PARAMETRIC METHODS OF EXPLORATION AND CREATIVITY DURING ARCHITECTURAL DESIGN
A case study in the design studio

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ABSTRACT: Parametric methods from different modeling paradigms were proposed to students in a design studio. The influence of these methods on creativity was studied using qualitative methodology. ‘Generation’ was found to stimulate ‘abundance’ of ideas and to lead to different evolution and flexibility, as well as to higher ‘engagement’ in the design process.

KEYWORDS: Digital design process, creativity, parametric models, architectural studio

RÉSUMÉ : Des méthodes paramétriques de différents paradigmes de modélisation ont été proposées aux étudiants en atelier d’architecture. L’influence de ces méthodes sur la créativité a été étudiée de façon qualitative. On a constaté que des modèles « génératifs » stimulent l’abondance d’idées et mènent à une évolution d’idées et des flexibilités différentes, ainsi qu’à un plus grand engagement dans le processus de conceptions.

MOTS-CLÉS : Processus de conception numérique, créativité, modèle paramétrique, atelier d’architecture

T. Tidafi and T. Dorta (eds)
Joining Languages, Cultures and Visions: CAADFutures 2009
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1. INTRODUCTION

With the new digital methods of representation, form generation and phenomena simulation that have been added to the already existing means for architectural design, design theory and cognition, as well as the pedagogical approaches undergo perceptible changes (Oxman 2008). The influence of these computational methods on creativity provokes contradicting opinions (Talbott 2004; Lyon 2005). Creativity is a complex human phenomenon that is widely believed to be inaccessible to analysis and even less so to measurement (Candy and Bilda 2007). According to some authors, creativity is the capacity to realize a product which is new but at the same time adapted to the context in which it is manifested (Lubart 2003). This study investigates creativity in situation of design with parametric methods and tries to establish some criteria for its evaluation.

In this paper, first, through a literature review, we will show the divergent, even opposed opinions on the question of the influence of parametric design methods on creativity. Then, some finding based on previous case studies will be discussed. As a following point, a specific case study will be presented, exploring the influence of parametric methods coming from the different modeling paradigms on student’s creativity. Finally, some conclusions as well as their implications for teaching digital architectural design will be laid out.

2. BACKGROUND

Some cognitive aspects of creativity seem to be influenced by the parametric methods of design in architecture. In what follows, we will introduce some of them, together with the divergent opinions of some researchers on this issue. Then, different modeling paradigms will be presented in order to study their effect on the creative processes.

2.1. On creativity

It is widely accepted that creativity depends on the interaction between cognitive, emotional and environmental factors. It is the capacity to find numerous ideas out of a unique stimulus. Its appreciation is often subjective. For example, Do Bono (1976, in Lawson 1980) writes that creativity is a value word and represents a value judgment—no one ever calls creative something new which he dislikes.

2.1.1. Cognitive bases

Even if divergent thinking is often shown as prerequisite for generating original ideas, cognitive theories suggest that the creativity is born by a balance
between convergent and divergent thinking (Lawson 1980). According to Hanna and Barber (2006), divergent thinking is speculative and unstructured as it explores ideas and combinations to arrive at ‘possible’ solutions to the problem.

According to Goel (1997) problem formulation and reformulation are integral parts of creative design. The knowledge needed is not available in a form directly applicable to the design problem and has to be analogically transferred. Numerous studies have been published on the crucial role played by analogical thinking for the design process (Léglise 2000; Leclercq and Heilighen 2002; Goel and Bhatta 2004). Having procedural knowledge independent from the domain, and even explicating it is also found to stimulate creativity in design (Christiaans 1992).

2.1.2. Indicators

Torrance (1966) identifies four principles which can operationalize creativity: abundance (generate a large volume of ideas), flexibility (have a variety in the ideas); originality (go out of the common) and elaboration (develop the idea). These are some of the indicators that we are using in this research in order to evaluate creativity.

Second type of indicators is based on Csikszentmihalyi’s (1990) idea that students’ engagement in the process of design is a sign of their creativity. Dorta (2008) explores the Design Flow (as defined by Csikszentmihalyi) in a design context, by asking the students to evaluate their emotional condition at the beginning, the middle and at the end of a design task by choosing among worry, anxiety, apathy, boredom, arousal, control, relaxation and flow (the latter being the kind of a nirvana-state in which creativity occurs the most). We studied the presence of some of these emotional states judging by the recordings (this way, the design process is not artificially interrupted, and the data may not be biased by the students). Our method though, may not be applied to a much greater number of designers because it is much more time consuming.

