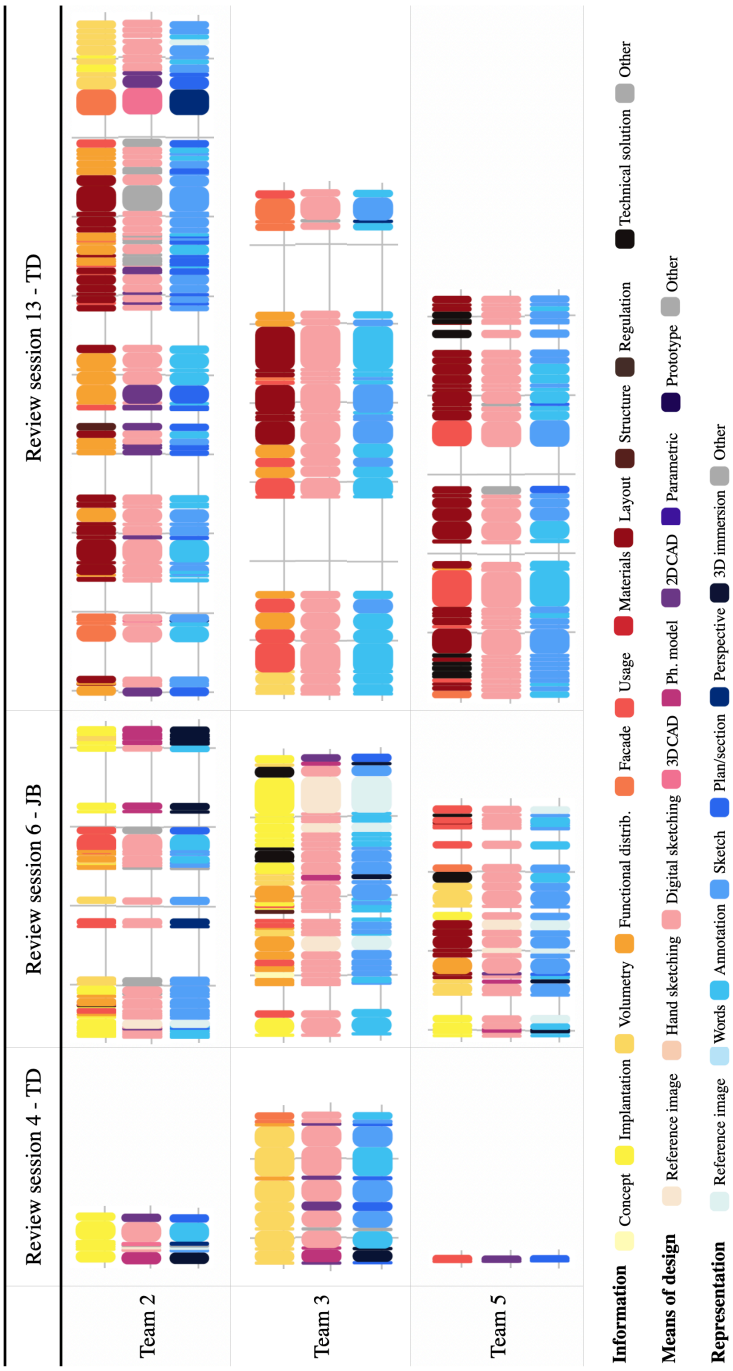

Fig 4. Data modeling for teams 2,3 and 5

Results

In this section, we will present the different results emerging from our observations.

Typical design activities

In order to determine whether there were typical design activities in this episodic design context, we calculated the occurrence of use of each class of means and representation, regardless of the participants, for each episodic design sequence observed (Fig. 5). Strikingly, we note a widespread use, all along the process and for every team, of the means "*digital sketching*" and external representations of "*annotations*" and "*sketch*" type. In some sequences, the model or 2D CAD is used as a complement.

