# Study of computer multi-instrumented reflexive conversation activity in preliminary architectural design

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*Abstract: The establishment of BIM raises issues at the transition between sketches, still mostly used in ideation, and project digital models. With the latest AI evolution, one way of supporting this transition is to provide sketch interpretation software generating digital representations. However, the question arises as to whether these two modes of representation can co-exist, and whether digital representations can provide a resource for designers in the preliminary phase. In this paper, we investigate the impact of auto-generated representations on the preliminary design activity of architects. We implement a Wizard of Oz protocol with 9 participants sketching their design and being provided with CAD plans, 3D models and inspirational images. We study reflexive conversations by analyzing and categorizing behavior patterns preceding and following the reception of self-generated representations. We identify 23 patterns, and show the flexible role of the digital representations, having a strong impact on the process.*

*Keywords: Preliminary design, Instrumentation, Auto-generated representation, Wizard of Oz, Reflexive conversation.*

# *1 Introduction*

The BIM process, which formalizes the building in the form of a single digital model containing all information, is becoming increasingly common in architecture. BIM, an acronym for Building Information Modeling, is defined as "3D physical properties with graphical and non-graphical information and documentation data formats for all phases of concept, design and construction, which is considered as a management process using specific platforms for the project life cycle" (Hijazi & Omar, 2017, p. 143). Primarily intended for the advanced stages of a project, its use raises the problem of the transition between the ideation and digital production phases, notably during which BIM models are designed. This transition is currently inoperative (Poirier et al., 2017) due to the work overload it generates (Kensek & Noble, 2014), the resulting fractures in the process (Baudoux et al., 2022) and the loss of information observed (Rahhal et al., 2020).

In a previous paper, we proposed an alternative to this current transition by using automated semantic and digital modeling from sketches to feed the BIM model. This proposed method would automatically collect, throughout the process, useful information from the graphical traces of the designers. This information will be automatically modeled in a semantic model, rich in meaning. Then, based on a specific ontology, a software will interpret these project's attributes to automatically generate a 3D model of the building under design that can be more directly implemented in the BIM digital model (Baudoux et al., 2022). This proposition of instrumentation leads us to question, ahead of the development of this technology, of whether returning these representations to the designer might be beneficial to stimulate their activity.

In this present study, we examine the impact of software-generated representations on a design activity. In particular, within the view of a system for modeling sketches and proposing

sources of inspiration, we seek to understand how alternative auto-generated representations are mobilized by designers during the design process. To this end, we implement a Wizard of Oz methodology, where software actions derived from our technical hypotheses are simulated by a team of architects (Baudoux & Leclercq, 2023). As the designer draws, the "software" sends back representations: 2D clean-ups of their drawings, 3D modeling and also inspirational images. This method enables us to understand both the process of interpreting the sketches to be implemented and the spontaneous mobilization of these representations by designers engaged in ideation activity, which is the main subject of our paper.

This paper will first introduce key concepts related to the topic (section 2). Next, it will present the issue identified (section 3) and the method developed to simulate the proposed technology (sections 4 and 5) in order to study its benefits and challenges. It will detail the coding (section 6). Finally, it will discuss the observed behaviors of designers when faced with the simulated technology and how and why they utilized this resource (sections 7 and 8).

# *2 Design Process*

Ideation, considered as an exploratory activity of fuzzy problem solving in the first phase of a project, has its own logic. It relies on the use of representations and analogies, and is largely supported by different tools. The design is a reflexive activity. This stage also requires an understanding of the specific issues involved in the digital mediatization of the design activity.
In this section, we will summarize the various theoretical concepts on which our research and analyses are based.

## *2.1 Ideation*

"Ideation is the process of generating ideas that are useful for achieving a desired state or outcome" (Briggs & Reinig, 2010, p. 123). It is an essential activity for linking the various aspects of the problem and connecting the different solutions envisaged (Dorst & Cross, 2001). It appears mainly in the early phases of the design process, where the core concepts are defined, but micro-episodes of ideation also continue to appear throughout the process, as soon as a problem is raised (Elsen et al., 2010). Ideation is characterized by three main cognitive activities: generating solutions, evaluating solutions, and structuring the problem.

One of the fundamental means of generating solutions in design is by analogical reasoning. Stimulating sources of inspiration can generate new reasoning and new approaches to the problem, and thus lead to the generation of new solutions. Leclercq and Heylighen (2002), in their study of analogical reasoning, point out that "in architecture, as in other design fields, design problems are generally ill-defined or difficult to solve. This difficulty itself makes reasoning by analogy a potentially powerful design strategy, since it can bring valuable knowledge from a known situation to the ill-defined design situation we are dealing with." (ibid., p. 2). Visual analogy, in particular, can improve the quality of design, as well as the quality of proposed solutions (Casakin 1997; Casakin & Goldschmidt, 1999).

Once different solutions have been generated, the designer evaluates them. They can validate them, by approving the various characteristics of this solution, or invalidate them, if one of the characteristics is not considered sufficiently satisfying or if one of the program criteria is not met (Baker et al., 2007). These validations can be implicit, when the designer moves on to the next sub-problem without having modified the proposed solution, or explicit, when they are supported by a positive or approving statement (Calixte et al., 2021). The action of invalidation can also be implicit, if the designer modifies the evaluated point, or explicit, if the evaluation of an element of the proposed solution is accompanied by negative criticism or questioning.

When an element is considered unsatisfactory and invalidated, the designer transforms their project. These transformations gradually build up the final project. They can be lateral, when jumping between different ideas, or vertical, when refining a given idea (Goel, 1995). Note that the designer can also transform the representations of their project, with or without transforming the project's content. Transformations also make design a reflexive and situated activity (Schön & Wiggins, 1992). Indeed, the designer is continually led to interpret the initial situation, contributing to structuring the problem, then to transform it to generate a new situation, which is in turn reinterpreted, and so on. Schön (1983) calls this form of design conversation see-transform-see theory. These reflexive design conversations can be detected as soon as the designer goes back and forth between the design object and its representations, in order to better construct their perception of it.

## *2.2 External representation*

Project perception and design are based on representations of the designed object. They serve as a space for simulation and reflection (Lebahar, 1983; Safin, 2011; Visser, 2006). More specifically, external representations, by materializing information, make it easier to perceive and manipulate, thus lightening the mental load and making cognitive design activities more efficient (Kirsh, 2010; Safin, 2011).

External representations can be of several natures, but the more common tools is architectural early design practice are twofold: sketches (i.e. freehand graphical productions) and computer-aided drawings. Numerous research studies have investigated the possibilities of these natures of representation in design, such as those by Bilda and Demirkan (2003), Vasantha et al. (2014), Carpo (2013, 2017), Aish and Bredella (2017). Sketching has the advantage of being intuitive, efficient, exploratory, ambiguous and multiple, relieving cognitive load, a mnemonic aid. On the other hand, it is highly unstable, thrifty and synthetic in ideation activities, as well as slow and costly in production activities. On the other hand, CAD is powerful, unifying and fixing. It is also unintuitive, ill-suited to opportunistic design and sometimes limiting.

In addition to traditional CAD tools, BIM has been added over recent years. The BIM process is an integrated working method in which all data relating to the building and its management are compiled in a single digital 3D model of the building, which constitutes the single reference for all actors involved in design and construction. BIM offers advantages in the

construction and maintenance phases of the building, but its uses differ when implemented in architecture offices, and are not very adaptable to the design phases (Migilinskas et al., 2013, Daniotti et al., 2020).