2.1.3. Ideation

New ideas may appear either from analogies, internal images and knowledge, or by external stimulation, mainly visual in the domain of architecture and design. As about this second type, the mechanism seems to depend on new interpretations of previous depictions when a designer is looking at them. Thus sometimes, they tend to be associated with a new concept, function or meaning. Goldschmidt (1991) called this phenomenon ‘seeing-as’ activity. This kind of unexpected discovery is usually discussed in the bibliography when recording design activity by sketching. If we could call this phenomenon ‘medium-provoked’ design idea, we could find similar events when working on a paper-
mock-up or on a digital model in a computer software (Iordanova et al. 2006).

2.2. On the different modeling paradigms

Parametric methods for design exploration can be of different kinds depending on the attributes which are parameterized (dimensions, relations or generation algorithms). In relation to this, as well as to some architectural aspects, Oxman (2008) identifies four paradigmatic classes of digital models: CAD (supporting posteriori automation of design drawings and visual models), formation (exploiting different geometries and parameterization), generation (considering shapes as a result of pre-formulated generative processes), and performance (which might rely on formation and generation processes, but includes the influence of external forces like structural loads, acoustics, site, etc.). The last three have parametric modeling and algorithms as a creation basis and could enrich the design methods of an architect with methods made possible by computers. The question is then, how working with these paradigms influences creativity, if it does so?

For the purposes of our research, we defined a more technical definition of these paradigms and the way in which one can pass from one to another. It should be noted that actual software readily provide transformation of digital entities from higher level of ‘intelligence’ to lower level, but the opposite is exceptional, if any, because it is mathematically difficult (implies form recognition), and non-determined (one entity can be created in many different ways). Here is an example: 1) Starting from a performance model where an external force influences the form, we can ‘freeze’ instances of the dynamic object with particular parameters, or at a precise time moment. The force will not be an active agent in this model stripped of a part of its initial intelligence. 2) Having a model created through generation, we can ‘explode’ it (terminology used by some software) and obtain a model that does not ‘remember’ the algorithms that have generated it, but still has some simpler parametric structure (becomes a ‘formation’ model). 3) A formation model, can only be ‘exploded’ to become a direct description model composed of meshes, faces and points (we do not use CAD here, because this abbreviation has a 2D technical drawing connotation, while a more general 3D modeling software is used in our case). It is important for the students to be aware of these conversions, as well as of their consequences.

2.3. Parametric methods for/versus creativity

We found some opposition to the use of parametric models during creative conceptual work in the specialized literature. According to Talbott (2004), for example, there should be ‘intermittent divergence’ in the process in order cre-
activity to take place. In traditional design: each model-building step generates an opportunity for intermittent divergence; attention to a local context reveals an opportunity for intermittent divergence; visualizing alternate positions and transformations trigger intermittent divergence. According to this author, parametric models do not create these conditions. By our study, we will try to investigate this issue. On an opposite position, Hanna et Barber (2006) study creativity with digital tools (scripting included) with first year students in architecture. The authors find augmented cognitive creativity, and more innovative designs in students who have used these digital methods. According to Fischer (2007), the computer (and specifically a parametric approach) can either ‘enable’ or ‘restrict’ the design process, depending on its use as a ‘medium’ or as a ‘tool’. When taking into account the way in which parametric models are constructed, Janssen et al. (2000) defined a creative solution as one which is not known beforehand, is useful for the project, and is not a mere application of a formula.

3. OBJECTIVES AND METHODOLOGY

The objectives of this research are to study how digital methods belonging to different modeling paradigms influence the process of design exploration. This will let us adjust their use during the design studio. Based on the above stated theoretical bases, generation of ideas, design exploration and evolution of ideas will be observed. The attitude and the emotional state expressed by the participants, as well as on the results of their work will be studied as well. The evidence on these themes will be collected by observations and questionnaires.

The methodology used for the observations is qualitative and observes students in a non-controlled natural environment of a digital studio in architecture. Students were in their third (and last) year of the first cycle of bachelor of architectural design education. As such, they can be considered novice designers. In terms of their knowledge of the digital tools, they were quite skilled, as the observations are held at the end (or soon after) a specialized digital studio. The modeling software used was Cinema4D© from Maxon, together with its regular plug-ins and especially MoGraph for its form-generating characteristics.

