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ANALYSIS OF COMPLEX INTEGRATED DESIGN ACTIVITIES: TRACEABILITY OF INFORMATION AND CHARACTERIZATION OF ITS EVOLUTION IN RELATION TO DESIGN MEDIA.

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SUMMARY

This paper summarizes a research project on collaborative architectural design aimed at understanding how the information characterizing the project evolves, and through which mediating objects this evolution takes place. Design activity in architecture has been extensively studied through various prisms. The originality of our approach lies in a paradigm shift that places information at the heart of our questioning. In this paper, we address the issue of information traceability throughout the design process, as well as the visualization of this evolution of information in the activity. We set up an experiment built to analyze an integrated design process of 13 weeks through 110 hours of exchanges and evaluation of information. The originality of this observation protocol lies in its ability to characterize design activities of different natures and temporalities in real time. We then propose new formalisms for visualizing this data. Our main observations reveal very rapid fluctuations and inconsistencies in the level of abstraction of successive information, recurrent or deviated uses of certain media. We also 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.

KEYWORDS: Architectural design - Information - Mediating objects - Visual formalisms - Graphic trace

I. BACKGROUND

Design activity in architecture has been extensively studied through various general activity models, such as Simon's (1969) three-stage problem-solving activity of structuring-generating-evaluating, Schön's (1983) opportunistic activity of successive see-transform-see transformations, and Gero's (1990) Function-Behaviour-Structure model. These models provide a clear and logical structure for understanding the design process. Design activity in architecture has been extensively studied through various general activity models, such as Simon's (1969) three-stage problem-solving activity of structuring-generating-evaluating, Schön's (1983) opportunistic activity of successive see-transform-see transformations, and Gero's (1990) Function-Behaviour-Structure model. Design activities have been extensively studied through the prism of tools. The theory of activity introduces the triangle between subject, object of action, and mediating object (Engeström, 1987). The instrumental approach of Rabardel and Beguin (2000) introduces the notion of instrument as an object to which a pattern of use is applied. Latour and colleagues (2006, 2008) consider mediating objects as actors in a network, similar to the designer. Boujut (2002) also employs the concept of the intermediate object, or frontier object, as a point of entry in his ethnographic studies. Design activities have also been examined through the lens of cognitive activities, as in the ergonomic studies of Falzon (2004, 2005), Darses' problem-solving studies (2009), and Détienne's work on collaborative cognitive activities (2007, 2021). Finally, Buckingham Schum (et al., 1997) and Lewkowiez and Zacklad (2000) document design rationale and decision-making processes.

The purpose of our research is to analyze the activity of conception with greater precision, in order to gain knowledge that focuses on information management throughout the design process. Goldschmidt (1997) decomposed the design process into design moves to graphically represent the project's transformation links. Our goal is to study the overall evolution of this process, including its articulation with other dimensions such as tool use, validation, collaboration, and more. To meet that goal, we thus build a new way of characterizing the building information and develop a new theorization of the designing medias.

II. THEORETICAL POSITIONING

II.1. DESIGN THROUGH INFORMATION

In this context, we consider design as the characterization of an artifact, i.e. a conceptual, communicable and transformable object, specified by attributes, to meet initial requirements such as functions to be fulfilled (e.g. architectural program),

goals (e.g. meeting a budget) or needs to be met (e.g. reducing energy bills) (Visser, 2009; Lebahar, 1998).

In our analysis of design activity, we are shifting from a traditional paradigm to a new one: we will characterize design through the information it generates and which subsequently feeds it back, as well as by describing the mediating objects that support this information. In our posture, we see the actors as the transmitters of this information, which we place at the heart of our questioning.

What we call information covers all the attributes characterizing design choices results and/or the reasons behind them. It can be very concrete and directly related to the building, such as a ceiling height or a choice of material, or more general, such as an intention for a luminous ambience or a functional division of rooms.

We thus approach the complex cognitive activity of design, via its externalized, tangible and precise elements, by tracing the information produced and used by designers. To avoid any bias of over-interpretation, we extract these elements directly from the designers' discourse and not from the project's representation documents.

II.2. MEDIA IN ARCHITECTURE

To study media in architecture, and thus mediation by tools, we begin with the "theory of activity", which considers activity as a set of relationships between three poles: the subject, the object of his activity and the mediating object of this activity (Engeström, 1987). In architectural design, this mediating object may be an object (pencil, computer, software, etc.) or a representation (drawing, digital model, etc.). The term mediator object extends the notion of artifact to encompass external representations (Elsen et al., 2010).

At the same time, in the field of human-machine relations and media use, Rabardel and Beguin (2000) developed the theory of the "instrumental approach". They develop the notion of instrument: an instrument is an artifact to which the actor has applied a pattern of use.

As the use of modeling software is nowadays increasingly present in the design process, Calixte uses the term tool to integrate this digital dimension to and thereby to designate "an artifact or a set of physical or digital artifacts, including or not codes specific to the activity, with the aim of carrying out an action" (Calixte et al., 2019, p. 4). The author also adds the notion of resources to the instrumental approach. Resources are defined as the elements of the work environment that can be used by the actor to carry out his task. They can be material (available tools), collective (team work methods) or individual (designer's skills, ability to take advantage of material and collective resources) (Calixte et al., 2019). The term Medium then replaces Instrument to designate the set of resources associated with the pattern of use to carry out an action.

This theoretical point will be important for the discussion of this paper.

III. ISSUE

To gain a better understanding of how information characterizing the project evolves in integrated architectural design, and through which mediating objects this evolution takes place, we pose the following research questions:

- How can we construct a protocol that enables us to analyze two types of architectural design activity (see 4.1 below) and extract the information characterizing the project from the designers' verbatims, without interfering in their activity?How can we define the variables characterizing this information, and how can we code them to reconstruct the design activity?

- How does information evolve throughout the collaborative design process? Through which media is it generated and communicated? Are these media used at preferential moments in the process or with preferred patterns? what role graphic interactions play in the evolution of this information?