Transition between sketch-based ideation and CAD or BIM-based production is usually challenging, time-consuming and source of errors. Several tools have been experimented to support this transition, by interpreting sketches to support 3D modeling (Juchmes, Leclercq & Azar, 2004; Demaret & Leclercq, 2011), or by generated BIM models based on 3D digital models (Aish et al., 2018). Recent progress in AI and deep learning suggests that the technical limits to the interpretation of fuzzy sketches may soon be lifted. What remains is the question of how designers will use these devices and how it will impact their ideation process.

## *3 Issue*

In the context of this inoperable transition between the ideation phases and the subsequent process of producing BIM models, the interpretation of sketches to generate digital models opens up a promising path to design assistance. The idea would be to develop a tool for the design process that automatically collects useful information from the designers' graphical traces, interprets the project's attributes to automatically build a semantic model and generates a 3D model of the building under design that can be more directly implemented into BIM model (Baudoux et al., 2022). This would allow designers to pursue their sketched ideation activities without interruption, thus avoiding the necessity of proceeding manually to the 3D modeling of the BIM model. The extracted building attributes will be incorporated into the instantiated semantic model of the building, which will then be transferred following the multi-agent system developed by Demaret and Leclercq (2011) into a 3D model that can be imported into the current 3D modeling tools, such as Revit.
But the implementation of this instrumentation leads us to question, ahead of the development of this technology, the potential interest of these automatic models being shared with the architect throughout their design activity. On the one hand, returning representations of their own project could nourish and help the design process by encouraging phenomena of analogy and rediscovery. On the other hand, it can be interruptive, or constraining for the designer and their flow of thought. Indeed, sketch interpretation tools are rarely put into practice as their promises often come up against poor anticipation of the reconfiguration of activities they involve (Safin, 2011).

Therefore, in this paper we study the impact of this future technology on designers' activities. We simulate the envisioned software (interpreting sketches to provide the user with 2D and 3D models of the designed building, as well as inspiring visual material) through a Wizard-of-Oz methodology and we analyze how the designer’s reflexive conversations are enriched or modified by the simulated instrument. More precisely, we address the following research questions:
- What are the reception behaviors of automatically generated representations?
- Are there patterns in the design activities that follow the reception of automatically generated representations? And how do they relate to each other temporally?
- What activities lead up to the consultation of automatically generated representations?

# *4 Wizard-of-Oz method*

To address our issue, we set up a laboratory experiment based on the Wizard of Oz principle. This technique consists of simulating the functions of innovative yet-to-be-developed technology, by replacing it with equivalent work carried out in real time by concealed humans. This makes it possible to assess the impact of this technology on users and to study their interactions with the machine (Dahlbäck et al., 1993; Browne, 2019; Rietz et al., 2021).

This Wizard of Oz methodology is widely used in research investigating Human-Robot interactions (Riek, 2012; Clabaugh & Matarić, 2019) and automated driving (Frison et al., 2020). This method has also been employed in the field of clinical psychology with conversational agents (Gaffney, Mansell & Tai, 2019), in the development of virtual or augmented reality (Cordeiro et al., 2019; Freitas et al., 2020), text editor design (Yang et al., 2019), video game design (Yesilbek & Sezgin, 2021) or Christmas ornament design based on voice descriptions (Cuadra et al, 2021). But, to our knowledge and as apparent in Peterson and Wik's literature review (2014), this method is uncommon in the field of architectural design and in the study of design behaviors. However, when it comes to interpretive devices for ambiguous data such as sketches, it has the advantage of informing researchers about both human-machine interactions and the interpretation processes underway. It provides a relatively easy-to-implement tool for simulating complex interpretations.

# *5 Experimental protocol*

Our experimental protocol (Baudoux & Leclercq, 2023) therefore aims to put designers in the situation of designing an architectural project for a client, interacting with a software environment that interprets sketches and automatically generates various representations of the project. This software environment is simulated with the help of human agents, hidden from the designer (Wizard of Oz methodology).

## *5.1 General principle of the experiment*

The experimental protocol (Fig. 1) involves a designer (architect or engineering architect), whose task is to design a family home in an urban environment. They receive a program specifying the various spaces required by the client, a plot survey and pictures of the building site. The designers have one and a half hour to draw project sketches using a graphic table, which is an input medium connected to the "software". This software is simulated by three "agent architects" who, in a separate room, produce in real time, from the designer's sketches, a rough 3D model of the building, the finalized CAD plans and a set of images, either inspirational or realistic renderings of what the project would look like. These three elements are displayed to the designer and updated every 5 minutes, until the end of the design phase. The subject can also, at any time, ask for specific requests to the software, for a cross-section, a particular point of view, or images on a specific subject for example.

The design session lasts 90 minutes. The designer is asked to think aloud, i.e. to express their thoughts for the protocol analysis. At the end of the session, the subject designer presents their project based on the sketches made and the various documents returned by the software, to a fictitious customer, played by a colleague from the laboratory.

