Backtracking Decisions within a Design Process : A Way of Enhancing the Designer's Thought Process and Creativity

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Abstract. This paper proposes a way computer sciences could contribute to stimulate the designer's reflexive thought. We explore the possibility of making use of backtracking devices in order to formalize the designer's thought process. Design, as a process of creating an object, cannot be represented by means of a linear timeline. Accordingly, the backtracking processes we are discussing here are not based on a linear model but rather on a non-linear structure. Beyond the notion of undoing and redoing commands within CAD packages, the backtracking process is seen as a way to explore and record several alternative options. The branches of the non-linear model can be seen as pathways made of sequential decisions. The designer creates and explores these pathways while making tentative moves towards an architectural solution. Our goal is to experiment ways that could enable the designer and his/her collaborators to get a clearer mental picture of the network of decisions. We believe that working with parametric objects is the most suited approach to explore such a concept.

1. Cognitive processes related to architectural design

The design process is a very complex one; it includes processing visual images[1], as also storing, classifying and transforming them [1]. Furthermore, in most cases, the responsibility of defining the problem lies with the designer. After defining the problem space, s/he must explore it. Afterwards, if the need arose, s/he must redefine the said problem space, readjust it accordingly to new circumstances and resume the exploration process in order to find an "optimal" solution.

[1] In this context, an image is considered as a mental representation of an object or a concept.

The sequence of actions involved within the design process, that is to say defining, exploring, and redefining a problem space, may be perceived as a cyclical process. The second part of this cycle, the exploration of the problem space, can be seen as a graph (for instance as a tree structure). Indeed, the designer explores several alternate pathways. When s/he is unsatisfied with the results of an experiment, or comes to a dead end, s/he may backtrack and explore other branches of the graph. Going to and fro between these two processes (cycle and graph structure) involves a relatively heavy cognitive load.

The thought process that brings the designer to define the design problem is beyond the scope of this paper. Within the framework of our research work, we focus on the exploration process. As Maher and Poon [2] pointed out, designers explore problem spaces as well as solution spaces. We examine how digital technologies present us with new tools in order to enhance the designer's thought process, by enabling him/her to explore solution spaces, either alone or in collaboration with his/her colleagues.

2. Making comparisons as a way to enhance a thought process

The design process has been identified as a learning process [3, 4]. The complexity of design process is such that the learning process never reaches completion. Doolittle [5] classifies two stages of learning, early learning and late learning. Early learning relies on assistance, while late learning need no assistance and can apply and theorize what has been learnt, thus pushing forward development.

This difference between early and late learning goes beyond the novice's lack of autonomy; it seems that novice and experienced designer do not tackle the design process the same way. Niblock and Hanna [6] tried to understand the influence the use of computers has on cognitive design actions and came to the following conclusion: "[…] The expert perceived using the computer as a visualisation tool to help develop design during a process-orientated approach where he generated many solutions and chose the best solution later whereas the novice designer perceived using the computer as a design strategy tool to help manage design complexity during a solution-orientated approach where he generated one main solution and made adjustments to this". So the novice designer seems to tackle the design process as a linear process whereas the "expert designer" tackles it as a non-linear process. Obviously, there is no clear frontier between the two states that brings the individual from one frame of mind to the other; an evolutionary process enhances gradually the designer's creativity.

Creativity plays an important role in design thinking. Guilford's research works [7] demonstrate that it encompasses two complementary components, namely a convergent mental process and a lateral mental process. De Bono [8] proposes the following analogy : convergent mental process digs always the same hole but every time deeper whereas lateral mental process digs various holes, each time at a different place. The linear process mentioned above can be assimilated to this notion of digging a hole deeper and deeper.

As the designer goes along, s/he becomes aware that s/he is well advised not to tackle the first stages of the design process as a linear process. This non-linearity rests on the propensity to establish comparisons and seems to be an important aspect of the learning process. In this context, comparisons are seen as a way to enhance the thought process. Indeed, it seems that the design process must constantly be fed with input of different kinds liable to increase the designer's creativity. In this area, digital technologies can help the designer to broaden his image repository and to go beyond the limitations inherent in short term memory. As a matter of fact, it can help designer to perceive the design process as a non-linear process, provided that the implemented digital tools are structured accordingly with the user's cognitive processes.

