Architecture students' search behavior in parametric design

How tool knowledge retrieval can affect early stages of design

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Over the last decade, architecture has witnessed a growing popularity for new computational tools such as parametric design environments (PDEs). Given their rapid evolution and development, expertise tends to become increasingly transient, and architects find themselves in a situation where they must constantly re-learn their tools. At the same time, access to information has become increasingly widespread. Self-learners can thus rely on information retrieval systems to address knowledge gaps. However, the inherent tool complexity has given rise to a new kind of knowledge. On the basis of the different types described by Anderson and Krathwohl, the authors have previously shown that conceptual knowledge is essential for teaching parametric design. In contrast, research on interactive information retrieval (IIR) has highlighted that procedural knowledge is preferred in create tasks like design. Consequently, it can be argued that in a self-learning situation, architects might not be adopting best practice in relation to knowledge retrieval, especially when considering the visual scripting nature of certain PDEs. The purpose of this paper is to observe cognitive patterns in knowledge search activities while designing in parametric environments and validate the integration of CLT and IIR for further research. We highlight the types of knowledge and sources architecture graduate students, novices in PDEs, search for during design over multiple sessions and why. The paper reports on three design tasks completed during a computational course that emphasized student's autonomy. A qualitative analysis of interviews reveals epistemic actions to fall prey to procedural information, which is in line with both IIR and CLT research. This research is part of a PhD project studying the impact of knowledge retrieval on architectural design when using PDEs. Eventually, it could raise awareness in education, research, and practice regarding information retrieval in architectural design.

Keywords: *Parametric Design, Interactive Information Retrieval, Cognitive Load, Searching as learning, Knowledge*

INTRODUCTION

As digital tools become more complex and evolve more rapidly, software tool expertise has become more and more transient. Relying on information thus becomes increasingly important while concurrently, it has become ubiquitous.

During the design process, architects retrieve information and eventually learn. They might retrieve a piece of missing information, or they might engage in exploratory search as architectural design problems are usually ill-defined (Gero and Maher, 1993; Goel, 1995).

Previous research focused on two fronts of design influence: tools (Abdelhameed, 2006; Cote, 2011; Yu et al., 2013, 2014, 2015) and how medium of curation can provide affordances for information-based ideation (Rosenbaum, 2011; Kerne et al., 2014). However, there is no research on the impact of tool-related information retrieval on the design process. Given the complex task of designing architecture and the need to learn tools to do so, working memory is potentially prone to quick saturation leading to the adoption of epistemic actions for mitigation (Erhan et al., 2017; Choi et al., 2019; Choi, 2020). This is especially true with more complex tools.

Parametric Design Environments (PDEs) are a prime example. The shift to process-based thinking, where architects need to model through parameters and functions and define relationships, brings a new kind of complexity (Lee and Ostwald, 2019). Consequently, the use of new complex tools such as visual programming interfaces like Grasshopper makes relying on external information a necessity.

This paper investigates how architects deal with the tool's complexity through information retrieval and how it potentially impacts their design decisions. It focuses on graduate architecture students' cognitive patterns by investigating the sources and queried types of knowledge in early design situations. Those behaviors are then compared to empirical results found in Interactive Information Retrieval (IIR) studies using the searching as learning framework.

The paper is organized as follow. First, PDEs are introduced. Theory on IIR and searching as learning is then presented to clarify the type of search task architects are confronted with in order to ground the architectural design task in a widespread model of information retrieval study, gaining from previous observations. Cognitive Load Theory, the notion of working memory and specifically Self-Regulated learning (SRL) are then presented. To validate the use of those theories, a qualitative study involving graduate students in an elective course on computational design is developed afterwards. Together, these elements substantially extend prior theory and point to specific implications for design research in regard to information retrieval.

PARAMETRIC DESIGN ENVIRONMENT

PDEs allow for a procedural design process based on defined parameters and thus serve automation, rapid exploration and other computationally demanding tasks. They deal with form finding as well as the management of all the metadata.

Visual programming (VP) tools like grasshopper have taken over given that textual programming is quite unpopular among architects (Leitao et al.2012). VP is particularly interesting here as complex forms can be described through series of simple steps without the need for syntax. A specific geometry can therefore be captured through a sequence of components and their relationships, then transcribed with other parameters to get variants within the established design space (see fig.1).