IV. METHODOLOGY

IV.1. DESIGN PROCESS OBSERVED

The design activity we're observing takes place in an architectural studio in an educational setting already described (Anonyme & Anonyme, 2021). This workshop is an ideal context in which to study design, because of its similarity to agency competition procedures, and for the diversity of the architectural constraints and issues to which the designers must respond.

This integrated design process lasts 14 weeks and sees 6 teams of 3 to 4 actors mobilized to create a 7,000m2 music complex with a variety of functions including performance halls, spaces for artists, a restaurant, etc. The timetable for this process is punctuated by informal presentations with the supervisors and formal reviews with five different professional experts. 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 (Milovanovic, 2019; Perisic et al., 2019; Nesposi et al., 2021).

The framework of this integrated design workshop also provides access to two different natures of design activity (Anonyme & Anonyme, 2022), naturally marked out by temporal organization:

- what we call long-term design: spread over several periods of time and in several places, alternating between moments of individual design and moments of collective design, and mobilizing various tools;

- and episodic design: when all designers work together, synchronously, to generate solutions to a specific problem.

IV.2. OBSERVATION PROTOCOL

IV.2.I. Variables selection

We aim to design a unique protocol for observing these two different types of design activity (episodic and long-term), since in both we are analyzing information generation and sharing. The difficulty lies in the difference in temporal granulometry of these two activities: from a few minutes for episodic design to several weeks for long-term design. We are therefore developing an observation protocol (Anonyme & Anonyme, 2023) aimed at collecting data that is sufficiently varied and, above all, complementary to cover these two activities.

Our protocol is classic yet effective and multi-functional. It consists of observing presentations and reviews by filling in an observation grid in real time. The strength of this grid is that it is easy to use and saves on recorded data. Indeed, we only need to track 5 variables to be able to reconstruct the activity in the aspects of interest to our research, covering both the design actions implemented and the tools mobilized to generate and transmit the information characterizing the project. This grid is even more effective in that it is filled in mainly by ticking, supplemented by a few key words, making note-taking fast enough to be carried out in real time, following the actual flow of design and enunciation of the project's intermediate characteristics. Furthermore, this method doesn't mobilize the subjects at all, so it doesn't overload them nor disrupt their activities.

We characterize the observed activity of generating and sharing project information by means of 5 variables:

- the type of information, i.e. the nature of the information: as an architectural concept, uses, ... ;
- the mean of design, i.e. the action taken to generate the information: such as hand-drawing or simulation-based thinking;
- the external representation on which the information appears: from diagram to plan;
- the type of transformation of the architectural object that takes place as a result of this new information: adding elements, detailing some, or substituting representations;
- and the production, live, of a graphic trace accompanying the enunciation of the information, i.e. the creation of an annotation, a drawing, etc.

When it comes to information typologies, there are many different types, and there is a lack of classifications in the literature. We have therefore chosen to stay as close to the observed ground as possible. To this end, we apply a bottom-up methodology, proceeding by inductive labeling of the types of information stated by

the designers. At the end of the process, we obtain 11 typologies (Table 1 - information).

Table 1. Classes of objectivized variables.

Information	**Mean**	**Representation**	**Transformation**
Concept*:* *General intentions, architectural style, ...*	Reference image*:* *Analogy with pre-existing images.*	Reference image*:* *Representation not produced by the actors.*	Duplicate*:* *Duplicate a drawing without modifying its content.*
Implantation*:* *Position on site, urban layout, ...*	Hand-drawn paper*:* *Graphic design by hand on paper media.*	Text or keyword*:* *Text-only representation.*	Add*:* *Add information with little change to the representation.*
Volumetry*:* *Size, volumes, ...*	Digital hand-drawing*:* *Graphic design by electronic pen on digital media.*	Annotation*:* *Symbol or note added to a pre-existing representation.*	Detail*:* *Rework different elements in greater detail.*
Functional layout*:* *Position of functional spaces, links between spaces, ...*	2D CAD*:* *Computer-aided 2D drawing.*	Diagram or sketch*:* *Symbolic, abstract representation, such as trial sketches.*	Concretize*:* *Make a representation more concrete.*
Usage*:* *Traffic flow, user experience, ambience, views, ...*	3D CAD*:* *Digital 3D modeling*	Plan or section*:* *Standardized 2D representation, such as floor plans.*	Modify*:* *Modify the representation without detailing it nor making it more concrete.*
Materials*:* *Materials, colors, textures, ...*	Mock-up*:* *Design using a physical 3D model.*	2D perspective*:* *Representation of a 3D object on a 2D medium, such as drawing on a sheet of paper a view of a building from the street.*	Substitute*:* *Replace with an alternative representation without detailing nor concretizing.*
Layout*:* *Internal partitioning of spaces, room layout, furniture, ...*	Parametric CAD*:* *Parametric design.*	3D immersion*:* *Navigation in a digital or physical 3D model, if the designer looks and rotates the project model.*	New*:* *Add information that change the project.*
Structure*:* *Load-bearing systems, dimensioning, ...*	Prototype*:* *Design using simulations.*		
Regulations *:* *Building characteristics derived directly from norms.*			
Technical solution*:* *Building characteristic in response to technical problems.*			

For design means, we took inspiration from the work presented by Borillo and Goulette (2002) and the research of Safin (2011) to derive, in our previous research (Anonyme et al., 2019), the classification into 8 typologies (Table 1 - means).

For external representations, we based it on the work of Safin (2011) and Elsen (2011) and developed a classification into 7 categories (Table 1 - representations) as part of our previous research (Anonyme et al., 2019). Note that we clearly differentiate the cognitive or physical action enabling design (i.e. the means), from the external representation of the designed artifact (i.e. the representation), even if these two variables influence each other. This overlap will be a valuable consideration later on.