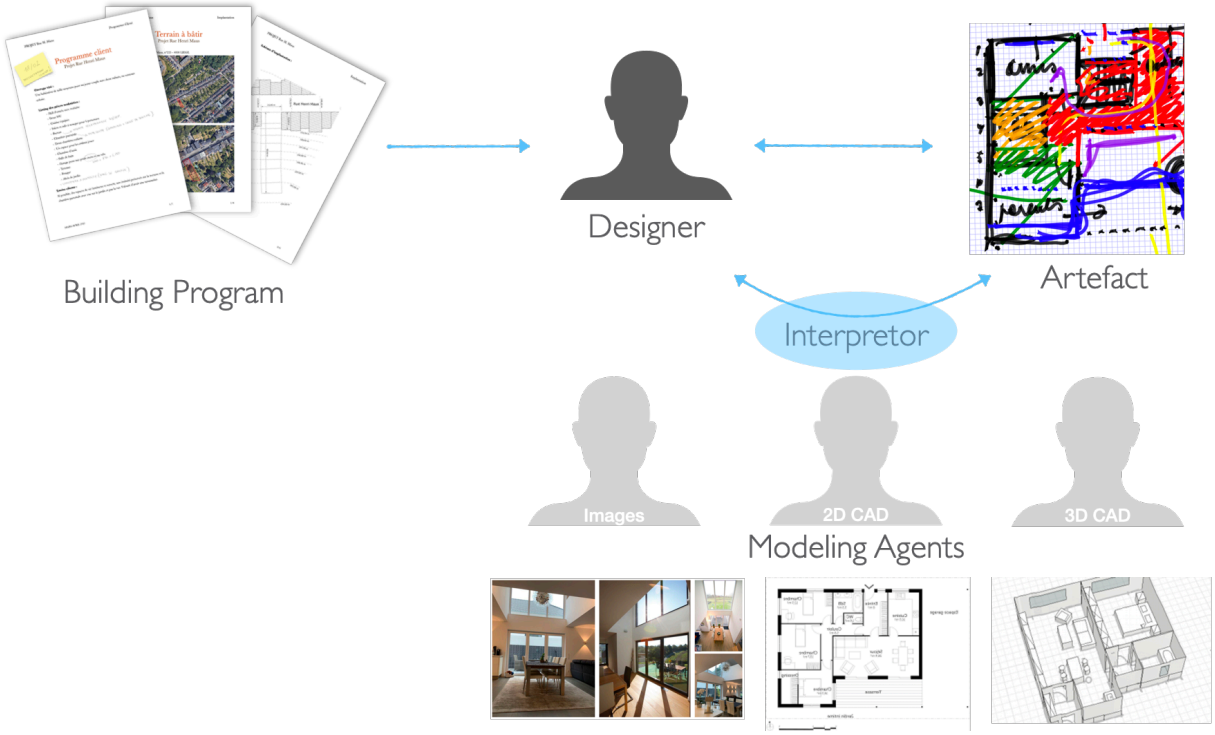


*Figure 1. General structure of the experiment.*

## 5.2 Experimental space

The experiment takes place in two adjacent rooms. In the first (Fig. 2) are **the subject designer and the researcher**. The designer sits at a virtual desk composed of a computer with three screens and an A2-sized graphics tablet embedded in the table. The graphics tablet, via the shared digital annotation software SketSha (Elsen & Leclercq, 2008), is the digital sketching interface serving as an input for the drawings. On the three screens, from left to right, appear (1) the experiment timer and the current board of inspirational images or realistic renderings of what the project would look like, (2) the current 2D CAD plans and sections, and (3) the current 3D model and the "software" control terminal. Paper documents containing the architectural program and information on the building site are also available on the designer's desk. The researcher is present to facilitate the use of the software, regulate the different phases of the experiment and collect the first observation data. Several cameras are also installed in the room to record the experiment: one on the ceiling, framing the use of the documents and the graphic tablet, one on the subject's back, framing the representations reflected by the screens, and one facing the subject, framing their facial expressions and gaze.

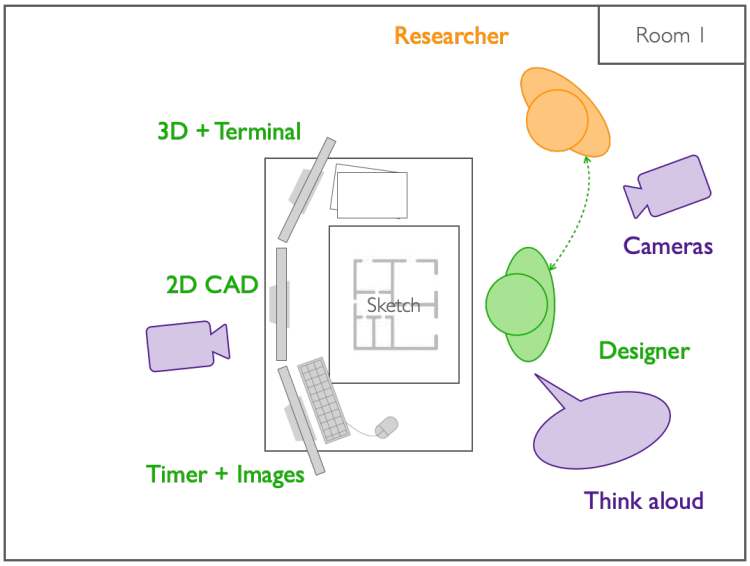


*Figure 2. Spatial and technical organization of the experiment - design room.*

The second room (fig. 3) hosts **the three modeling agents and their coordinator**. They face a control room screen (86”), enabling them to follow the design under development in the adjacent room. This screen displays, from left to right and top to bottom, (1) the images, 2D CAD and 3D model currently being displayed to the subject, (2) the evolution of the sketch in real time, (3) the overall view of the design room, relayed by the cameras, and (4) the software control terminal. The modeling agents work continuously, each with a specific task, namely (a) generating a board of inspiration images (inspirational images, i.e. images of a divergent idea but on the focus of design, or realistic image of what the project would look like, i.e. convergent images) adapted to the current focus of the project, (b) producing clean plans and sections, and (c) producing the 3D model based on the sketches currently being drawn by the designer. The coordinator interacts with the subject via the control terminal, transmits the designer’s requests to the modeling agents, sends the representations to the designer’s screens each and every five-minute, and finally provides a fourth opinion to help the sketches interpretation.

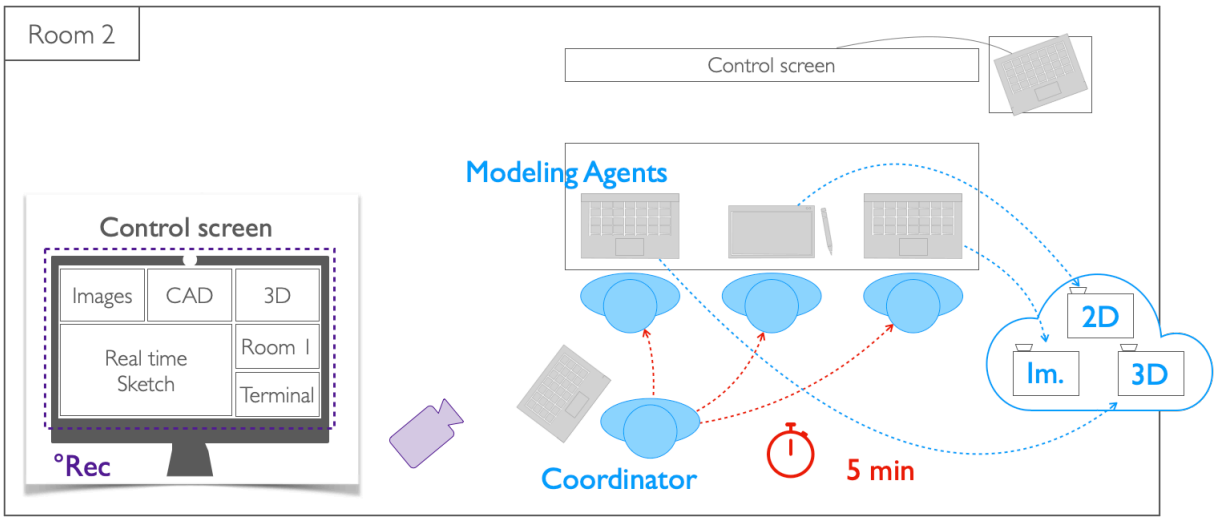


*Figure 3. Spatial and technical organization of the experiment - Modeling room.*

Figure 4 illustrates an overview of the global experiment's physical set-up.