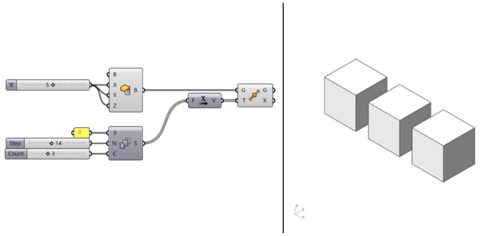

Figure 1
Example of visual programming and resulting geometry Dissaux & Jancart (2022b)

This means that a design can be accessed without the need for the mental rebuilding of a reference, which would require an effort of understanding. It can be as straightforward as a recipe from which the architect can deviate. Indeed, parameterisation allows for different outcomes and easy appropriation of the design, although it highly depends on the design space originally set by the algorithm. Furthermore, based on the designer's experience, parts of the algorithms can be copied from various sources and pasted together for more variations. This greatly reduces the effort invested into designing. Conversely, going from an analog representation to a PDE requires architects to translate the thought process into an algorithm. According to Woodbury (2020), that kind of computational thinking necessitates a new kind of knowledge.

So, although working with PDEs can be seen as an epistemic action towards accessing complexity in design, it is responsible for additional mental effort leading to further cognitive investments and behaviors, which in turn lead to other epistemic actions such as specific information retrieval strategies during the design process.

This is obvious for software novices but can be applied to software experts who eventually deal with new components which they are not familiar with. Therefore, they are likely to fall prey to already-made black box recipes found on the Internet.

SEARCHING AS LEARNING AND KNOWLEDGE TYPES

Interactive Information Retrieval (IIR), also known as human computer information retrieval, studies users' interaction with information retrieval systems (Borlund, 2013). Previous research postulated the relationship between searching and learning. Searching as learning is born out of the sense-making paradigm (Dervin, 1992) in IIR and defines searching as a knowledge construction process in opposition to the bibliographic paradigm that describes information seeking as the gathering and collection of information (Vakkari, 2016). Information is stored in different types of sources and can be shared whereas knowledge is information that has been processed and integrated into one's knowledge structure (Kintsch, 1998). Out of simplicity, given that information is supposedly retrieved for knowledge construction, information and knowledge will be used interchangeably for this paper.

Over the years, simulated search tasks have been developed in order to create consensus and eventually obtain large quantities of empirical data built on a common basis. One model in particular introduced by Jansen et al. (2009) leverages Anderson and Krathwohl's (2001) revision of Bloom's taxonomy (referred to as A&K's model) to classify searching tasks in terms of complexity and has gained some popularity over the last decade. A&K's model defines learning objectives by using two dimensions: the cognitive process and the knowledge type. Cognitive processes are defined from least to most complex tasks: remember, understand, apply, analyze, evaluate and create. To each category correspond specific cognitive processes. For example, the remember category encompasses recognizing and recalling as specific cognitive processes. Based on A&K's revision, a design task would fall under producing within the create category. The latter is defined as "putting elements together to form a coherent or functional whole; reorganize elements into a pattern or structure" (Anderson & Krathwohl, 2001, p.84). The create task is particular because it might require the learner to integrate the other cognitive processes. The create category will be considered in this study since it relates to the design task.

Knowledge dimension is described through 4 types: factual knowledge, procedural knowledge, conceptual knowledge and metacognitive knowledge. Factual knowledge consists of the basic aspects a learner must know to be acquainted with one discipline. Procedural knowledge consists of methods of how to do something, routines and solving skills. Conceptual knowledge is the ability to bring basic elements within a larger structure that enables them to function together. Finally metacognitive knowledge is the awareness and knowledge of one's own cognition. The first three types are intrisically related (see fig.2). Regarding the knowledge dimension, only a few studies have been conducted yet (Vrouwe et al., 2020, Urgo et al., 2020, 2022).

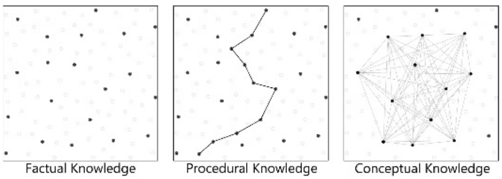

Figure 2 Representation of factual, procedural, and conceptual knowledge as graph of dependency states between bits of knowledge.

In a recent paper investigating the term “knowledge” in parametric design education literature, Vrouwe et al. (2020) described conceptual knowledge as the main focus in teaching parametric design. However, recent IIR research suggests that investment into conceptual knowledge is minimal when dealing with information retrieval compared to procedural knowledge (Urgo et al., 2020). Despite those results, there is no trace of any research concerned with neither information retrieval in architectural design nor parametric design. There are however traces of early research on procedural knowledge in CAD interfaces. Lang et al. (1991) discussed the high transferability of procedural knowledge in CAD education vs declarative knowledge (what button to push). In the case of PDEs, procedural knowledge is embedded by nature. To access declarative knowledge, one needs to have procedural knowledge in order to query for declarative knowledge. This is even more difficult when dealing with ill-defined problems and unclear objectives.