For project transformations (Table 1 - transformation), we use the classification of Visser (2006), detailing the vertical and horizontal transformations of Goel (1995). We add a 7th class to Visser's for new representations. These represent an addition of information, but unlike the add class, they modify the representation considerably.

Finally, the production of a graphical trace is simply coded as yes or no. It should be noted that we make a clear distinction between the nature of the document used as visual support (i.e. the representation) and whether or not a graphical trace is produced to accompany the stated information, as designers can use an external representation of the project without producing a live drawing.

Finally, all these classifications are positioned on a scale of varying levels of abstraction (and, specifically for transformations, levels of modification). They are summarized in the diagram below.

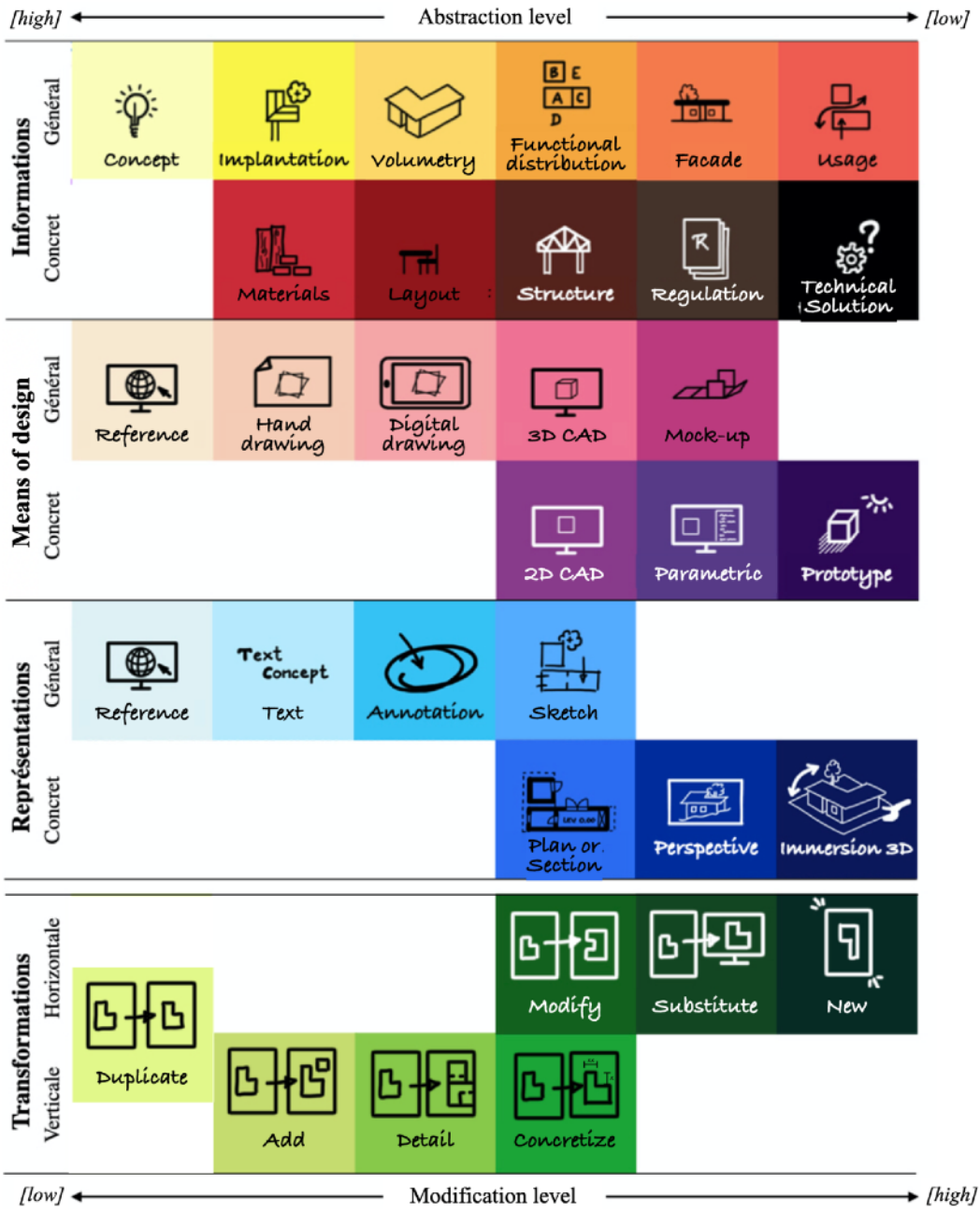


Figure 1. Classification of information, means, representation and transformation typologies with varying levels of abstraction and modification (Anonyme & Anonyme, 2021, 2022b, 2023).

IV.2.II.Strengths of the proposed protocol

In summary, this protocol has two major strengths. Firstly, it makes it possible to observe design activities of very different kinds and of very varied temporal

granulometry, from long design to episodic design. Secondly, it is simple and data-efficient, since just 5 variables enable us to reconstruct the evolution of the project through the information characterizing it. This means that the process can be coded in real time, without overloading the subjects.

The originality of this protocol also lies in the fact that it characterizes the design activity by focusing observation on the evolution of the information characterizing the project.

IV.3. COLLECTED DATA

To characterize long-term design, 6 parallel 14-week processes were observed through 13 presentation moments. We captured the exchange of 1,549 pieces of information characterizing the project. Each of these items of information was described by 5 variables, giving us 7,745 coded data. From these 5 variables, we can deduce, by simple statistical calculation, other data such as the crossing probabilities between types of information, means and representation, as well as calculating the shifts in abstraction levels. This gives us a final total of 11,167 analyzable data items. It is important to bear in mind the granulometry of this data, which is of the order of one unit of information.

For the characterization of episodic design, we were able to identify 64 episodes within the expert reviews of the 6 teams. These episodes involved 3 to 25 successive transformations of different building features, giving a total of 514 pieces of information described using the 5 variables. This enabled us to collect 2,570 analyzable data items. For this type of design, the unit of analysis is a step of 10 seconds of activity.