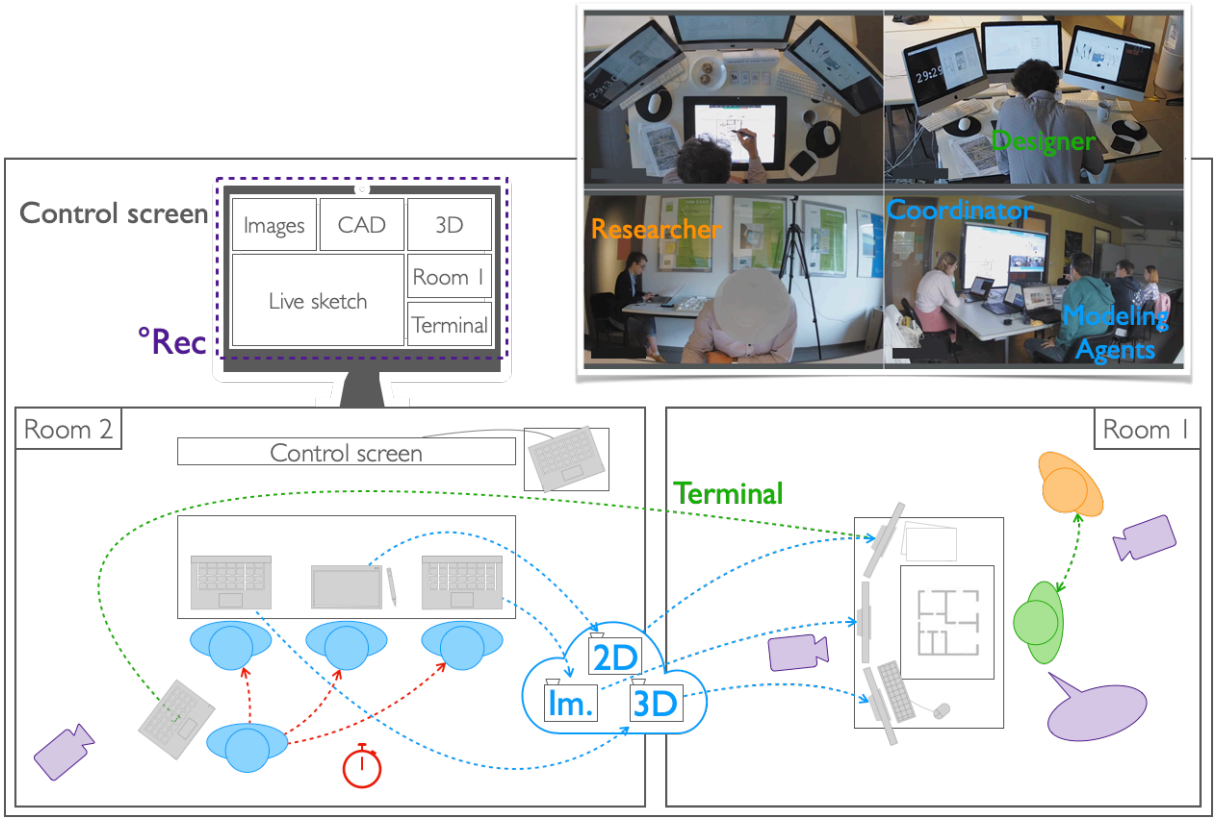


*Figure 4. Spatial and technical organization of the experiment - overview and camera viewpoints.*

## *5.3 Subjects' profiles*

The modelers and coordinators are all engineering-architect students in the third and fourth years of their five-year degree program, meaning that they are proficient in reading architectural floor plans, CAD drawing, and 3D modeling. They were pre-selected based on a task performance test set in the same conditions as the experiment and, after selection, they received a complementary training of 1.5 hours. It should be noted that for logistical reasons of availability, two teams of agents were composed, each including three modeling agents and a coordinator.

The designers' profiles were intentionally diversified (Table 1). Our population was made up of 9 subjects, including 6 men and 3 women, with varied educational backgrounds (7 engineer-architects, 2 architects; 7 agency professionals, 3 research scientists) and experience (10 +-8 years).

**Table 1. Characteristics of the studied population**

| **Subject** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| **Date** -dd.mm | 18.03 | 21.03 | 30.03 | 01.04 | 15.04 | 20.04 | 25.04 | 27.04 | 09.05 |
| **Gender** | Man | Woman | Man | Woman | Woman | Man | Man | Man | Man |
| **Age** -years | 52 | 24 | 25 | 34 | 30 | 30 | 48 | 30 | 28 |
| **Background** | Eng. Archi | Eng. Archi | Eng. Archi | Archi | Eng. Archi | Eng. Archi | Eng. Archi | Archi | Eng. Archi |
| **Activity** | Agency | Agency / Research | Agency | Research | Agency | Agency | Agency | Research | Agency |
| **Experience** | Senior | Junior | Junior | Interm. | Interm. | Interm. | Senior | Junior | Junior |

## *5.4 Data collection*

Data is collected through a variety of channels.
Firstly, data documenting the **course of the experiment** is collected by recording the control room screen and the cameras in room 1. We thus collect all data characterizing the sketching stages, the visuals sent, their time codes and any software commands asked by the designer.
Next, data documenting the **subject's activities and reasoning** are collected using the cameras in Room 1, the camera framing the designer's face, the think-aloud protocol, and a self-confrontation interview conducted at the end of the experiment on the basis of the camera recordings of key moments identified by the researcher during the design activity. We collect the designer's focus of attention at each moment, as well as verbatim: declared errors in design or misunderstanding of the software, assessments of the relevance of the received visuals, validations and invalidations of project elements, decision-making and choices justification, and analogies made.

# *6 Analysis methodology*

In this section, we describe step-by-step the method used to analyze the collected data, specifying the different variables studied and the modeling of the observed design activities.

## *6.1 Temporal framing of the design activity*

To gain a better understanding of the multi-instrumental reflexive conversation activity, we begin by modeling the design process observed for all subjects on a **global timeline**. We first highlight the various successive *phases* of this process (fig. 5 - "Sequences"), as well as the moments when the *representations* generated by the system are *sent* to the designer (fig. 5 - "Visuals").
We characterize the **object of attention** according to the subject's visual focus. This can be (i) *working documents*, i.e. sketches, program or site photos, (ii) *machine-generated digital representations* of the project, i.e. 2D plans or 3D model, or (iii) *images* generated by the "software". These images could be either inspirational one, intended to stimulate analogy making, or realistic ones, intended to stimulate projection. The object of attention variable is coded, throughout the process, according to the direction of the subject's gaze. Specifically,

we identify the moments when the subject looks at the “software"-generated visuals. Although the images have been classified according to whether they are inspirational or realistic, this distinction in nature was not found to be associated with different behavioral profiles. The remainder of this paper will therefore consider the images without reference to this difference in nature.

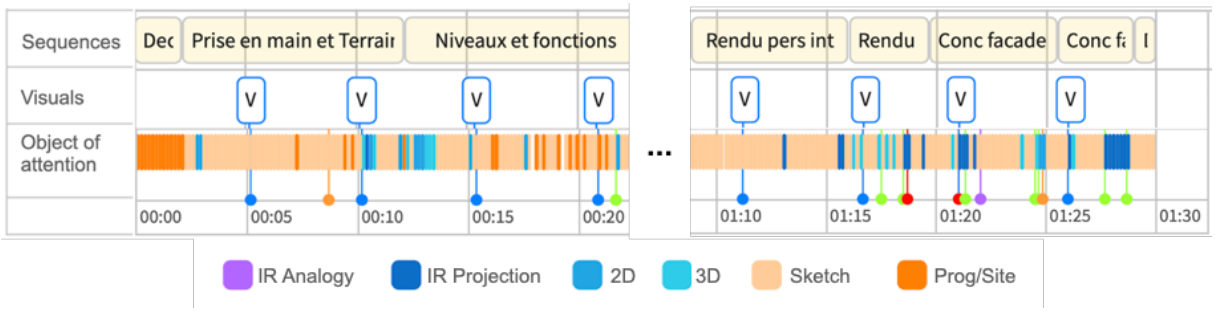


*Figure 5. General modeling of the design process for an illustrative subject.*

## 6.2 Behaviors coding

The variables observed in this study are of several types.
First, we characterize the **object of attention**, (Fig. 5 - “object of attention”), according to the subject's visual focus. This can be (i) *working documents*, i.e. sketches, program or site photos, (ii) *machine-generated digital representations* of the project, i.e. 2D plans or 3D model, or (iii) *inspiration images* generated by the “software”. This object of attention variable is coded, throughout the process, according to the direction of the subject's gaze. Specifically, we identify the moments when the subject looks at the “software"-generated visuals.
Then, several variables relate to **interaction with the software** (Table 2). Based on the verbatim collected, we record, throughout the process, *commands* given to the software (labelled "C"), *misunderstandings* of the software (symbolized as "?"), and modeling *errors* noticed by the subject (identified as "E"). Positive and negative *comments* on the representations received are also recorded throughout the process.
Finally, several variables describe the **design activity** (Table 2). Based on verbatim, we record explicit positive or negative *evaluations of the project* throughout the process. We also identify, on the basis of the subject's behavior, characterized by their design focus and gaze, *changes in the phase* of the process, i.e. when the subject shifts to a different part of the project, and *lateral or vertical transformations* of the project in the sense of Goel (1995), i.e. jumps in ideas or their refinement, which result directly from consulting a representation.