Research shows that undefined objectives tend to lead to abandonment or reliance on other types of knowledge such as procedural knowledge that offers the luxury of a starting and an ending point (Bystrom, 2002; Urgo et al., 2020). The search effort might therefore lead to potential satisficing behaviors (Choi et al. 2019) through displaced, but available, procedural knowledge and eventually impact design.

In design, idea exposure can quickly lead to fixation as it offers clearer objectives for ill-defined problems (Perttula and Sipila, 2007). The issue is that it leads to potential convergence whereas divergent thinking is preconized in early phases of design. In PDEs, that idea exposure can be born out of procedural information and might amplify convergence towards an inadequate response.

Finally, the retrieval system used can affect the load on user’s cognitive resources during the search process (Gwizdka, 2010).

COGNITIVE LOAD THEORY

The cognitive load theory (CLT) is based on the principle of a limited working memory (Baddeley, 1992). Any task imposes a cognitive load that can go beyond mental capacity and thus lead to errors, stress or even abandonment (Safin et al., 2008). To alleviate this overload, tools are used as cognitive supports. Concurrently, due to their intrinsic complexity and expertise requirements, they can carry a load of their own. Therefore, tool expertise becomes essential for load reduction. CLT is particularly relevant when dealing with complex information and, as mentioned earlier, this is even more relevant for PDEs.

In a late retrospective of CLT, Sweller (2019) provided an extensive review of all cognitive effects described around that theory and in particular instructional design and its cognitive effects on working memory and knowledge construction facilitators. According to the theory, the design of learning material needs to take cognitive load into consideration. However, the internet allows information to be created and shared by anyone with no regards for instructional design. Self-management effect is one response to that as it promotes the teaching of CLT principles. Nevertheless, it is not commonly taught in architecture. Aligned with this context, self-regulated learning (SRL) is seen as an important perspective for supporting learners dealing with massive amount of information (vanMerrienboer and Sluijsmans, 2009). The research was born following poor results on people’s regulation of their own learning (Bjork et al., 2013). Coarse data can be overwhelming, obsolete, and even sometimes wrong. Furthermore, low-quality information production and sharing can lead to considerable cognitive load (Sweller et al., 2019). Compared to the self-management effect which promotes learning cognitive load principles and is more in line with meta-cognitive knowledge, SRL focuses on the selection of relevant learning tasks and learning resources, or information literacy, in information rich context where learners are provided with abundant opportunities for self-teaching (deBruin and vanMerrienboer, 2017).

Although cognitive effects won't be taken into consideration in this paper, the principles of working memory through an established theory had to be mentioned.

METHOD

Eighteen graduate architecture students participated in an experiment that was conducted during an elective course on computational design at the faculty of architecture. The class is considered an introduction to PDEs. None of the students had previous experience with neither the tool, Grasshopper, nor parametric design environments in general. They were asked, by group of 2 or 3 people, to complete three design tasks over an 8-week period. The tasks were in order: a pedestrian bridge, a series of pavilions and a high-rise building. Contexts were imposed for each task as well as specific constraints such as minimum dimensions and basic programs. For each task, students had intermediary feedback and had either 2 or 3 weeks to complete their design on which they received a final feedback. The course was held weekly through a 4-hour class divided into four sections. The first hour was dedicated to feedbacks on previous week's work, the second to a presentation about theoretical aspects of computational design, the third hour to hands-on exercises using worked examples unrelated to the design tasks and finally the fourth hour was dedicated to in-class work on the design task where students could communicate in person with each other as well as the student monitors, the assistant, and the teacher.

For this experiment semi-structured interviews were conducted the week following the third design task. The interviews were part of a larger protocol involving weekly questionnaires and presentations which are presented in concurrent papers this year (Dissaux & Jancart, 2022a, 2022b).

15 out of the 18 students were interviewed for 20 to 30 minutes. The questions asked focused on their individual design process. As soon as information retrieval was mentioned, participants were encouraged to follow up on their answers providing source types and hints on the type of knowledge queried. At the end of the interview, students were asked to compare their experience in the course to the one they typically have in the design studio regarding their use of information. Interviews were audio-recorded, transcribed, and coded. The first coding used structural deductive coding, filtering the data to focus on information retrieval. The transcript was then examined in a sentence-by-sentence manner and labeled according to the source and the type of knowledge retrieved. The second cycle coding produced codes related to seeking behavior while designing. We used inductive thematic analysis to identify themes related to the material searching behavior that emerged from the data (Saldana, 2013). A coding example can be seen in Table 1.