Three kinds of comparisons will be commented below. The first kind of comparison the designer must be able to establish is between the concept and images previously seen (in the real world, books, internet, etc.). It bears mentioning that an image that is not even remotely connected with the broad field of architecture can prove to be a useful source of inspiration. The image is not given to the mind, but it is formed through past experiences [9]. When seeing something of interest, the designer's mind takes selective focused data and elaborates an image. Afterwards, abstraction makes it possible to apply this image to the matter being considered.

The second kind of comparison the designer must be able to establish is between his own work and other architects' production. Most of the time, the architectural designer belongs to a team. In order to be able to come to an agreement with his/her colleagues, s/he must be able to communicate the concept s/he is developing. The feedback s/he receives from them may result in fruitful discussions. The designer is then able to establish comparison between his/her own work and what the other members of team propose.

Finally, it is of utmost importance to the designer to be able to compare a given architectural solution with his previous work. Indeed, every step of the design process is valuable; a previously discarded solution may prove to be useful later on. In so far as the designer keeps track of the sequence of his decisions, s/he will be in a position to propose to his/her collaborators different alternative scenarios and explain the correlations existing between them.

In the first case (comparisons with images), information and communication technologies offer a very effective way to enhance the designer's thought process. It goes without saying that internet can provide a huge amount of images. Obviously, it is incumbent on the designer to sort out these images, and select what can be of any use to him/her.

In the last two cases (comparison with other architects' production or propositions and with one's previous work), computer sciences may provide tools to enhance the designer's critical thinking. These tools aim to help him/her construct a mental image of the different ways a given design problem can be solved. In the next section, we will examine digital environments that help the designer to make comparisons between alternative scenarios.

3. Digital environments enabling the user to make comparisons

Several kinds of digital environments enable the designer to make comparisons between architectural solutions. Three kinds of environment will be commented below : searchable indexes, generative systems and parametric objects. These three approaches have something in common : since they aim to enhance the advantages of a lateral mental process, they may foster communication and encourage discussion among designers.

3.1. Searchable indexes

The implementation of searchable indexes consists in listing and classifying a set of existing architectural solutions. The user consults the index and selects the solutions being most liable to be adapted to the context being considered. This kind of digital environments [10, 11, 12] enable the user to become aware of the existence of several precedents that are likely to become sources of inspiration when tackling similar design problems. From this perspective, the architectural designer does not elaborate the architectural project from scratch but rather make use of the results of previous creative processes.

Since designing an architectural object is a very complex process, it goes without saying that these indexes are useful insofar as a good many precedents are listed. In order to be effective, the index must act as an incentive to make comparisons between several alternative solutions. Those precedents must be organised so as to form a system that is structured in a logical way that is liable to be understood by the user. There is no denying that the structure of the system greatly impact on the user's ability to make sense from the multiplicity of cases [13]. Indeed, the main point is to make the organisation of the system compatible with the user's cognitive processes. The designer must be able to establish a network of references from the images and information included in the index.

While this appears to be a valid approach, usually the user has access to sets of architectural solutions but cannot act on the index itself. Other kinds of digital environments enable the user to elaborate his/her own repository of architectural solutions. The user is then able to record the various solutions s/he found regarding a given architectural problem. S/he can compare them and eventually put them to use in different contexts. This is precisely what generative systems and parametric objects are for.

3.2. Generative systems

Generative system can be defined as applications enabling the user to generate virtual architectural objects by means of semiautomatic methods [14, 15]. In this case, the problem space is structured as an algorithm in which the values assigned to some parameter may change randomly (within a range of acceptable values). The user is able to generate and compare alternative configurations simply by running the programme.

Since the designer follows some sort of rationale in his/her exploration with these systems, s/he can explain how s/he came up with a given set of potential solutions. As when using a searchable index, the designer is in a position to propose alternative scenarios to his/her colleagues. Nevertheless, in both cases, it is not possible to communicate the creative processes that brought forth a given solution because it already reached completion (the solution being either existing or based on random selection).

3.3. Parametric objects

The implementation of parametric objects consists in establishing relationships by which parts of the architectural object connect. "The system takes care of keeping the design consistent with the relationships and thus increases designer ability to explore ideas by reducing the tedium of rework" [16]. The user can assign interchangeable values to the different parameters, modifying the morphology of the entity. These values are chosen intuitively (rather than randomly as in the generative system approach). The designer can evaluate the repercussions of his/her actions on the generated configurations.