**Table 2. Data coding summary**

| **Studied variable** | Modality | Code | *Example* |
|---|---|---|---|
| **Interaction with the software** | Visuals consultation | X | *Look at one of the three software screens* |
| | Command | C | *Request a special view of the 3D model or analogy images on certain keywords* |

| | | | |
|---|---|---|---|
| | Misunderstanding | ? | *Draw an element the software doesn't understand.* |
| | Error | E | *Notes that the software has made an error in its interpretation* |
| | Positive comment on the software | $S^+$ | *Shows satisfaction at having been understood or the relevance of the analogy images proposed* |
| | Negative comment On the software | $S^-$ | *Regrets delays in feedback or inadequacy of proposed analogy images with their ideas* |
| **Design activity** | Positive evaluation of the project | $P^+$ | *Approves the proposed layout* |
| | Negative evaluation of the project | $P^-$ | *Invalidates the choice of facade materials* |
| | Change of phase | / | *Completing the 1st floor layout and moving on to the facade composition* |
| | Direct influence from visuals on the change of phase |  | *Consults visuals because he/she starts a new phase or changes phase in response to visuals* |
| | Project transformation |  | *Modifies the layout of the living room after realizing that the space was larger than he'd thought from the scale drawing.* |

## 6.3 Reception pattern of representations

Once we have modeled the subjects' design processes, we define our analysis granularity. As our first research question concerns the subject's activity when receiving machine-generated representations, we focus our analysis on the moments of transition when these representations are received. We therefore study the subject's reaction within 3 minutes of the arrival of a visual, the maximum time identified for the representation to be mobilized by the designer.
We characterize the sequence of cognitive operations carried out by the subject, based on their actions and verbatim. We thus construct a schema of the different possible behaviors (Fig. 6 - set of gray arrows). We identify reception "patterns", which are sequences of cognitive operations following the reception of new “software”-generated visuals, that appear recurrently in the corpus (pink “sticker” in figure 6). They are described by the codes detailed in table 2 and categorized throughout the corpus.

To illustrate the construction and identification of a behavioral schema, we take as an example the coding of subject 6's activity, following the visuals received at minute 65 of the experiment (fig. 6 - pink path). Table 3 illustrates the activity and shows how the “pattern” is coded.

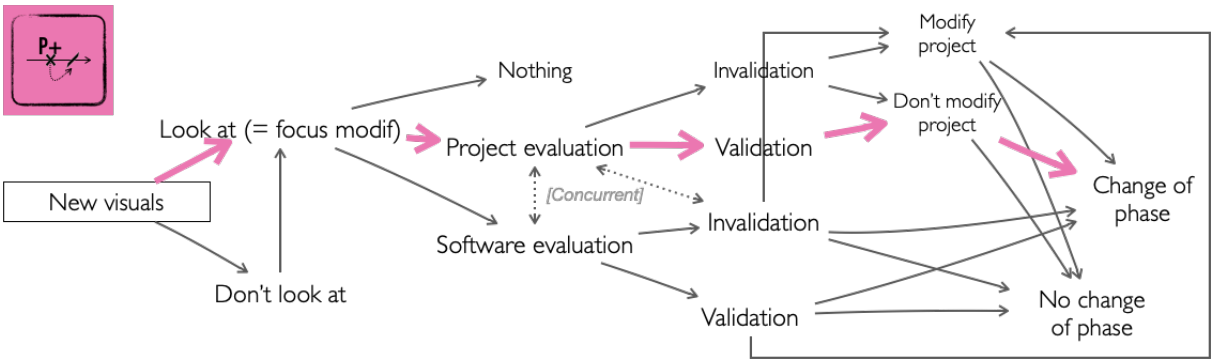


*Figure 6. Identifying representation reception patterns - example of subject 6.*

**Table 3. Illustration of the identification of a characteristic behavior based on the coding of subject 6's activity in minute 65.**

| | Cognitive operations and actions | Behavior coding |
|---|---|---|
| 1 | The subject is designing the living room when the visuals appear on the screen. | The design activity is symbolized by an arrow « → » |
| 2 | He consults the visuals | A cross « ✕ » marks the visual consultation. |
| 3 | Based on the 2D CAD representation of their plan, the designer declares that there will indeed be enough room for the guest room, thus validating its placement in the plan. The designer then consults the project's rendering projection images and validates their design once again, as the images show a living room that will be spacious and easy for the customer to furnish, thanks to its appropriate size. | Coded as a positive evaluation of the project « $P^{+}$ ». |
| 4 | He then realizes, however, that the designer has lost sight of the structural aspect of the building, which triggers a new design phase | The phase change is coded by « / ». |
| 5 | The phase change is triggered directly by the visual display. | So an arrow « ↷ » is added. |
| 6 | The project remains unchanged. | So there's no project transformation « ↴ ». |
| 7 | The software is not mentioned. | There is no mention « $S^{+/-}$ ». |

We carry out this behavior coding for all the units analyzed, i.e. for each of the 3-minute sequences following the arrival of a visual for each subject. We thus obtain a corpus of 135 representations' reactions forming a corpus of 155 patterns, which are classified in 23 types (see 7.1).

# *7 Results: analysis of conversational activity*

Let's recall that the aim of the analysis presented here is to study the impact of machine-generated representations on design activity, and to assess the relevance of an interruptive aid

of this type. We analyze the patterns of activity resulting from the reception of automatically generated representations.

## *7.1 Conversation patterns*

In response to the first research question, namely how does the designer mobilize the visuals received from the machine, we have synthesized all the cognitive operations characterized in our analysis into a decision tree illustrated in Figure 7, and containing a quantification of the occurrence of each path, amongst the 135 total software-generated visuals.

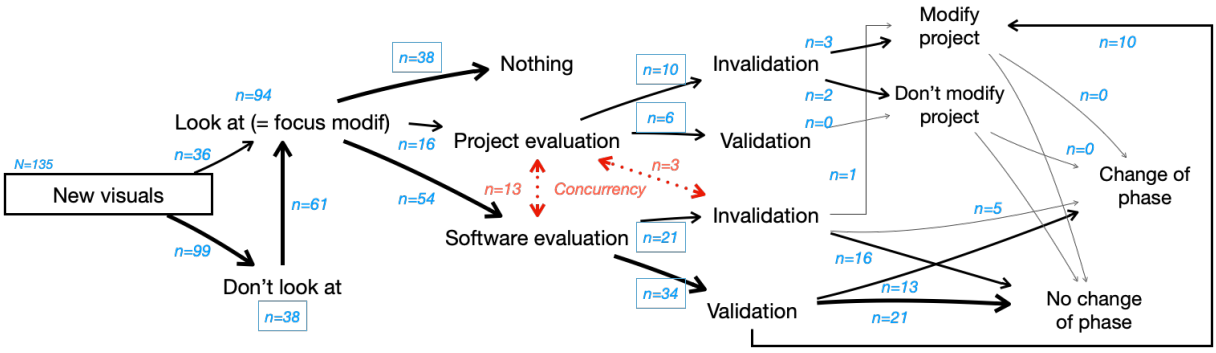


*Figure 7. Decision tree for mobilizing machine-generated representations.*

At first, we note that in around half of the situations, the "software"-generated representations do not impact the designers' activities: they either don't look at it (n=38), or don't react (n=38).