RESULTS

Overall, results show that knowledge retrieval strategies play a key part in design by either **starting**, **serving**, or **translating** ideation. A schematic model based on the identified themes is developped in order to frame the results (see fig. 3). Each move represents a code indicating the direction of service of knowledge retrieval. $D \rightarrow I_D$ (1) for example triggers the retrieval of design-related information for ideation support, like a reference image. However in $I_T \rightarrow D$ (4), the tool-related information triggers ideation and thus design. There are 8 processes (see table 2) which are not unique as they often compliment each other. Translation, for example, happens after $D \rightarrow I_D$ if the retrieved knowledge is not in line with the query, the process therefore consists of $D \rightarrow I_D \rightarrow D$.

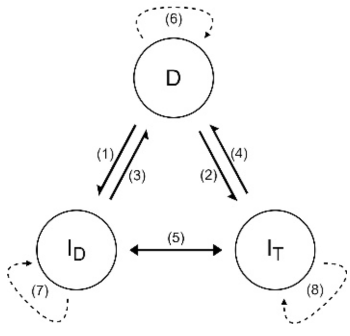

Figure 3
Schematic model of encountered retrieval strategies observed

Table 1
Coding example

Id	Time	P.	Transcript	Source	K.Type	Theme	Code
78	12 :34	1	*(...) and then we try to look for a tutorial or something that could correspond to the idea and then transcribe (uh, well...), what we wanted to do on Grasshopper.*	Video	PK	Tutorial that would serve the initial idea	$D \rightarrow I_T$

Table 2
Description of all the codes from thematic analysis with relevant examples

Ref.	Code	Description
(1)	$D \rightarrow I_D$	Design-related information retrieval to serve previous ideation
e.g.	*P1: "I really like to have my idea. I visualize the project and then I'll go and look for references to try to show that there are other examples that exist and that it justifies my choices a little bit."*	
(2)	$D \rightarrow I_T$	Tool-related information retrieval to serve previous ideation
e.g.	*P8: "No, I don't think so. We were hooked on the basic idea and what we wanted to achieve in the end. And if the tutorial didn't correspond to what we wanted to do, well, we often said "Next!". That's maybe why we're having trouble with the design tasks."*	
(3)	$I_D \rightarrow D$	Reference-based ideation process
e.g.	*P10: "Well, at the beginning, from a design point of view, we limited ourselves to a reference, so (yes) we were told to make a bridge, thus we looked at a reference and we really started from that"*	
(4)	$I_T \rightarrow D$	Tool information-based ideation process
e.g.	*P13: "Well there the tutorial doesn't seem too bad, and we tell ourselves: all in all... and then we leave on that other idea..."*	
(5)	$I_D \leftrightarrow I_T$	Interaction design and tool information
e.g.	*P14: "Well, the bridge. I looked at different types of bridges and I said to myself: well, this is interesting, this could work, this is related to what we wanted to do or not, etc. And then we adapt. (You were looking at image references?) No, no, it was really: I watch several videos on YouTube, and what was (interesting). So yes, directly from the videos on YouTube."*	
(6)	$D \rightarrow D$	Interaction in a group
e.g.	*P4: "Then there were a few sketches to agree on"*	
(7)	$I_D \rightarrow I_D$	Design information leading to further design information
e.g.	*P6: "Well, I searched on Pinterest, and I was putting in the word "bridge". Then, every time I clicked on an image, and it would send me lots of other related images underneath."*	
(8)	$I_T \rightarrow I_T$	Tool information leading to further tool information
e.g.	*P1: "In fact the geodesics were really an idea we had from the beginning, because we had already seen projects like that and the Voronoi... Well, it's really when we came across them on YouTube while looking for tutorials on geodesics, we said to ourselves "oh it's nice", so we did that too."*	

Knowledge types are identified for every combination of move and source. By looking at knowledge types and sources, patterns of retrieval strategies appear. However, given the scope of this paper, (6), (7) and (8) will be omitted. Processes (7) and (8) can be implied in (1), (2), (3) and (4). Process (6) does not rely on information retrieval anyway as it pertains to a conversation with oneself through drawing, writing, etc... At no point in the analysis was there any indication of the retrieval of meta-cognitive knowledge. It was therefore omitted in the analysis.