IV.4. ACTIVITY VISUALIZATION

IV.4.I. Data coding

These data are coded in a dual entry table. The columns show the different variables characterizing each piece of information: the five observed variables (type of information, means of conception, external representation, project transformation and presence of an accompanying graphic trace) and the deduced variables (shifts in abstraction level, focus, etc.). The lines successively show each new piece of information. At the intersection, a number acts as an occurrence tick, while also symbolizing the abstraction level of the class presenting this occurrence, enabling the subsequent calculation of abstraction level differences between two pieces of information.

IV.4.II.Strengths of the proposed protocol

Beyond histogram representations and other usual statistical graphs, our use of the CommonTools platform (Ben Rajeb & Leclercq, 2015) creates the following mode of data visualization:

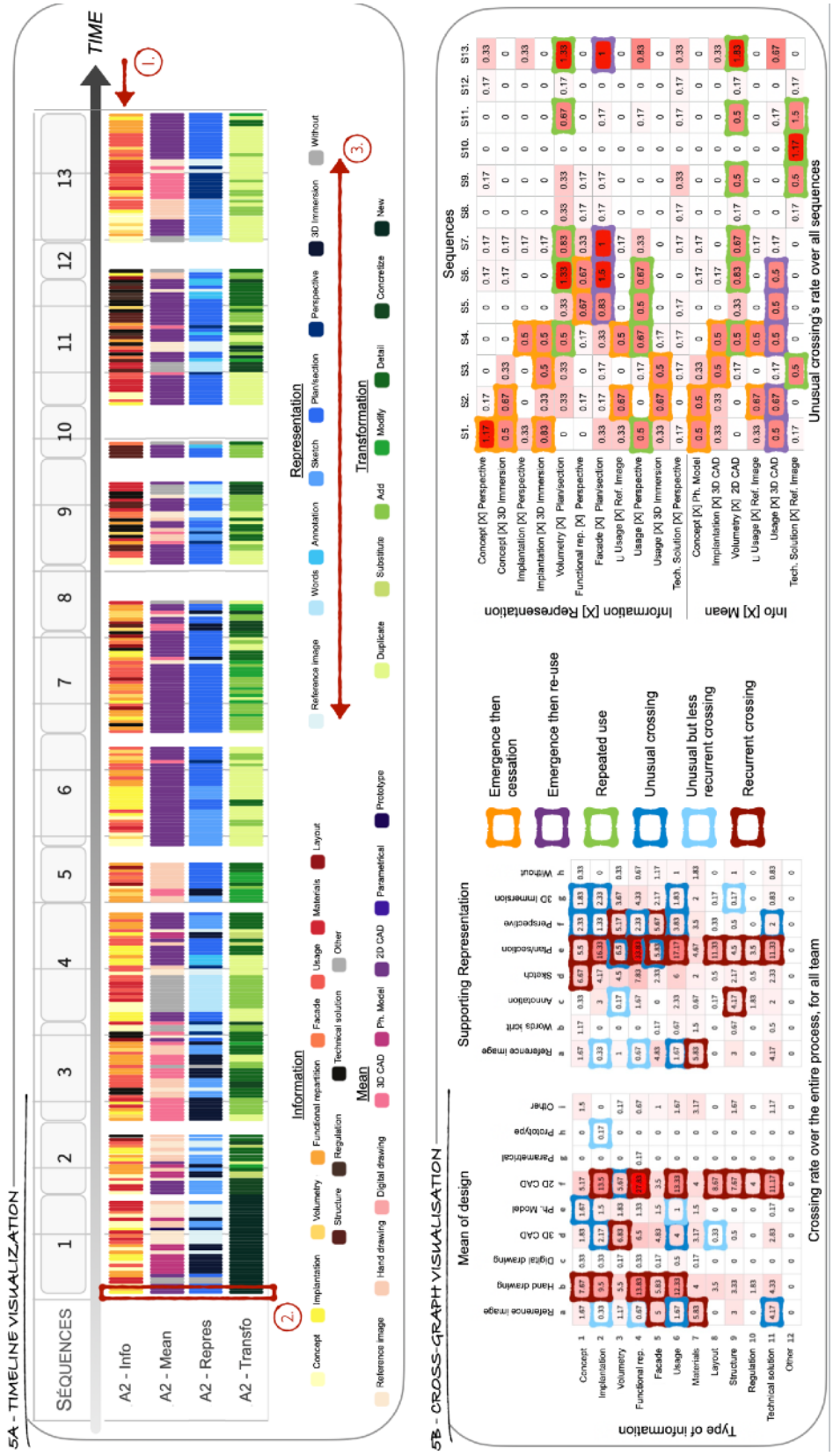

5A - TIMELINE VISUALIZATION
SÉQUENCES
TIME
A2 - Info
A2 - Mean
A2 - Repres
A2 - Transfo
Information
Mean
Representation
Transformation
5B - CROSS-GRAPH VISUALISATION
Mean of design
Supporting Representation
Emergence then cessation
Emergence then re-use
Repeated use
Unusual crossing
Unusual but less recurrent crossing
Recurrent crossing
Type of information
Crossing rate over the entire process, for all team
Sequences
Info [X] Mean
Information [X] Representation
Unusual crossing's rate over all sequences

Figure 2. Original visualization of data as triple-read succession line (5A) and as crossings (5B) from (Anonyme & Anonyme, 2021, 2023).

The first is an original visualization, in the form of an arrangement of colored bars that can be analyzed in triple reading (figure 5, left). On a timeline, at real or fictive scale depending on the type of design represented, we represent the information successively stated by the designers. Each piece of information is represented by the quadruplet of variables that characterizes it, with the production or non-production of a graphical trace treated separately, statistically. Thus, horizontally, we can see the succession of types of information generated and shared, the means of design employed, the representation of the project and the transformation of this project through the new information exchanged (point 1 in figure 5A). Vertically, the description of each piece of shared information is shown, along with the associations made between the type of information and the media used to generate and share it (point 2 in figure 5A). Finally, the color variations (in both horizontal and vertical reading) represent the abstraction levels of the variable classes: the lighter the colored bar, the higher the abstraction level, the darker the bar, the lower the abstraction level (point 3 in figure 5A).