Secondly, in the most frequent path of representation use (n=21, in bold in Figure 7), the subject doesn't look at the visuals right away, but after a certain delay. They then evaluate the software positively and returns to their activity where they left off. There is no explicit evaluation of the project. This most-used path seems to be an effect of curiosity, and also results from the experiment's protocol, where the machine occupies a central position. To illustrate this path, let's take Subject 6 at minute 42'30. The designer is in the process of synthesizing and sorting out the various representations of their project when, looking up between a section drawing and the drawing of a plan, the designer sees that new visuals have arrived. The designer describes the inspirational images received as "*cool*" and validates the choice of software. The designer then goes back to the drawing phase, without any change of phase.

Thirdly, we observe that 12% of the time (n=16), after looking at the visuals, the subject evaluates their project. And, in the case of an invalidation, this can lead to a modification of the current project.

Following the coding procedure detailed in Table 2 and exemplified in Figure 6 and Table 3, we identify, within the 135 sending of representation and in the 155 reaction paths, i.e. combination of behaviors within the decision tree, observed in respond, 23 different patterns. We divide these 23 patterns into 6 classes (Fig. 8) using a bottom-up approach and we quantify the number of occurrences of each pattern.

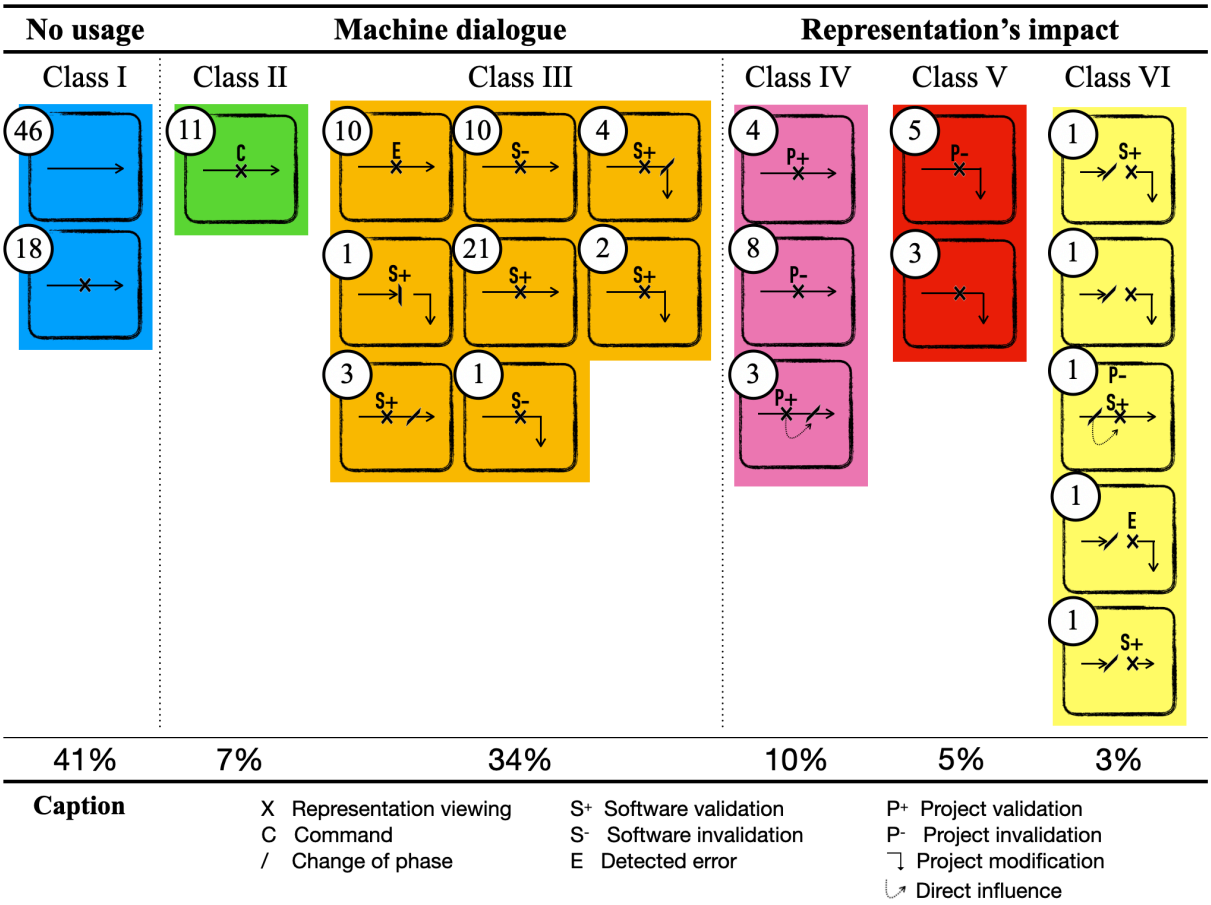


*Figure 8. Pattern classes and occurrences (the occurrence is indicated in the bullet).*

The first class, in blue, groups together two behaviors with no use of the visual. It is either not looked at, or looked at but without reaction.
The next two classes are machine-oriented behaviors. The subject may carry out a specific command to the software (green), following or not the consultation of a previously proposed visual. Or they may evaluate, positively or negatively, the software (orange).
The 4th, 5th and 6th classes focus on the impact of the visual on the process or project. These impacts can be, respectively, an evaluation of the project (in pink), a modification of the project (in red), or a modification of the design activity (in yellow).

As an example, a pattern relating to human-machine dialogue is the behavior of Subject 9 after receiving the representations at minute 41: the designer looks at the representations and praises the software for having correctly understood what the designer had been drawing up to that point ("*it's good, it understands*"). The designer then nevertheless notices an error of proportion in the CAD drawing of the layout ("*Well... it went a bit overboard on the proportions*").
An example of a pattern with an impact of the proposed representation on the project appears at minute 51'40 with Subject 6: after receiving the representations, the designer consults them and comments positively on the 3D model and its adequacy with the sketches. The designer then declares "*I see what's not working and what I need to change*" and returns to their sketches to implement changes on the critical points.

Quantifying the number of occurrences of each pattern, we observe the following breakdown.
In 41% of cases, the received representations are not used.
In 34% of cases, the received representation leads to software evaluation.
In 15% of cases, the representations are used for project evaluation, half of which leads to direct project modification (i.e. modifications of the characteristics of the building proposed).
On the other hand, only 3% of visuals change the actual design activity (i.e. modification or change of the activity of the designer).
Finally, 7% of representations are followed by a request for additional representation via a command to the software.

## *7.2 Impact on design activity*

Let's take a closer look at the pattern classes that impact design. Generally speaking, we've seen that these impacts can be, respectively, an evaluation of the project (class IV, in pink), a modification of the project (class V, in red), or a modification of the design activity (class VI, in yellow).
In the pink evaluation patterns, subjects often use the displayed documents as a summary of their project. They then analyze the project's characteristics in relation to the brief: "*Ok, so I don't mind the neighbors*", "*no, it's still too high, there's one more floor than necessary*".
Some subjects evaluate their project solely with the auto-generated representations, validating the rendering generated by the "software", thus validating the idea and moving on to the next phase: "*this kind of image is typically that, so I can go into more detail*". In the same dynamic, representations are the basis for assessments identifying what can be validated, and what still needs to be reworked: "*Ah, 3D is great (...) I see what doesn't work and what I need to rework; I'm going to change in the living room...*".
The red project modification patterns highlight three core roles of the auto-generated representations. (1) They may be used to identify an error, as was the case of Subject 9, who realized that the designer had incorrectly dimensioned their plan and was only using part of the width of the street frontage of the adjoining property. (2) The inspiration images may be mobilized by the subject for ideas generation, either because they were running out of ideas, or because the image sent corresponded precisely to what they were heading towards, and thus provided them with a quicker, more precise and concrete solution. Subject 9, in their facade design, works on a proposal for openwork cladding, and then says, looking successively at the inspiration images proposing various facades in wood cladding, "*Yes, that's not bad…we're getting closer... there you go, he's got it; so that'll be it*". (3) Received representations may modify the course of the design activity (yellow, class VI). To illustrate this type of impact, let's take Subject 7 after both 25 and 50 minutes of design. At the end of the zoning of the various rooms, the subject consults the received representations. The designer then moves on to a completely different aspect of the design, tackling the façade composition. Further on in the design process, once he's more or less satisfied with their second project proposal ("*I'll distribute here... the office space there... OK, that's good.*"), the designer consults the visuals, which have been available for a few seconds now and show inspiration images of mezzanine spaces, to see what the software proposes as an idea. It is on the basis of these inspiration images that the designer evaluates, not a given proposal, but the very relevance of the customer's request for a mezzanine space. Initially skeptical because of the noise pollution, the designer finds the inspiration images "*nice*" and concludes that "*you*