Among all sources cited, video is the preferred source type as implied by all participants and actually stated by participant 15 (P15). They also help alleviate the potential language barrier (P8) and are easy to follow (P10), which influences retrieval strategies. Videos are almost always referred to as tutorials and are thus mainly sources of procedural knowledge

(PK). Websites and blogs are not popular. Indeed, knowledge retrieval is seen as difficult (P4,5,13). However, P5 says that it gets easier with experience. Images are popular for referencing and thus play a role in the retrieval of CK in D→I_D and I_D→D (P1-15). One participant (P10) mentioned feeling trapped by his/her reference images on the first task, which made him/her avoid them for the other tasks. This somehow indicates awareness of his/her design fixation, therefore avoiding those references. Nevertheless, there is one mention of images showing Grasshopper definitions (PK). The participants did not mention a lot in terms of information sources as they tend to work individually before merging their work. Monitors are the last resort method. As they were available, they could accommodate multimodal means of communication and were involved in FK, PK and CK. Assistant/Professor appear as similar sources as monitors but are not often mentioned as sources as they were not easily available outside class hours.

D→ I_T often leads to translation (D→I_T→D) and is often due to the popularity of video tutorials.

In PK retrieval, participant P1,3,13 say that they looked for tutorials (videos) that match the initial ideation but say later in the discussion that they eventually found other tutorials to constitute "good/better ideas". In contrast P5 explains that while following tutorials he/she did not achieve what he wanted to. P14 states that he/she found exactly the PK needed to serve his/her ideation (D→I_T). However, the tutorial was considered to be too long therefore he/she settled for an alternative. A couple of participants (P5, 8) mentioned looking for factual knowledge (FK) in videos as the latter are easy to navigate and come with satellite information. However, exposing themselves to videos, usually tutorials, increases the risk of translation as stated previously. This is also the case with the retrieval of conceptual information as several students invested time in watching as many tutorials as possible to build on CK (P8,11,14). P9 reaffirms this by saying that starting from an already made recipe is potentially easier because it reduces the risk of getting stuck while trying to arrange something based on previously acquired PK.

As looking for information on websites and blogs appears to be difficult, the participants often ended up searching for video tutorials given that assembling pieces of information proved to be difficult (P5). Query construction seemed to be the main issue as search engines require precision and are meant to serve FK. P5 also mentioned that it eventually gets easier, which is in line with Mimi and colleagues' paper (2006) on query as a learning process.

Another case was observed by P15 and P8 who declared that the information received by the assistant and the monitors was at times too complex to be implemented and settled for a more comfortable alternative.

Translation is also visible in one instance (P5) when the group is the source of information. One participant (P5) suggests depending on a group member's knowledge for the design tasks.

After struggling for 1 or 2 design tasks, some participants (P2,5,9,12,13,14) directly adopted video-based I_T→D as their ideation triggered strategy and therefore saved cognitive effort and time. They described the process of mixing and matching parts of different tutorials or even just going through one tutorial and adapting the parameters (P9, 12). That behavior was also pointed out by P15 who described that strategy as one to avoid.

I_D often serves as the ideation trigger (I_D→D). P8 suggests that the ill nature of the design task makes referencing a good starting point. P9 goes further by saying that the CK retrieved will guide further knowledge retrieval. However, this requires a good computational understanding of the reference and there is thus a risk of falling prey to further translation (I_D→D→I_T→D). I_D can sometimes be close to I_T, which is illustrated in P8's interview where he/she mentioned that he/she chose references to accommodate the tool. One participant (P10) reported getting stuck with a reference trying to replicate its features.

Finally, there is some resilience towards translation (P7,8,10,15). Whenever students are stuck in the design process, they rely on monitors instead of “being a victim” of the tool-related PK. Occasionally, monitors could not help, or their answers were too complex. When this was the case, students eventually fell back to earlier design state or their own alternative. P14 even mentioned that when he/she met a problem and monitor failed to help, then he/she would stop there. The lack of tool-related information therefore impacts design and for that reason they are also victim of design translation ($D \rightarrow I_T \rightarrow D$).

Table 3 summarizes all the strategies (1-5) observed during the interviews. Videos show the most flexibility. Images and videos allow for information-based ideation and ideation support ($D \leftrightarrow I$) whereas the other sources are unidirectional ($D \rightarrow I$).

