Multidisciplinary approach to study of design cognitive process: the case of human errors in architectural preliminary design

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This contribution aims to show a multidisciplinary method to understand and formalize design process, from a cognitive point of view, in the particular case of human errors in architectural preliminary design process. We first emphasize the importance of error detection and recovery in the sketching phase in architecture. After the description of our methodology, we explain the general theory and model on human error, the short study we made and our proposition of a model on human error in architectural design. We finally conclude by giving some first requirements from this model in order to improve to the development of sketch-based CAD tools.

Errors in sketching phase

The sketching phase, one of the first of an architectural project, generally represents about 8% of the budget. Errors have a quite particular status in that phase. As an integral part of the process, usually qualified as trials-and-errors process, they could be very usual and they are quite cheap to recover. The sketching phase, in case of huge errors, allows the designer to start back the design “from scratch” and change the concepts. Error can also be very productive, but, as the process goes further, remaining errors become quite more expensive and their recovering is very difficult. In the production phases of design, it is not possible to change concepts but only to correct them (and sometimes not completely). So this emphasizes the need to assist the designers to detect and correct their errors during the sketching phase, in order to detect them before it is too late (when the price of design is already too expensive).

Methodology

Convinced that this thematic can not be understood from only one point of view, a team of architects, ergonomics and cognitive scientists tried to adapt cognitive theories on human error to the architectural design domain.

The methodology we used consists in four steps:

- The definition - by cognitive and ergonomics scientists - of an analysis grid of human errors. This grid is based on human cognitive theories and is concrete enough to allow a practical observation of a human activity.
- The internalization of this grid by domain knowledgeable observers (architects students in this case).
- The observation of the activity by the trained observers (direct and video observations of a design session).
- The adaptation of the general model on human errors to the specificities of the architectural design domain, by an architect, an ergonomist and a cognitive scientist, according to the interpretation of the results.

Human errors

The first general model we used is based on Reason's theory (1993). This taxonomy allows the attribution of a possible origin to an error and to temporally locate this error in one of the three main stages that range from the conception (*planning*) to the production (*execution*) of an action sequence through a *storage* (retention) of the information. The planning phase involves processes that identify the goal and the ways to reach it. As an action rarely occurs directly after its planning, a storage phase (retention in memory) is generally essential between the formulation of desired actions and their execution.

- *mistakes* are due to *planning problems* (the action is executed according to the plan and the intention, but the plan is wrong)
- *lapses* result of *retention deficits* (the intention is not retrieved or recalled on time or at all)

- *slips* are the consequences of *execution problems* (the plan is correct but the execution is wrong because the action is not appropriate to the intention).

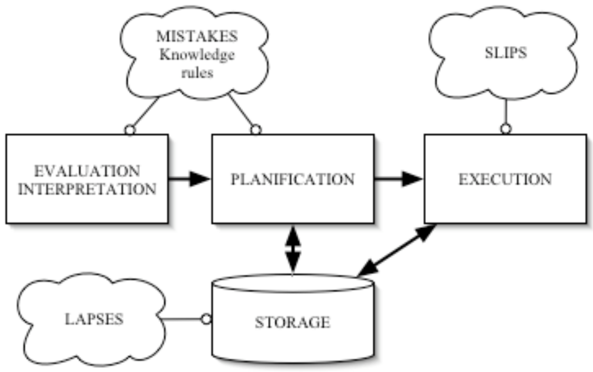

Fig1. Types of errors according to their level of control

Sellen[1994] identified three levels of error detection: (1) the detection based on the actions: the error is detected by using information resulting from the erroneous action; (2) the detection based on the results of the actions, the error is detected from the observation of the consequences of the erroneous action; (3) the detection due to the limitation of later functions, the error is detected thanks to information coming from the environmental constraints processing, reducing or preventing the actions of designer. These detections appear at different levels according to the action evolution.

Study

To understand errors in the design process, we made a short study, consisting in the observation of a design activity. The observed activity was the sketching activity of a complex building (a school) by a last year student in architecture and building engineering. The experiment duration was two half-days, this duration being regarded as a minimum to achieve a whole solution. The designer was asked to compose by thinking aloud. Two observers (also students in architecture) were previously trained and followed the exercise, silently, and noted the errors made by the designer, according to our analysis grid. The activity was entirely filmed, to help analysis (see figure 2).