The second original visualization consists in generating crossing graphs, as shown in Figure 5B. These crossing graphs highlight the occurrences of association between classes of variables, and thus provide information on recurrent or, on the contrary, more surprising occurrences between project characteristics and design media. These crossing graphs are produced for the process as a whole (Figure 5B, left), but also sequence by sequence (Figure 5B, right), so as to reflect the temporal evolution of crossing occurrences and thus the usage patterns of the associations observed. To feed an analysis of the results, this type of occurrence graph will then have to undergo statistical post-processing to calculate co-occurrence probabilities in order to standardize these occurrences relative to their own frequency, in the manner of Bakeman (& Quera, 2011), thus avoiding an apparition bias.

V. SUMMARY OF MAJOR ANALYSIS RESULTS

In order to illustrate the efficacy and applicability of this protocol for the analysis and modeling of the intricate activity inherent to architectural design, we present below a summary of the results obtained.

V.1. FLUCTUATING LEVELS OF DESIGN ABSTRACTION

Fluctuations in abstraction levels can be observed between successive shared pieces of information. When we look at the "Info" line in the following figure, we can

see that successive bars are only a few times of similar color intensity, i.e. of similar abstraction levels. This is true for all sequences. At the start of Sequence 1, for example, Team 2 begins by discussing the layout, before moving on to the functional distribution, to return to conceptual information, then plunges straight into the specification of materials, back to the distribution of functions, back to a concept, and back again to the specification of a user flow, ... More explicitly, if we number the levels of abstraction, we get the sequence 2-4-1-7-4-4-1-6-1-2-2-4-1-4-6-7-5-7-2-1-7-1. The fluctuation is thus clearly visible. After counting, for all teams and all sequences, only 30.73% of successive items of information are of the same type. On the other hand, 33.38% show a shift of more than 3 abstraction levels. The design process therefore tends to be opportunistic, i.e. a sequence of activities alternating between structuring and exploration more or less randomly, depending on evolving architectural constraints, in which the designer constantly revisits previous decisions to improve the proposed solution (Elsen, 2011). Design resources and external representations also alternate rapidly.

Figure 3. Fluctuation in the level of abstraction of successive items of information and the means and representations mobilized to support them.

V.2. TRANSFORMING DESIGN MEDIA USAGES

The second element to emerge from our data analysis is the observation of discrepancies between the levels of abstraction of information and those of the means and representations used to support this information. These shifts are highlighted in the figure above. For several triplets of bars (vertical reading), we can see significant differences in color intensity between the different lines, and therefore differences in abstraction levels (figure 3 - blue inserts). These numerous discrepancies between the levels of abstraction of the information generated or conveyed and those of the means of design and external representations respectively employed in the processes observed, in fact highlight hijackings in the use of mediator objects. Indeed, if the level of abstraction of a medium, i.e. the level of abstraction of the information

supposed to be supported by this medium, differs from the level of abstraction of the information actually conveyed by this medium, then the type of information expected for this medium will be different from that actually conveyed. In other words, the uses initially expected are not those actually implemented.

In fact, some of these unexpected uses are reiterated throughout the process (figure 2 - inset 5B), and from this we deduce that they are relevant since designers have the freedom to choose the media they use, and continue to use these specific types of jobs. Three uses fall under these criteria: (i) the use of perspectives from 3D models to support information about building flows; (ii) the use of 2D CAD plans to convey features related to building volumetry; and (iii) the use of reference images to design the necessary technical solutions.

On the contrary, some of these uses are abandoned during the process. This decision may be based on the realization that the use is only appropriate in certain situations, or that the use in question has little relevance and is therefore abandoned after being tested. Two uses fall into this category: the use of models or sketched perspectives to illustrate concepts, and the use of digital 3D models to describe building layouts. Other hypotheses might lead us to believe that concepts and layouts are fixed after a single use of these media. However, this hypothesis alone cannot be validated, even if we can support the fact that these uses intervene in sequences specific to formal building research. Indeed, we find these themes in the middle and at the end of the process, but with different mediatizations.

V.3. Typical activities by type of design

In a third analysis, we intersect the use of these media and representations with the types of information they generate and convey. The figure below illustrates these crossing occurrences. Blue boxes highlight the columns of occurrences of information generated and conveyed by the media observed as predominant in usage. We note that the typical dominant activities differ according to the nature of the design observed: episodic (fig. 4) or long-term (fig. 5).

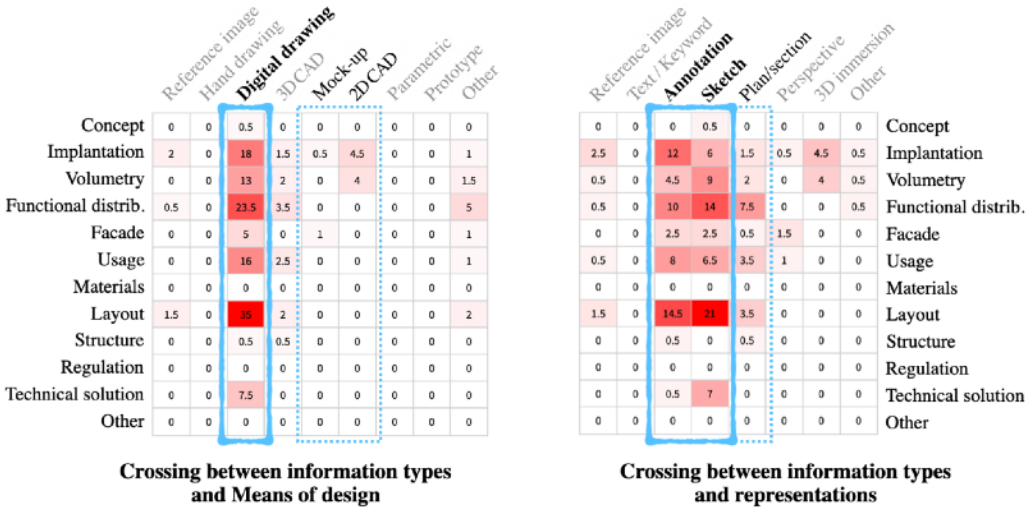


Figure 4. Proportion of use of the different Information-Mean and Information-Representation intersections, throughout the process, all teams combined, in episodic design.