Table 3
Matrix of observed strategies in relation to sources and knowledge types

S.\K.	FK	PK	CK
Prof. & Ass.	(2)	(2)	(2)
Course	(2)	(2)	(2)
Groups	(1)(2)	(1)(2)	(1)(2)
Interactive retrieval systems			
Blogs	(2)	-	-
Images	-	(4)	(1)(3)
Videos	(2)(4)	(1)(2)(3)(4)(5)	(1)(2)(3)(4)(5)

DISCUSSION

Studying occurence during the interviews was not possible given the time constraints and the evolution of the discussions with the students. However, there is a pattern that indicates retrieval strategies to be more often used due to the fact that some strategies lead to abandonment. Our results show that whatever the starting strategy, all participants eventually go through translation ($I_T \rightarrow D$) at some point in the process, mostly through PK from videos (tutorials). For the last exercise, some students mentioned that they started with that strategy from the start because it was "simpler" and mixed different video tutorials together (P9,12,13,14). Monitors also appeared in most interviews as sources but mostly in last resort (P1-15). Compared to a search engine, monitors were pointed out to be preferred as explanations were more abstract and allowed multimodal ways of communication. However, there is one instance (P8) where $I_T \rightarrow D$ comes into play. CK is considered too complex to be applied and therefore simplification based on previous experience is made and design intent is not achieved. P5 described the design process as difficult but simplified by videos, monitors, and other group members that were knowledgeable.

If we consider Urgo and colleagues’ paper which is the first to implement both dimensions of A&K’s taxonomy, we find similarities in results. Students often report simplicity as a driver of decision regarding knowledge retrieval. Conceptual tasks are perceived as more difficult and show more evidence of query abandonment and longer completion times. The reasons proposed are based on prior research. First, concepts may be more interconnected than procedures thus requiring students to learn about larger structures whereas procedures can be considered in isolation. Secondly, search tasks with amorphous goals were found to be more complex (Liu et al. 2013), which resonates with the idea of architecture’s ill-defined problems. Procedural knowledge offers a clear goal while conceptual knowledge may be associated with broader levels of understanding (Urgo et al.,2020). Although the use of assistants as sources is not part of IIR, it is a behavioral pattern that has also been noted in earlier studies. Indeed, Byström (2002) demonstrated the use of people as sources when task complexity increases or information acquisition requires effort. Regarding the use of video, all the participants turned to Youtube and displayed similar seeking behaviors as those described by Loke et al. (2017) in their paper on SRL through videos. It resonates with their conclusion on the leverage of videos to seek out similar ressources, especially via the “related videos“ option. Moreover, videos have shown to be the most flexible in terms of knowledge retrieval. Although our research was not as granular regarding system features, the very high consumption of videos observed in our results has reaffirmed the choice of implementing SRL in further studies.

CONCLUSION

The goal of this paper was to observe cognitive patterns in knowledge retrieval activities over multiple sessions while designing in parametric environments and to validate the integration of CLT and IIR for interpretation. By highlighting the type of knowledge students were retrieving and presenting the reasons while designing in PDEs, we were able to extrapolate and align the results from both theories.

Our results show several important tendencies. First, all participants relied primarily on PK with videos as sources. Even FK and CK were searched in procedural information. Whatever the retrieval strategy adopted at start, all participants eventually ended up using videos to support PK and got exposed to the risk of design translation. Triggering strategies such as exploratory searches made use of conceptual knowledge with images but also relied on videos and their corresponding PK. Second, all participants used assistants as a last resort source of information. Given the complementary complexity of the task and the tool, those results are in line with empirical results found in IIR and CLT thus validating their use for future research specific to design in architecture. Furthermore, information-based ideation has shown to be eased by the use of images and more surprisingly videos, which is an opportunity for further developments.

Given the importance of videos in the design process, their use in SRL could also prove to be a good topic of research in the future. Other aspects not yet covered are the automating ability of visual scripting tools and how it could affect working memory, the group dynamic in information retrieval and the long-term protocol analysis over multiple sessions which is uncommon in design studies. The similarities of design with the "create task" and its SRL aspect should also be investigated in the future, in education specifically. Furthermore, it would be interesting to implement guidelines used in CLT to foster certain search behaviors into the design course in order to improve information retrieval and design in general.

This paper is part of larger thesis project on the impact of information retrieval on architectural design. Previous paper focused on the observed impact of search behaviors (2022a) and on their integration into the Function Behavior Structure ontology (2022b), a popular framework to study design cognition. The goal is to eventually provide a conceptual framework to foster more research on the impact of information retrieval in architectural design.

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