The cognitive model on human error was used as an analysis grid for the observation of a design process. The design error was defined as: *Any action and/or decision and/or declaration which carries out to a non-compatible result with the data of the problem and with the development of an effective solution from a functional, cultural and technical point of view*. The two supervised observers were asked to identify the errors and their origins and consequences, the type of error (slip, lapse or mistake), the mode of detection, the author of the detection (observer or designer), the previous knowledge of the result or not.

Fig2 . Experimental setting

Our results showed:

- Most frequent errors were mistakes (72%), in a more marginal way the slips (22%), and finally the lapses (6%). The mistakes covered a "wrong intention" or the fact that the constraints from the "external world" were not considered.
- Among the mistakes, only 30 % were detected by the designer, the remainder being found by the observers.
- In the majority of cases, the good result or what it should have been done was not known (72%). This was one of the causes of the non-

detection of error. When the result may be known in advance, the subject detected his/her error two times on three.

- Among the three modes of error detection, the detection by observing the result was mainly used. Moreover, detection was more effective when the perception of the result was outstanding and the expected results belong to a familiar situation.

These findings emphasize the importance of the knowledge of the result in the detection process. However, the previous knowledge of the result is almost impossible in the design process which is a creative and thus unpredictable process.

Model

Based on these first simple results, the three authors of this paper (a cognitive scientist, an ergonomist and an architect) tried to formalize the notion of errors in the design process. This multidisciplinary way of doing allows to integrate strong validated models of human cognition with a deep understanding of the domain and of the activity processes. This leads to a model with three components:

- The classification of the consequences of an action
- The notion of evolutive context
- A model of design micro decision process coupled with the error detection process in design.

Each action is carried out on a single design unit (a part of the object) but has different consequences on this design unit or on other design units. The figure 3 shows the different consequences. Every action has a main goal and leads to direct and expected consequences. Nevertheless, every action also generates a lot of indirect effects on other objects. These indirect consequences, in opposition to direct consequences, are not intentionally required by the action, but are produced by the carried modifications. When the designer is conscious of the influence of his/her action on some other objects which are not directly noted, we consider that (s)he works in "a intentional context" and we call these consequences indirect expected consequences. However, some indirect effects are not necessarily considered by the designer and he discovers them when they appear: these effects are "detected but unanticipated indirect consequences". These three types of consequences (direct, indirect expected and indirect detected) occur in a conscious context. However, some consequences are not detected by the designer; they remain hidden and are considered as "undetected indirect effects". This last type of consequences belongs to the "unconscious context" (cfr. Figure 3). Each of these consequences can be positive or negative for the design.

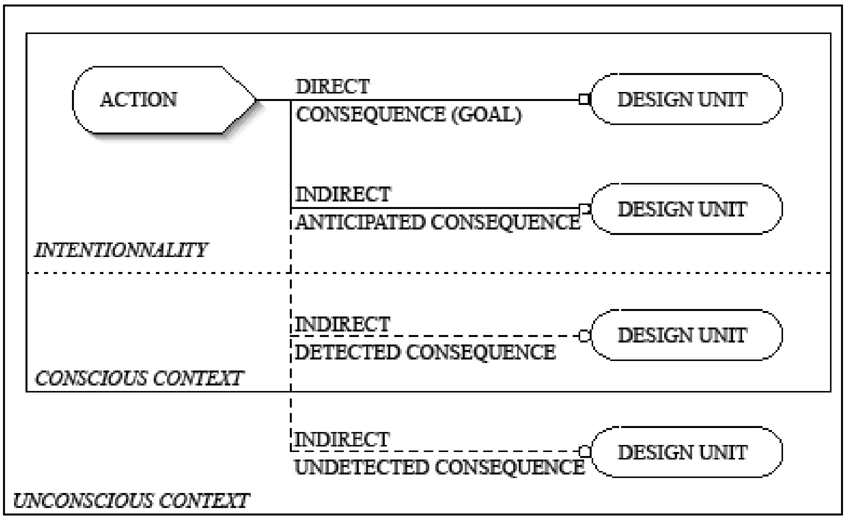

Fig3 . Consequences of an action

Some of these consequences may not be detectable, based on the state of the context in the design process. Indeed, some actions can have consequences that will only emerge later in the process. In our model, we define the context in design as “the set of elements of a situation that provide resources on which intentionality is grounded” (the internal or external constraints, the internal and external representation and the history of the design that allows the designer not to get twice in the same “deadlock”). We emphasize the context is evolutive: it constantly changes throughout the design process.