Parametric objects, as also generative systems, are more suited when the element being currently designed is an architectural component rather than a building. Clearly, it would be utopian to think that the whole building could be a huge parametric object; it would involve an overwhelming number of parameters and the designer would have to deal with too much constrains. Nevertheless, the model of the building could include several parametric objects communicating amongst themselves (but this is an aspect that goes beyond the scope of this paper).

There exist digital environments enabling the user to assign values to parameters and visualize the resulting configurations [17]. The iterative modification of parameters values may result in a huge gamut of alternative scenarios. The moot point is : how does the user take his bearings within a broad set of potential solutions ? How can we help him/her to get a clearer mental picture of the way his/her decisions (and incidentally the resulting solutions) are interconnected ?

It would be interesting if the designer could give an account of the creative processes that brought forth different solutions and if a colleague could select one or several solution(s), resume the explorative process and explore other scenarios. We argue that this approach may result in fruitful exchanges. Indeed, when it is a matter of trying to roll back the frontiers of creativity, it seems that parametric objects offer great possibilities. The whole point of this approach is similar to the objective both generative systems and searchable indexes try to achieve. Nevertheless, parametric objects make use of a strategy that enables us to record the user's decisions and examine the designer's thought process.

4. Exploring a predefined problem space

In the preceding section, we establish the relevance of an approach based on parametric objects within the framework of this research project. Our aim is to enable the user to explore a solution space and make multiple comparisons so as to enhance his creativity. In this perspective, the solution space can be seen as a territory. What is of interest to us is to examine 1) the designer's movements within this territory, 2) to what extend these movements can constitute a clear picture within the user's mind, and 3) how it would be possible to give an account of these movements and communicate the exploratory process to an interlocutor.

Our interest in parametric objects is grounded on two reasons. On the one hand, the user is called to make several decisions; the generation of a solution is based on a sequence of actions. So, there exists a possibility of communicating and comparing processes (an aspect that would not be conceivable when dealing with approaches such as searchable indexes and generative systems). On the other hand, the implementation of a digital environment enabling the exploration of a solution space compels us to define the scope of the problem space. This is the *sine qua non* for two things: 1) the user should be in a position to move about the territory in a rational way and 2) as developers, we should be in a position to formalise this territory. Therefore, it must be a "structured space", that is to say a clearly delimited domain. We argue that it would be very difficult, maybe even impossible, to elaborate a graph formalizing the relationship between decisions occurring during a creative process involving free form modeling. We believe that an approach based on parametric objects will allow us to elaborate such a graph and implement digital environments that will enable us to conduct experiments.

First and foremost, we have to determine which problem will be solved. After having identified the nature of the case study, we examine what kinds of decisions are involved within a design process, how they are connected, and what could be the best ways to formalize these relationships (see section 7). Afterwards, we are in a position to identify which sets of solutions will be accessible to the user. The digital environments could not possibly present all feasible solutions in an exhaustive way. It would merely gather a sub-set of possible solutions. Nevertheless, the exploration of such a "territory" might help the designer to get acquainted with alternative scenarios, compare them and turn these comparisons to account.

So when the designer navigates within such a digital environment, he explores a problem space already structured and defined. Some researchers consider that any interference with the design process, any constrain, would hinder the designer’s creativity [18]. Indeed, one may posit that it is totally useless to ask the designer to elaborate an object that is already designed. Nevertheless, sometimes the novice designer has only a rudimentary knowledge of a given architectural component (for example sloping roofs, windows, staircases, etc.). In this case, making use of the digital environments aforementioned could be a way of acquiring some of the necessary skills to design such an element.

Clearly, the user is not restricted to the territory defined by the developer. After having explored the sub-set of possible solutions, it could give him/her (or the team) incentives to push forward the object’s development and explore other solutions beyond the predefined solution space. In this case, the digital environment could contribute to extend the scope of the designer’s activities beyond his/her cognitive limitations. This does not apply solely to the novice designer; the experienced designer may have his/her own motives for exploring a predefine solution space, as we shall see in section 6.