The students worked on a design task in teams of two, so that there is natural verbalization of design intents and moves in the dialogue. A mini-project was developed on one computer, while interacting with two mice, so that each student has immediate access to the ‘digital space’. The design sessions were recorded by a screen capturing program, as well as by video camera. The moments of generation of ideas were then identified. The verbal expressions, the gestures and the design actions around these moments were transcribed.
The study is based on two observation experiences: (1) studio-context observation, which was very close to the natural studio situation; and (2) specifically parametric design observation, during which the participants were asked to follow specific instructions in terms of digital methods to be used. The first one allowed looking generally into the design process and seeing some differences when parametric methods are used or not; while the second one focused on differences when 3 different parametric methods are used.

4. STUDIO-CONTEXT OBSERVATION EXPERIENCE

During this first observation, five teams of two students in architecture were given the possibility to use digital methods of their choice and to work on a small design task during approximately two hours. Some aspects of this research were reported in a previous paper (Iordanova 2007). The observation of the design process showed a pattern in terms of timing, in respect to the number and the type of generated ideas, as well as concerning their evolution.

4.1. In terms of timing of the design process

All of the teams started their project by a discussion and looking through references (see the bubble on the top of Figure 1). Several design ideas were generated during this period (1 to 4 per team, see the 1st line in the table of Figure 2). Then, a moment came when the representation of the design object through modeling started. No major differences in the number and the types of ideas were observed by this moment.

The modeling methods used by the teams seem to influence the different development and evolution of these first conceptual ideas, as well as the process of ideas generation throughout the modeling phase of the observed session. Thus, naturally, the teams split into two groups: two teams using predominantly parametric methods of form creation, and two teams using predominantly descriptive, direct methods of modeling. One of the teams was using both types of methods (shown by the intersection of the ensembles on the scheme on Figure 1). The higher density of the points in the bubble showing the parametric-predominance methods corresponds to higher number of ideas.

4.2. Number and type of generated ideas

The ideas generated were many more in number when the modeling was performed by parametric methods (see Figure 2). It is important to specify how we determine the emergence of an idea: it has to be considered either by naming it, or by mentioning the possibilities or the solution it gives to some architectural aspects of the design object. A variation, on the other hand, is just a different volumetric (or visual) expression of a given idea (no architectural
aspects are reconsidered). During continuous parametric modifications of the
digital object, a variation was 'counted' when the continuous process was
stopped and looked at for evaluation. Of course, even during the dynamic
process of change, there is evaluation going on, which stops the modifications
at a precise moment.

The analysis of the ideas generated during the discussion period at the
beginning of the design sessions, showed that they were of similar nature for
all the teams (provoked by the context, or by functional analogies or meta-
phors), and concerning the relation to the site, or the structure, the functional
organization and the movement of the users. So, not the ideas themselves, but
their evolution later-on was responsible for the differences observed in the
design process and in the productivity. This might show that depending on the
digital medium used, the initial ideas were either taken more as design prin-
ciples and then explored by modeling; or represented as a solution and de-
veloped by refining. This is supported by the fact that a large share of the difference
in the number of generated ideas is linked to ideas emerged by the seeing-as
phenomenon provoked by the medium, that occurred mostly during paramet-
ric explorations (Figure 2, last line).

**FIGURE 1. SCHEMATIC REPRESENTATION OF THE DESIGN PROCESS DURING THE OBSERVATIONS:
IDEAS GENERATION AND IDEAS EVOLUTION DEPENDING ON THE CHOSEN MODELING METHOD.**

**FIGURE 2. IDEAS GENERATION DURING THE DESIGN PROCESS.**

<table>
<thead>
<tr>
<th></th>
<th>Team-1 descriptive</th>
<th>Team-2</th>
<th>Team-3</th>
<th>Team-4</th>
<th>Team-5 parametric</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of generated ideas</td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>16</td>
<td>12</td>
<td>50</td>
</tr>
<tr>
<td>during the initial discussion</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>during modeling</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>12</td>
<td>11</td>
<td>37</td>
</tr>
<tr>
<td>Moments of ‘seeing-as’</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td>during the initial discussion</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>during modeling</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>16</td>
</tr>
</tbody>
</table>
**4.3. Evolution of ideas**

Development of ideas was taking longer with the direct object description method. Ideas were taking form and evolving quicker when parametric methods were used. They seem to be more ‘enchained’ and dynamic (depicted by the links between the flexible ideas on the scheme on Fig. 1). As mentioned before, according to Talbott (2004), the lack of intermittence during this process deteriorates creativity by diminishing the number of prerequisites for a creative leap. Nevertheless, if we consider the definition of ‘creative leap’ given by Cross (2006), it is more akin to ‘bridging’ between problem space and solution space. Moreover, the results of this observation prove that parametric exploration provokes generation of a multitude of ideas. Based on the dynamic character of a modeled solution, the ideas become more flexible.