*never have everyone all at once during the day, so it could work*". The designer then began to draw up a proposal for a mezzanine office space on the double height of the living rooms.

## *7.3 Behavior profiles*

Throughout our analyses, we observed that the behavior and use of the provided representations vary between subjects. This variation is particularly apparent, in Fig. 9 and 10, in the nature and temporal distribution of the employed patterns.
Figure 9 presents, for each subject, the sequence of observed behaviors shown as stickers, each color-coded to refer to its class. Note that some sent representation triggers more than one pattern, which is why some stickers presents two colors. Below the temporal sequence of observed behaviors, we show the individual details of the decision tree. In this tree, we highlight, in with the classes' color code, the paths corresponding to the pattern classes that appear most frequently in this subject.

As an example, a comparison of Subjects 6 and 9 (Fig. 9) shows that Subject 9 evaluates the software almost exclusively, and 83% positively, which leads him to modify their project in about one third of reception patterns; whereas Subject 6 evaluates both the software and their project, but never actually modifies their sketches, which are nevertheless evaluated negatively one time out of two.

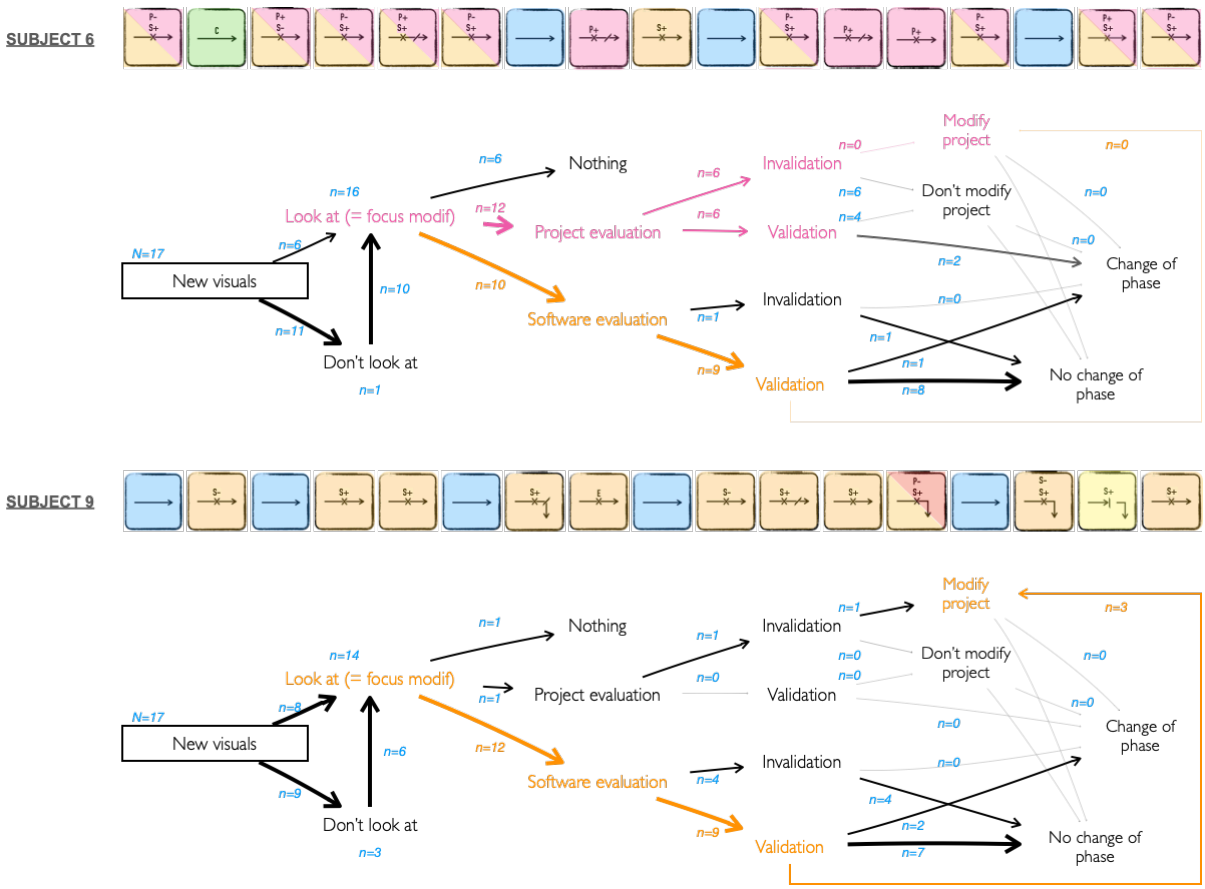


*Figure 9. Comparison of the behavior of subjects 6 and 9.*

Beyond this particular interpersonal difference, we can identify 3 profiles among the subjects of this experiment (see Figure 10).

1. The first profile (Subjects 4 & 6) uses the “software” as a new design tool on the same footing as all existing ones. The representations are used regularly throughout the process and in direct connection with the activities.
2. The second profile (Subjects 2, 7, 8 & 9) uses the provided representations as key resources. They mobilize the proposed representations at key, critical moments in their process to evaluate their project, or before moving on to another aspect of the project.
3. The third profile (Subjects 1, 3 & 5) makes minor use of the provided representations.

Furthermore, to examine the temporality of mobilization of the patterns, we highlight in Fig. 10, in the patterns following each reception of generated representations, those with an impact on the design process.


*Figure 10. Temporal distribution of analyzed patterns.*

We observe that there is no specific moment in the activity that is particularly conducive to the emergence of patterns that impact the design process. They can therefore be mobilized at any time, according to the designer's needs. They also seem to be considered useful and/or relevant by the designers, since they are not abandoned during the process.

## *7.4 Triggers*

In order to understand the determinants of the occurrence of these different patterns, we list the activities that just precede the consultation of the visuals, and that trigger the emergence of the different reception patterns. These are described and summarized in Table 4.