5. Backtracking within a predefined problem space

The design process is a heuristic process because the designer discovers architectural "solutions" by himself/herself, proceeding by trial and error. S/he tries out different alternative scenarios in a tentative way. His/her decisions are based partly on his/her intuition. This is why, when designing with the aid of the computer, it is very important for him/her to be able to backtrack within the creative process, make other decisions and explore alternative scenarios.

Commercial CAD packages almost always preserve the design history. According to Akers [19], there are two variants of history models : linear and branching. In the linear model, the history is maintained as a simple ordered list. In the branching model, all previously executed commands, or decisions previously taken, are preserved in the history, even when they are not part of the active path being explored. Most of the time, commercial CAD packages provide undo/redo devices based on the linear model. We may surmise that it is so because this model is the simplest.

We start from the premise that the non-linear model, although far more complex, tallies with the creative process. This model may be seen as a graph structure composed of multiple branches connecting the alternative decisions. Within the design process, backtracking enables the user to experiment with non-linear processes and explore such a graph.

When the system enables the user to move backward, s/he can change his/her mind, go back to a previous state, carry out some of the previous step of the process over again, and successively orient the concept towards different directions. Consequently, backtracking enables the designer to establish and act on a network of interrelated decisions. This notion is fundamental. It is quite obvious that information, in order to be meaningful, must occupy a specific place within an informational network. The data, separated from its context, is devoid of interest. By the same token, a decision takes on significance solely in combination with other decisions.

The user must be able to go wherever s/he wants within the graph structure so as to establish the network of his/her decisions. In order to do that, s/he must be able to move backward and forward. This way s/he can get reacquainted with previous design processes. As a matter of fact, it acts both ways : to reassess or to confirm a decision. On the one hand, the designer can go back to previous states, reconsider past choices, and eventually modify them. On the other hand, s/he can move forward and revisit a given sequence of decisions, so as to recapture the essence of a previous design process.

It goes without saying that knowledge regarding the design process is constructed by the designer from his/her own experiences. The designer elaborates the graph unbeknownst to him/her. The more s/he explores alternative scenarios, the more the graph becomes complex. Since the designer's perception evolves as time goes by, the network of decisions constitutes a model that is continuously questioned and restructured. The designer does not elaborate solely an architectural object, but also an evolving model formalizing the way s/he achieved his/her aim. As Le Moigne [20] pointed out, the model itself produces knowledge; afterwards, the designer can examine it so as to get a clearer mental picture of his/her own cognitive processes.

Furthermore, it can be used by his/her colleagues in order to understand which thread of ideas led the designer to a given visual result. From this architectural solution, the collaborator can backtrack, resume the design process and eventually reorient it. When a third party grafts new branches onto the graph, it becomes even more complex. We believe that such teamwork can result in a new way of collaborating.

6. Exploring a corpus of existing architectural elements

As we said earlier, backtracking is a way to give an account of design processes. Tidafi [21] demonstrated the benefits of communicating processes rather than focusing on results. This approach seems to be valuable not only when the designer is elaborating an architectural object, but also when s/he wants to acquire knowledge or familiarize himself/herself with a given know-how.

Backtracking within a predefined solution space could enable an "asynchronous collaboration" between architectural designers from different periods. So, digital environments enabling backtracking during the exploration process of a solution space could be useful to both the novice designer and the experienced one. The seasoned designer, while reflecting on the elaboration of a given architectural object, may be tempted to explore a corpus of existing artefacts. For instance, architectural elements conceived in the past, while sharing several characteristics, can form a corpus liable to be put to use in research project dealing with parametric objects [22, 23, 24].

This kind of exploratory process could lead the user to become more knowledgeable about the architectural production of a given historical period. We do not argue that parametric modelling approach improves the knowledge management more than any other system, but rather that it is one of the digital tools the designer should consider.

7. Implementing and testing tools

Our research project is a work in progress. We are currently working on a case study dealing with staircases and elaborating the corresponding parametric object. We are implementing a digital environment enabling backtracking processes within the first version of the graph structure (see Figure 1). The digital environment is implemented in the form of a plug-in in a commercial CAD package[2]. We opted for this package because 1) it contains an embedded language (MEL) that enables us to quickly implement and test graphical user interfaces (see Figure 2) and 2) it enables us to use an object oriented programming language to communicate with the geometric modelling kernel. The plug-in is implemented with Python because this type of language provides us with the flexibility required for changing the parameters values iteratively.