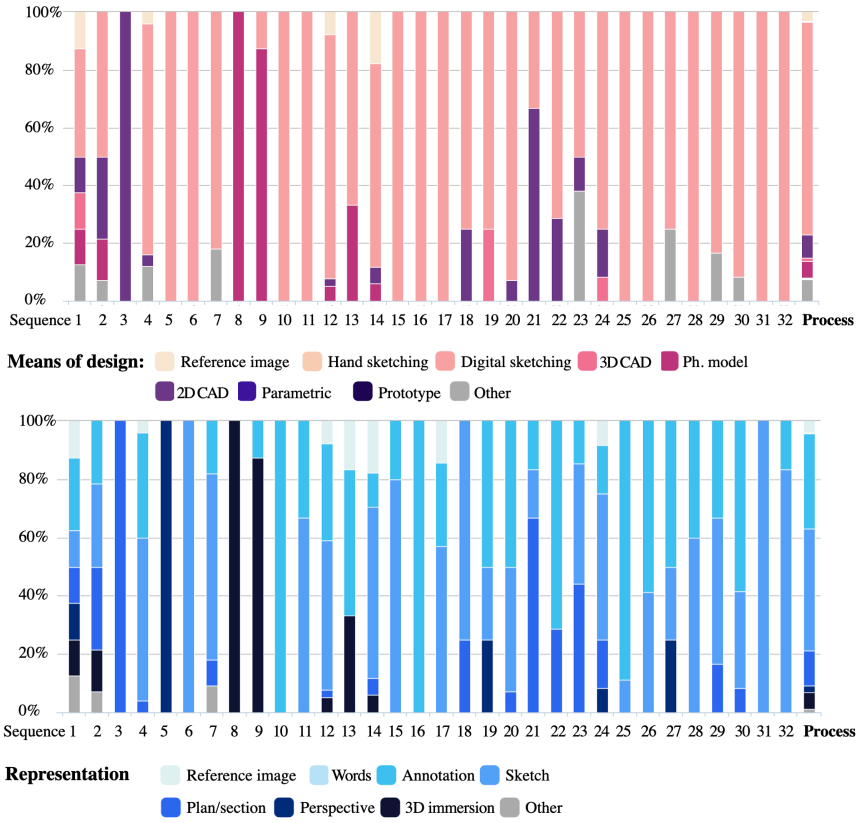

Fig 5. Proportion of use of different classes of information, media and representation throughout the process, all teams combined

To refine our analysis of design activities, we intersect the different means and representations used with the type of information conveyed by them (Fig. 6).

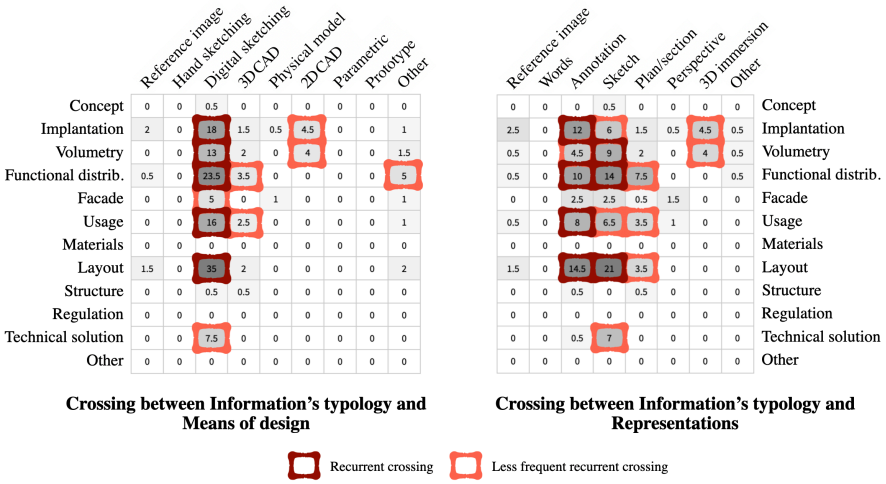

Fig 6. Proportion of use of the different Information-Medium and Information-Representation crossings, throughout the process, all teams combined

This graph highlights the means and representations most commonly used and for which type of information as illustrated by the red boxes.

In conclusion, we can see that, whatever the information generated or conveyed during these 64 design episodes, design activities take place largely through annotations and sketches and, in a second stage, through physical models and CAD plans or sections.

It is interesting to note that these results, specific to the analysis of "episodic" design moments, diverge from the results obtained when analyzing "long" design activities, in the same experimental context. These studies on long design [13], [14] showed a diversified use of design media and an intentional and specific choice of media depending on the situation.

Our explanation hypothesis is based on the statement that the design activities observed here are not free individual design activities, carried out over several days, but rather short moments of project's critical point resolution where all the actors choose to carry out their design activities in a

single physical space and in a shared space of reflection, recognizing Ben Rajeb's "*We-space*" [26]. Therefore, the cognitive economy encourages designers, in their activities, to use the medium and representation already present, in this case SketSha, to design [22]. This phenomenon has been more widely studied and validated in the recent studies of Calixte [27].

Recurrent information associations

This experience also revealed recurrent information associations.

Let us recall that by "information" we refer to a specific characteristic of the building such as the material of a floor, the height of a window, etc. Thus, for a given focus, for example the main entrance door, we can find different typologies of information such as the position of the opening in the main facade (*facade* type), the shape of the pathway leading to the door (*layout* type), the trajectory of visitor flows through this door (*use* type), the width of the passageway required in case of fire (*regulation* type), etc.