Indeed, in **episodic design**, if we focus on the predominant mediating objects of design, i.e. digital drawings, annotations and sketches, we find that they are used to support most of the designed information, as shown by the blue inserts (fig. 4). It should be noted that, occasionally, information on the distribution of functions is also expressed using 3D digital models or orally only (i.e. the other class). In addition to the predominant media, 3D immersion is sometimes used to provide information on layout and volume.

In **long-term design**, however, we find that traditional plans and elevations are used predominantly, whether by hand or in CAD, complemented by reference image research, sketch drawing, mainly for facades, or perspective representations for volumetric features.

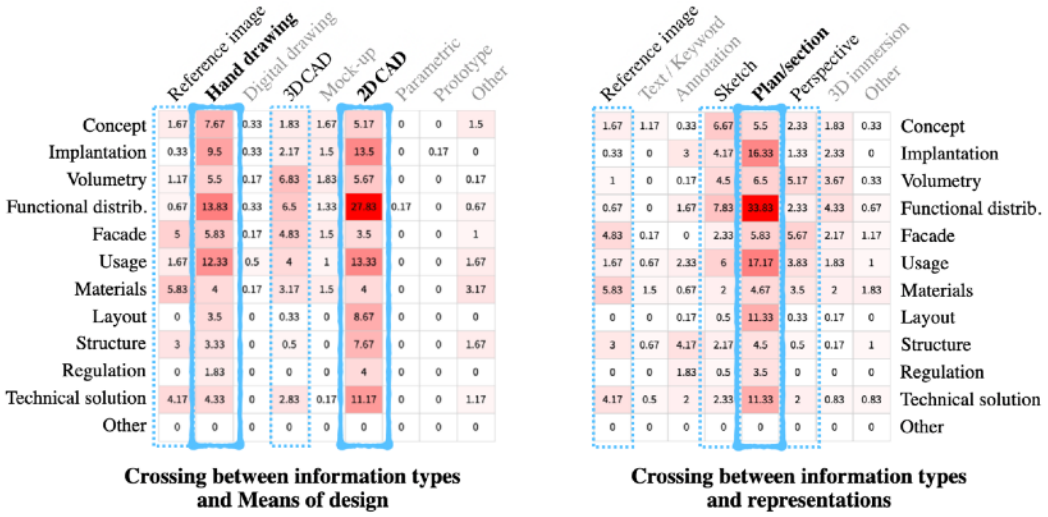


Figure 5. Proportion of use of the various Information-Mean and Information-Representation cross-references, throughout the process, all teams combined, in long-term design.

Our hypothesis to explain this discrepancy is based on the observation that episodic design, unlike long-term design, is not a free, partially individual activity, but rather constitutes a moment of collaborative resolution of specific points of the artifact being designed. We observe that designers work on their design activity in a We-Space, in Ben Rajeb's (2012) sense, i.e. in a single shared space of reflection, both mental and physical. The principle of cognitive economy is then applied, and we see designers using the tool already at their disposal when episodic design begins. They will only change tool if it is too limiting. This phenomenon is confirmed by Safin (2011), and more recently by Calixte (2021), in their observations and research work. In this experiment, SketSha was made available to the designers. The media used are digital annotations and sketches.

It should be noted, however, that designers were free to use any other media they wished, with the exception of old paper plans (chosen by the supervisors). We deduce from this that the use of digital drawing for sketching or annotating plans, observed in the majority of cases, is satisfactory for carrying out design tasks. Designers only need to supplement it with the physical model during certain episodes.

It's interesting to note that these uses of hand sketching and annotation, which are characterized by a high level of abstraction and vagueness, persist even during the production of online documents.

VI. GENERAL DISCUSSION OF ACTIVITY CHARACTERIZATION

VI.1. PROTOCOLE EVALUATION

The primary advantage of this protocol and the selected variables for analysis is that it enables the investigation of a diverse range of phenomena. This method allows for the examination of a range of design approaches, from long-term design, which is distributed over multiple time periods, locations, and collaborative configurations, to episodic design, in which all designers collaborate simultaneously and utilize the same tools for a specific moment. The selection of the variables to be characterized, along with the associated coding and visual formalism, facilitated a multifaceted comprehensive range of analytical approaches, as illustrated in Section 5.

The second benefit of this protocol is that it is relatively straightforward for both the observed designers, who are not disrupted, and the researcher, who can track five variables in real-time thanks to the developed grid system.

The primary limitation of this protocol is that by making the paradigm shift and focusing on the project-specific information exchanged by the actors, we lose access to the qualification of the social dynamics of collaboration between designers. In favor of a more detailed understanding of the evolution of the collaborative object, we must therefore forego a detailed understanding of the social dynamics of collaboration between designers. It should be noted, however, that the existing literature already presents sophisticated methods for characterizing collaborative activities. The objective of this study was to supplement the existing literature with a new analytical framework for examining the comprehensive evolution of this process, including its interrelationship with other key dimensions such as tool utilisation, validation, collaboration, and more.