Within the framework of this research project, it matters to us to always be able to modify our strategy, rather than being captive of a given tool or language. During the next stages of the project, we will be able to change from MEL to Java, translate code from Python into C++, stock the parameters values within

[2] Since we work in collaboration with Autodesk, we choose Autodesk Maya environment [25].

text files or within a data base, make use of another geometric modelling kernel, etc.

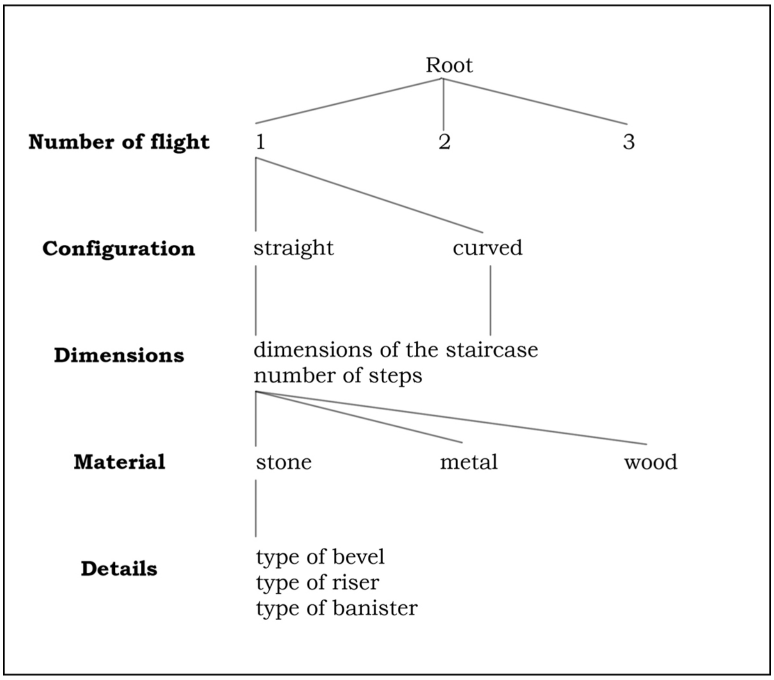

Fig. 1. Section of the graph of design decision (first version).

The parametric object is conceived as an algorithm in which objects communicate among themselves. While the user takes successive decisions regarding the object's attributes, the system assigns values to an increasing number of parameters. The system record and stock the result of the designer's decisions at each one of the phases of the design process, without consuming a large part of the computer's memory. Temporary solutions are generated taking into account the values assigned to some of the parameters and the identity of the parameters whose value is still undefined. Insofar as the designer can backtrack and gain access to other versions of this set of values, s/he is able to compare the current configuration of the object with previous states.

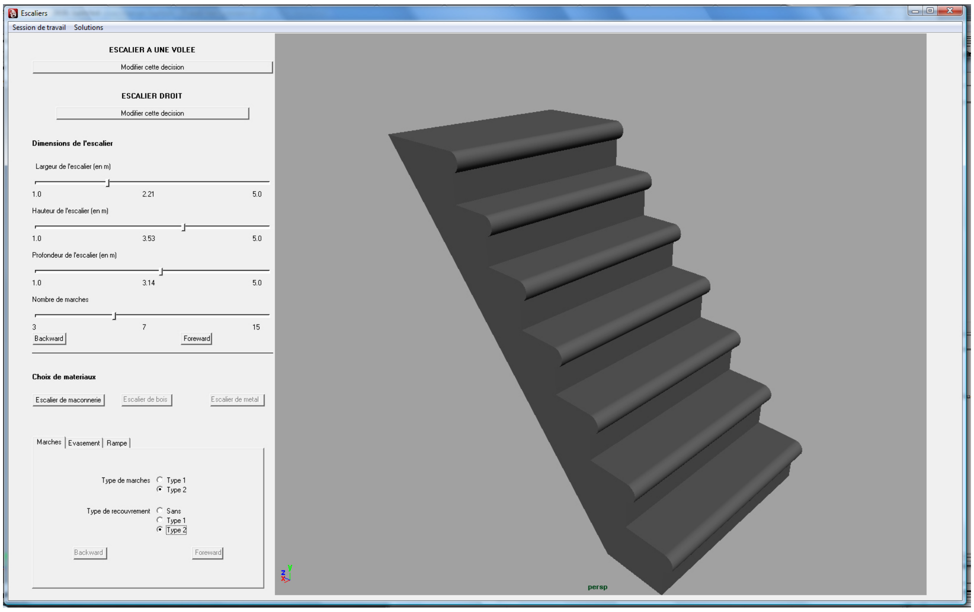

Fig. 2. Graphical user interface of the digital environment.