By crossing the typology of each successive piece of information with the typology of the information that follows this one (Fig. 7), we can observe that pieces of information are mostly followed by another piece of information of the same type (most important occurrences are on the diagonal). Moreover, when a change of information type occurs, three preferential associations are observed:

- *Volumetry* and *Layout*;
- *Volumetry* and *Functional Distribution*;
- *Use*, *Functional Distribution* and *Layout.*

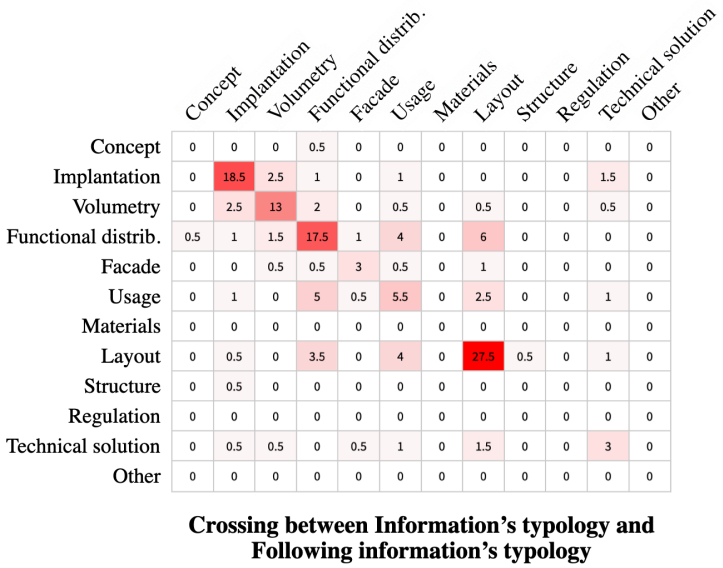

Fig 7. Occurrence of crossing between typologies of each piece of information and the following one, along the whole process, all teams combined

The observed associations between information of the same type show that these design moments in a review session, which aim to address invalidated architectural proposals, are focused on a unique and precise focus, *i.e*. on one single and detailed discussion topic. When we went back to watch these recorded moments, we actually witnessed that an invalidated solution is continuously worked on until a satisfactory compromise between the different constraints is reached and thus the proposal is validated. For example, in the 8th episodic design sequence, team 5 is challenged, in the central building atrium, by the lift battery which blocks the circulation on the platform and by the irregular distribution of the columns surrounding the atrium. The expert suggests placing the lifts a little further away and redistributing the position of the columns. This leads to changes in the shape of the landings to remove some of the columns from the passage. These modifications are then reflected on the upper and lower floors. Finally, the new layout is validated and the columns are determined to be circular sections.

Furthermore, the preferential associations appearing in second stage between different types of information suggest that, in their thinking patterns, designers have preferential cognitive pathways between the different possible focuses and have associative ideas reasoning logics.

Importance of graphical traces

Finally, we observed that a graphical trace accompanies on average 78% of the project information generated and communicated. This high percentage of presence and the low standard deviation between the different teams reflects the importance of graphical traces in "episodic" design activities.

Table 1 Percentage of information supported by a graphical trace

Teams	1	2	3	4	5	6	**Total**
Information nb	102	334	91	113	83	110	**833**
Graphical traces occurence	78	225	75	93	68	86	**625**
Percentage	76.5 %	67.4 %	82.4 %	82.3 %	81.9 %	78.2 %	**78.1 %**

Graphical traces seem to be the preferred means used by teams to support these design episodes. This can be explained by its potential to support communication between designers, to reinforce oral comments, to concretely illustrate the proposed solutions or to crystallize the evolution of the artifact.

Conclusion

The study presented in this article aims to qualify the so-called "episodic" evolution of the information characterizing the architectural project and to better understand the design activities that generate this information. For this purpose, we observed the design episodes present in the project review sessions of a 14-week integrated design process. This allowed us to highlight the following:

- design activities are largely achieved through annotations and sketches and, in a second stage, through physical models and CAD plans or sections, which is explained by the cognitive economy that encourages designers to use the medium and representation already present to quickly and directly design the new architectural solution;
- the design focus is unique and precise for each sequence of architectural problem solving and once the solution is validated there are preferential paths to move from one focus to another;

- the graphical traces are an important support for the generation and communication of successive information characterizing the evolving project.

These results provide a better understanding of how information appears, evolves and is shared, we can better grasp the issue of collecting this information and we know that it will have to be done by using graphic traces made up of annotated sketches and CAD plans.

Replicating this experiment in a different work environment would isolate the influence of this environmental factor and exclude a potential bias related to the use of SketSha as a design tool [20], [21].

Having studied the evolution of project information during the collaborative design of an architectural project, we will now study how to, concretely, collect this information. Micro-experiments on specific focuses in a laboratory will allow us to set up a specific and operational method to collect and formalize this information in a more detailed way.

We also intend to study more in-depth the specific role of graphical traces in episodic design moments.

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