So the designer, in order to take decisions and to advance in the design, carries out the following set of actions (figure 4).

- The formulation of an intention, based on the current state of the context
- An anticipative evaluation, prior to the drawing. During which the designer tries to identify the consequences (direct and indirect) of his potential action.
- A decision to act or not (the idea can be cancelled if the set of consequences is not sufficiently beneficial) and then the behavior, e.g. draw-

ing. The behavior could also be not to act. This nevertheless constitutes a behavior and has an impact on the context (see further)
- An evaluation of the results and consequences of the behavior, and the gap between anticipated consequences and post execution consequences.

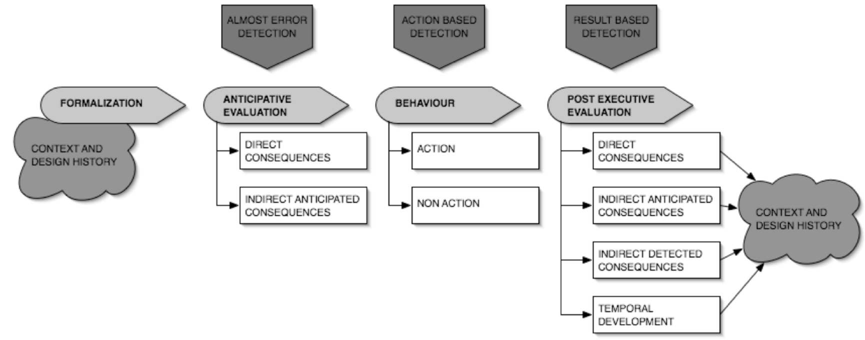

Fig 4. Design micro-decision process and errors detection

The context evolves in each step according to the detected consequences of the decisions and actions. Therefore, the error can occur from several sources.
- Some errors are slips: they consist principally in a problem of execution (the drawing is different from the intention)
- Some errors are lapses (for example, problem in recovering the history of design)
- Some errors are mistakes based on rules (for example, wrong anticipative evaluation, wrong evaluation of the situation) or on knowledge (wrong intention), or on both rules and knowledge (for example, problem in the management of constraints, formalization of the context).

According to our model of decision and action in design, the different levels of error detection occur at different moments. The error may be detected when the designer formulates her/his intention and evaluates its potential direct and indirect consequences. At this moment, the error has not yet occurred and is not usually considered as an error but as an "almost error". The second moment of detection is when the action occurs. At this moment, the error detection is based on the action and principally concerns the slips. If the error is not detected at this moment, the post evaluation will allow result-based detection. This type of detection principally concerns mistakes. And in the last case, the detection will be highlighted by the limiting functions.

Conclusion

Although very incomplete, our model highlights the following elements:

- Most part of errors are mistakes and their detection comes mainly from observing the consequences of actions.
- But these consequences are not always directly observable. They can occur on other design units or they can occur later in the process.
- The notion of evolutive context can help us to understand the nature of errors in architecture.
- The paradox is that errors may be hard to discover or may be detected very late. But later it is detected, more complex and expensive is its recovery.
- Errors are integral part of the process. So it is useless to try to prevent them. But errors become harmful if they persist after the sketching phase. It is thus important and possible to help errors detection in the preliminary phases of design in architecture.

The final purpose is to use this model to define specifications and concepts for the design assistance and the prevention of errors. This first study shows first concepts to help the designer to detect errors in preliminary design, from a computer-aided point of view

- Not only take in account the actions, but also the consequences on the whole project and the history of the design
- Help anticipative evaluation and/or post-executive evaluation
- The tools should help the designer to broaden this point of view.
- Help the designer to have a complete view on the context and/or help him to change his point of view

Based on the observations of a single design session, our multidisciplinary methodology has shown promising and leads us to define the draft of a particular model of human errors in design. This model has now to be validated and integrated to the wide domain-specific literature (sketching and architecture), and more operative concepts of assistance have to be designed.

References

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