Without any doubt, the usefulness of such an environment, that is to say the possibility of enhancing the user's thought process, lies with the developer's ability. The latter must contrive to 1) represent the graph structure in an intelligible way and 2) enable the user to navigate in a flexible way. It is impossible to know beforehand to what extent the functionalities and representations put at the user's disposal will correspond to his cognitive mechanisms. From this undeniable fact, we can presume that the digital environment will prove to be suitable only for a portion of the potential users for whom it is intended, and not for all of them. As Waterworth [26] observed, the validity of a GUI is mostly determined by unconscious reactions from the user.

This is why it is of the utmost importance to implement multiple prototypes and validate them by means of working sessions involving potential users [27]. We plan to test the trial versions with potential users so as to observe how they respond to them. These tests will be performed throughout the development process of the digital environments. It is essential to elaborate these environments not only in accordance with the potential users for whom it is intended, but also in collaboration with them.

To be able to backtrack within the design process, and to do so in a structured way, may have a positive influence on the designer's behaviour. We can surmise that the novice designer will get into the habit of elaborating various alternatives and will become prone to make comparisons between alternative options. In order to verify this assumption, we will evaluate to what extend being in contact with alternative solutions encompassed within emergent shapes helps the designer during the creative processes and encourage discussion among designers.

There are several ways of testing a digital environment and assessing its usefulness. For instance, we will conduct tests in which we will ask the user to think aloud, to describe the exploratory process and explain the potential effects and the drawbacks s/he perceives. Another method for testing the digital environments will be to attend meetings with the designer's team mates. In doing so, we will be in a position to evaluate to what extend the designer is able to communicate the creative process and make comparisons between alternative solutions by means of the digital environment. We will also conduct interviews during which the members of the team will evaluate the quality of the generated solutions, answer to open questions and express themselves regarding their concerns (or dissatisfaction) with the system.

Without any doubt, it will be very revealing to observe designers while 1) they make moves within the solution space and 2) when they meet together. The observation and analysis of their behaviour may help us to better understand to what extend digital environments based on parametric objects and enabling backtracking could be useful in a collaborative context. We will then be able to elaborate new strategies to present the designer with improved digital tools. The research process, just like the design process, is a cyclical one; the researcher elaborate a prototype, run tests and makes observations that bring him/her to restructure the problem, elaborate new approaches, test them anew and so forth. In other words, programmers and designers must work jointly to bring the creative process to a satisfactory conclusion [28].

8. Conclusion

This paper examined the ways we plan to help designers explore a given solution space, structure the ideation process, make comparisons and communicate their reasoning to their colleagues. The proposed approach is based on the use of parametric objects because it enables us to structure a solution space, and organise the user's decisions as sequences of actions. We make use of algorithms in order to record multiple previous states, without overloading the computer's memory.

We believe that exploring a network of interrelated architectural forms, and afterwards pursue the exploration beyond the predefined solution space, could potentially result in very fruitful cognitive processes. We are currently implementing a digital environment in order to conduct experiments. The challenge we take up is twofold: on the one hand, we want the designer to get a clear mental picture of the network of his/her decisions. On the other hand, we want the designer's colleagues to understand and follow the user's thread of ideas. In the near future, we will proceed to verify these assumptions. We shall then be able to draw conclusions on both aspects.

Our next paper will deal with the aspects liable to impact on the user's propensity to use the implemented tools, namely the structure of the parametric object (nature of parameters, sequence of assignation, etc) and the structure of the digital environment (graphical representation of the graph, types of movements allowed within the solution space, etc.)

When the designer is elaborating an architectural object, which alternative options is s/he exploring and how are they interrelated ? Which sequences of decisions led to existing architectural objects ? These questions are fundamentally interconnected since they both tackle the complexity of creative processes. We believe that approaches based on the exploration of problem spaces could contribute towards the circulation of ideas belonging to different area of expertise, within the broad field of architecture (pedagogy, architectural design and history of architecture, to name a few).

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