**Table 4. Proportion of activities triggering consultation of generated representations.**

| Type of activity | Percentage of occurrence (N=109) |
|---|---|
| Attention drawn by image change / Raises head to think and see new representations | 28% |
| Search for additional information | 23% |
| Check-up before or at the beginning of the next phase | 12% |
| Consultation at the end of an action | 10% |
| Thinking about a topic that calls for inspiration | 9% |
| Check that the software understands properly | 7% |
| Attention drawn by the researcher, either voluntarily (to correct an error or notify the arrival of the requested representations) or involuntarily (through posture) | 4% |
| Project evaluation using software representations | 2% |
| Viewing requested representations | 2% |
| Checking visual updates | 2% |
| A pause in the design process | 1% |

In most cases (28%), the designer’s attention is either drawn by a change in the visual on the screen, or their gaze is drawn to the screen at the right moment, while they are deep in thought, looking up. It is therefore without any particular intention, nor as a result of any specific activity, that they consult the representations provided.
However, we note that in 23% of situations, designers use the provided representations to search for information. This confirms that designers can use the proposed software as a design aid, and that giving them access to representations of this kind constitutes an added value in their activity.
Finally, other interesting, yet less common, triggering activities can be identified. The designer consults the visuals to seek inspiration (9%), to check up on their project at the beginning or end of a phase (12%), because they are worried about being understood by the machine (7%) or simply because they are at the end of an action (10%).

It should be noted that although only 2% of patterns are triggered by an explicit need to evaluate the project, 15% of the actions following this consultation, as shown in Figure 7, are evaluation activities. This is a positive aspect of the proposed instrumentation, which proposes and encourages evaluation activities.

# *8 General discussion*

We first need to highlight that when modeling the activities, we globally found a classic design process, similar to those regularly observed in practice and described in the literature, beginning with a phase of discovery of the site and the program, followed by a functional diagram of the distribution of premises and/or a diagram of general intentions before drawing up the plans and facades in greater detail. This process is punctuated by moments of synthesis. This similarity between the processes observed in our experiment and those described in the literature shows that there is no major disruption induced by the tested instrumentation influencing or modifying the subjects' usual design methods.
Additionally, the data collection methods of think-aloud and self-confrontation did not appear to introduce any bias into the results, as indicated by the participants' ability to speak aloud in a casual and continuous manner, neither romanticizing their behavior nor seeming disturbed by the cognitive load of verbalizing their thoughts and rationale.

It's also important to point out that we initially processed the data by distinguishing between representations generated as inspirational material (inspiration images) and those generated as models (projection images, 2D plans and 3D models). After analysis, this difference in nature had no impact on the results and behaviors of the design subjects. To avoid duplication, we present our results here without making this distinction.

The observations on the use of the various patterns are favorable to the implementation of such a design aid, as these visuals positively permeate the process, but do not determine it. In fact, with an impact rate of 15%, these representations represent potential added value for the design process. They are resources, mobilizable if necessary, and not mobilized 41% of the time, but not structural elements of the process, since only 3% have modified the design activity. Note that the 34% of dialogue with the machine, which could be considered as interruptive, may tend to fade with extensive use of such a system (Defays et al., 2012). Furthermore, the patterns showing negative comments on the "software" do not call into question the relevance of the device.

The conversations between designer and “software” lead, in synthesis, to 4 design actions: evaluating the project (Fig. 11a), validating the exchange (Fig. 11b), rediscovering one’s own project (Fig. 11c) and inducing an impulse in the process (Fig. 11d).

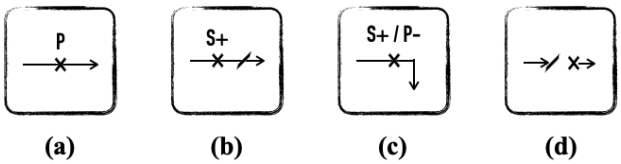


*Figure 11. Schematic diagram of design actions resulting from reflexive man-machine conversations.*

The uses of the proposed instrumentation were sometimes combined: the designer evaluated both the "software" and their project. It is also interesting to note that the activity of evaluating the "software" is sometimes followed by a modification of the project. In this case, the evaluation of the "software", i.e. the validation or invalidation of the accuracy or relevance of the proposed representations, may (1) lead directly to the modification of the project and therefore of the building's characteristics, or (2) lead to a negative evaluation of the project, not verbally expressed by the think aloud, through the comparison of the designer's sketch and the images proposed by the "software", leading to a modification of the project.

We have highlighted this "software" is considered as a resource for design. Consulting auto-generated representations can lead to unexpected discoveries (as identified when it leads to a modification of the project), recognized as a key process in preliminary design (Suwa *et al.*, 2000).
Furthermore, this resource is mobilized by subjects in three different ways: using it as an integrated design tool throughout the process, using it for its specific functions at certain key moments in the process, or using it punctually as an additional external representation. In this light, we could design several different interfaces as well: offering representations on a regular basis, rather on demand, or still on demand except at pivotal moments when they would be offered automatically.

The findings of this experiment must be interpreted with consideration of its two inherent limitations. Firstly, the experiment was carried out with a sample of nine professional designers, which limits the generalizability of the results. The experiment is currently reproduced with eight additional designers, and the premises of the analysis of this new data exhibit a similar trend to that observed in the results presented here. The second limitation is intrinsic to the method of simulating technology in a Wizard of Oz setup. To assess the validity of the simulation by the wizard, we conducted an analysis of the wizard's productivity, reliability, absence of fatigue effect, absence of bugs, adequacy of the images produced, and user satisfaction with the received outputs (Baudoux & Gronier, in submission). The results demonstrated that the simulation has been conducted successfully. The software function that was simulated here were highly graphical and not based on natural language processing, and the inevitable human latency was declared in advance to the user and set at 5-min fixed intervals, which reduced the usual limits of the Wizard of Oz method in terms of its ability to perfectly mimic a rapid software. Nevertheless, slight inter-wizard team variability could not be entirely avoided, particularly with regard to the selection of the inspirational image to be sent back. In light of this potential influence, no discernible link was identified between the team of wizards proceeding and the subject profile of behavior or satisfaction.

# *9 Conclusion*

To address the issue of the potential interest of automatically-generated representations for designers, we set up a Wizard of Oz protocol consisting of immersing 9 expert designers in a realistic task supported by a simulated sketch interpretation technology. We asked them to

design a house project on a virtual desktop that sends their graphic traces to a team of modeling agents located in the next room in real time. This team models the designed project in real time and sends back, via visualization screens, inspiration images, previews of the project's actual rendering, finalized project plans and a rough 3D model of the project in progress.

The primary findings indicate that representations are employed as a means of summarizing the project, facilitating the evaluation of what can be validated and what still requires refinement. Additionally, representations assist in identifying design flaws and serve as a resource for inspiring additional design solutions. Unexpectedly, the study also revealed the existence of three distinct behavioral profiles among the designers, each exhibiting a unique manner of mobilizing this resource.

Looking at the impact of this technology on designers' activities, we can conclude that the reflexive conversations of these designers are enriched by the role of the proposed instrument. The provided representations constitute information resources, project evaluation resources and supports for the generation of solutions by analogy. They also enable rediscovery of one's own project, thus supporting errors detection, evaluation and stepping back processes, opening the way to project enhancements.
In terms of their potential negative impact on design activities, the auto-generated representations are resources that may or may not be used by the designer, but are not structural elements of the process. These representations permeate the design process, but do not determine it.

In view of this real interest in sharing auto-generated representations with the architect throughout their process, and given the limited risks of negatively disrupting their flow of thought and activity, we can therefore pursue the path of sketch interpretation software supporting the transition between sketches and BIM digital models, in the knowledge that this proposal also constitutes a resource for designers in the preliminary design phases. To integrate the current workflows of design, this technology could be implemented on a tablet for a more lightweight individual version or in a virtual desktop, similar to the one used in this experiment, which has been adopted by various laboratories and architecture schools in France and Belgium for multi-pen collaborative design sessions. The utilization of a cloud-based platform for digital drawing would ensure the comprehensive integration of all design data into the model, facilitating the automatic transfer of complete information to the BIM models.
Subsequent studies, following the completion of the prototyping process, could investigate the manner in which collaborative design activities are conducted within this novel augmented environment.

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