VI.2. CONCEPT OF MEDIA

Following on from the various theorizations of tools mediating design activity and the many existing terms such as instrument, tool, mediating object, etc. In our opinion, there remains a gap in the various concepts that have qualified the mediating activity and the mediating objects. Indeed, it is often the object itself, and to some extent its use thanks to Rabardel, that is theorized, reinforcing the perception of the passivity of the mediating object in the design activity. However, Latour (2006) points out that the role of the mediating object is only visible at certain moments. Most of the time, the objects modify the design activity and are therefore agent objects. As theorized in the "make make" theory, Latour no longer distinguishes

between subject(s) and object(s). In this theory, all actors and objects are involved in the action of "making" because the things we do also make us "make". Activity is seen as a chain of production linking human and non-human entities, rather than a state of the object before or after the action. As mediator objects modify the course of action, they are therefore agents (or actant object) in the design process. In our research, we wanted to analyze the actions taken to design and produce project representations, beyond the objects and tools, and beyond the representations themselves.

We have proposed, with Dr. Anonyme the notion of Means of Design (Anonyme, Anonyme, Anonyme & Anonyme, 2019). This is defined as the set of resources, whether material, methodological or relating to skills, mobilized through a usage scheme by an actor to carry out his/her design task. The Means thus goes beyond the tool and the instrument to include any action enabling design. It is a mediator in its role, but not an object in its nature. This first definition allows us to nuance and distinguish the action performed from the graphical representation produced or the tool used. For example, a designer may use 3D modeling software to draw a plan, create volumetry, or simulate cast shadows. Conversely, the designer can use the 3D model produced by the software to extract a perspective on a 2D support, such as a printout or screen capture, and navigate immersed in the model. We therefore distinguish between the cognitive or physical action of designing (i.e. the means) and the external representation of the designed artifact, although these two elements influence each other.

We then use the term "medium" to refer to the combination of design means and the external representation produced.

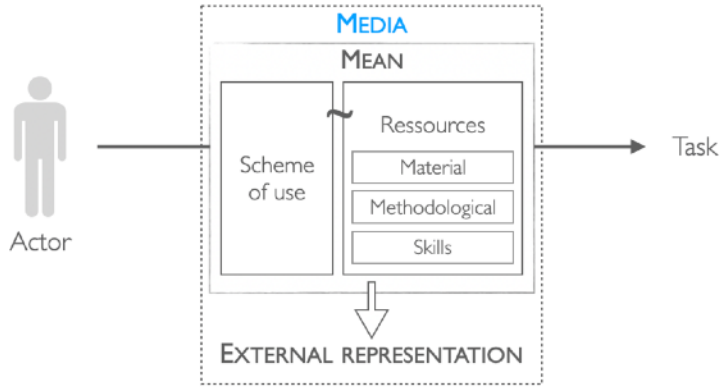


Figure 6. Schematization of the Media concept.

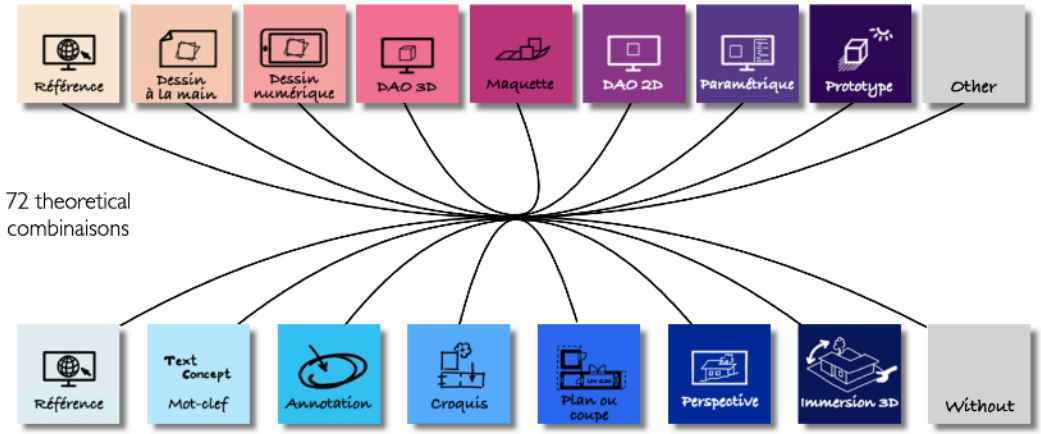
We had initially separated the Means of design and external representations in our analyses of the information generated and conveyed in design, in order to nuance our observations. Indeed, these types of representations are independent of the tool

used and the action taken to produce them. Let's take Autocad as an example. The designer can use this software to draw plans of the building, thus producing a "2D plan/ section", just as he can draw the project's formal layout, thus producing a "schema". And conversely, this diagram may be the result of a “Paper drawing by hand” action, a “Digital drawing by hand” action, a “2D CAD” action or a “3D CAD” action.

However, we found that certain combinations of Means and representations, i.e. certain media, prevailed, and even that unexpected combinations appeared, while other potential combinations were not identified. Here, we take a look at the different media-representation combinations observed (fig. 7).

The 9 possible typologies of design media and the 8 possible types of representations theoretically constitute 72 possible combinations. But our observations were reflecting the significant use of 14 design media, excluding single-occurrence uses.

Faced with these 14 media, we might be tempted to group them into families, for example (i) the use of plans, (ii) sketches, (iii) 3D representations, (iv) annotations or note-taking, (v) reference images and (vi) exclusive oral communication. But this would be to concede too much importance to the formalism of representation, minimizing the impact of the means employed on design. In the belief that the object is not neutral but active, annotating with a pencil, CAD software or digital pen cannot be merged into a single annotation task. We therefore insist on the importance of the nuance of these means of design when analyzing design activities.



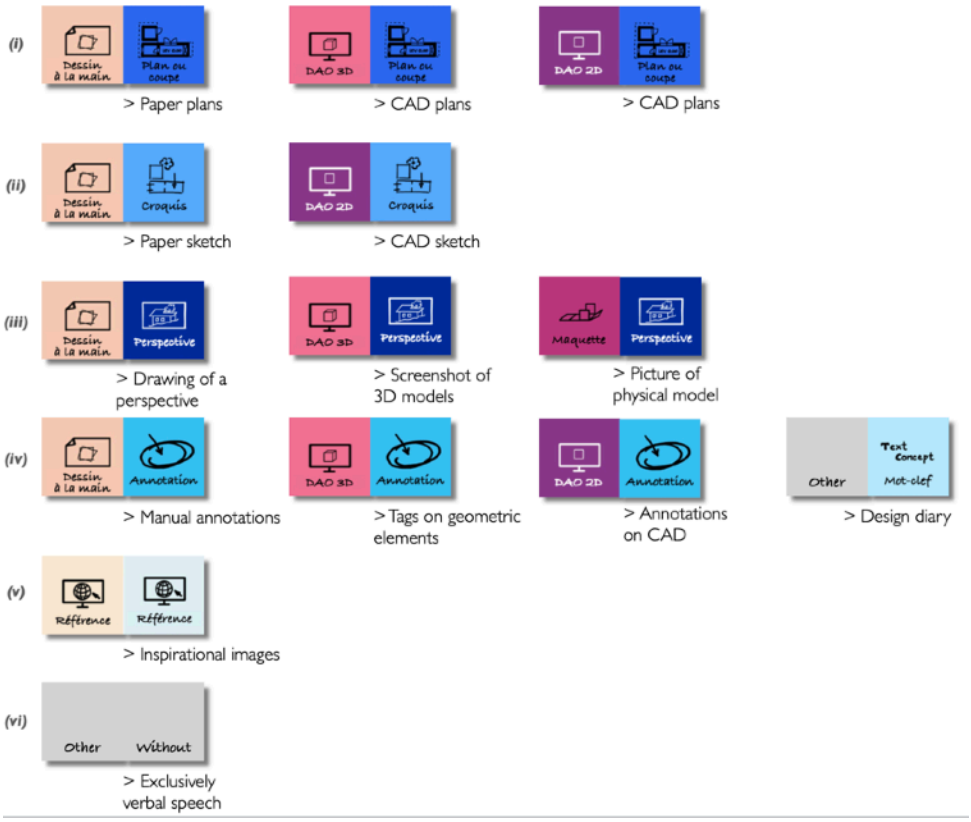


Figure 7. Combinations of Means and Representation constituting Media, observed in the design.

VI.3. General implications for instrumented design activity.

This paper is part of a broader framework of fundamental research into design instrumentation. In this section, we extend our observations to elaborate on the instrumentation of design activities.

We have determined that the types of information range from the most general, such as the architectural concept, to the most detailed, such as solutions to standards or technical challenges. Information is expressed through specific mediating objects, which vary depending on its nature. Computer-generated or hand-crafted plans and sections are the most common, but other types of information may require the use of other mediating objects, such as sketches, annotations, or reference images. Among the various types of information, we are particularly interested in 'concepts' and 'usages' as they are often lost during the digital production of building deliverables. Although they appear partially in plans, they are mainly conveyed through physical or digital mock-ups and reference images. Our observations suggest that reference images are a valuable

means of project design and communication, which tends to be underestimated in the literature.

In addition, designers frequently move from one type of information to another and from one medium to another. As previously mentioned, they intentionally select their design methods and forms of representation, and may even repurpose existing media in unexpected ways. Therefore, designers utilize the available tools at their disposal. This observation emphasizes the significance of modifying design methods and the difficulties of transitioning between different mediums. This will aid designers in discovering new sources of inspiration and making informed decisions among available alternatives to achieve a satisfactory end result. Therefore, it is crucial to provide designers with the freedom to choose their tools.

In moments of episodic design, designers heavily rely on hand-drawn sketches and annotations to generate and share information. It is crucial not to hinder these essential activities. It is important to avoid constraining designers' organizational and coordination practices. Our observations have shown that there are different uses between long and episodic design activities, as well as focus-by-focus design processes that follow a certain recurrent cognitive path through typical associations of information typologies with each other.

VII.CONCLUSION

In complementing the existing research on architectural design activities, we carry out our analysis by making a paradigm shift: we consider the actors as passers-by and characterize the design by the information it generates and subsequently feeds, as well as by describing the mediating objects that support this information. The objective of this article is to construct a protocol that enables two types of architectural design activities and to extract project information from designers' verbatims without interfering with their work.

A simple, all-terrain protocol is developed in this article that can be implemented in real-time without requiring the subjects to participate. This protocol allows us to characterize two different types of activities using only five variables. The protocol's feasibility is ensured by the economy of variables, while also allowing for the deduction of additional data in the future.

This article presents the original means of data visualization proposed, qualifying the evolution of information and the use of media to facilitate this evolution. The original visual formalism is a timeline that represents the process unfolding in a triple reading format. The horizontal axis displays the succession of information, mediator object, and project transformation. The vertical axis describes the type of information generated and exchanged, as well as the media that generates and transmits them. The

variation in color of the classes represents the variations in the level of abstraction of the data. This visualization allows for various analyses of usage proportions, patterns, abstraction level shifts, and media hijacking.

The second visual formalism consists of crossover graphs for the entire process and each sequence, enabling the visualization of evolution over time. The global graphs show two outcomes: recurrent use or media detour. The sequence graphs reveal temporal patterns in these uses.

The limitations of this research work are that the observation protocol does not evaluate the relevance of the information exchanged or the quality of the project itself. However, it does allow for the analysis of the project's evolution and the validation of various ideas during design sessions, which may indicate a certain level of quality.

The pedagogical workshop's structure sets themes for specific project reviews, orienting the design process towards architecture, technique, or the final integration of multiple constraints.

Finally, this corpus of collected data can continue to be exploited from both a research and a practitioner's point of view, to document design practices, the actual use of different tools, the evolution and stability of ideas, or the levels of abstraction of design reasoning to be supported by future instrumentation proposals. Our results enable us to formulate several recommendations regarding design instrumentation.

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