Having in mind the existence of different modeling paradigms, we hold a second observation giving more specific requirements to the students.

**5. SPECIFIC OBSERVATION: USING THREE DIFFERENT MODELING PARADIGMS**

In this second observation, three different design modeling paradigms were proposed to students as methods of work on a small design task (create a conceptual design for a train stop with exhibition space). More precisely, three teams of two students were asked to work for approximately 20 minutes with each of the following types of digital methods: direct description, formation and generation (without stipulating the order in which each method is used). The performance method was not included in this observation because it is relatively more time consuming and needs more input from the context. The students had to generate (one or more) ideas for the project with each of them and explore it as far as possible in the limited time. After this, each team had to choose one of the mini-projects and develop it further for another 20 minutes (overall observation time was about 1 ½ hour per team).

Following the theoretical background exposed at the beginning of the paper, the recordings are interpreted regarding the following aspects: design process, vocabulary and attitude, and design result. The answers on questionnaires are also taken into consideration.

**5.1. On the design process**

Generation of ideas, design exploration and evolution of ideas will be studied, as important aspects of creativity in a design process.
5.1.1. Generation of ideas-abundance

According to the specialized literature on creativity, among other indicators, quantity may serve as an indicator of quality when design ideas are concerned (Osborn 1965). The number of ideas generated by the observed teams with each of the three methods is given on Fig. 3 (the asterisk* presents projects which were not created by strictly direct methods of modeling, but rather with a parametric one, more similar to ‘formation’). The number of variations for each idea is written between parentheses.

We could notice that naturally, the students were tempted to select parametric methods and not direct-description ones (even if they were asked to use the latter ones). This might be due either to the higher interest to these methods because they better serve design intentions, or because they are more unusual compared to traditional designing, or maybe because they are considered easier for reaching a solution. All these reasons are mentioned in questionnaire answers.

If the number of ideas is not so different for the three methods and seems to represent more the design habits of each team (Iordanova 2007), the number of variations per idea is clearly augmenting towards the ‘generation’ methods.

**FIGURE 3. IDEAS GENERATED BY EACH TEAM WITH THE DIFFERENT MODELING PARADIGMS**

<table>
<thead>
<tr>
<th>Type of Method</th>
<th>Direct</th>
<th>Formation</th>
<th>Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team-1</td>
<td>1* (3)</td>
<td>1 (3)</td>
<td>2 (17) (8)</td>
</tr>
<tr>
<td>Team-2</td>
<td>1 (1)</td>
<td>2 (6) (3)</td>
<td>2 (6) (2)</td>
</tr>
<tr>
<td>Team-3</td>
<td>3* (1) (1) (5)</td>
<td>2 (2) (2)</td>
<td>2 (4) (4)</td>
</tr>
<tr>
<td>Total</td>
<td>5* (11)</td>
<td>5 (16)</td>
<td>6 (41)</td>
</tr>
</tbody>
</table>

In what follows, some more qualitative aspects are discussed.

5.1.2. Design exploration strategies and flexibility of ideas

Design exploration shows the willingness of an architect to look for various solutions for a given design task, before developing one solution as a final project. This corresponds to the ‘breadth-first’ search in Artificial Intelligence terminology and according to some authors (Cross 2006) is an indicative cognitive approach of expert designers. It depends on many personal and contextual factors, amongst which, the Design Space within which an architect works: previous experience, precedents, metaphors, knowledge and methods (Schön 1983). In the case study presented here, the digital methods are different, and account for the observed differences.
Thus, given the relative rapidity of the production of a solution through ‘formation’ or ‘generation’, more exploration ‘at large’ was present. The global flexibility of the form modeled through these methods was much appreciated in the conceptual stage when it serves as ideation ‘material’.

5.1.3. Evolution of ideas

A deeper look into the data informs us about the evolution which the ideas are undergoing during the design process. Even if the observation time is quite limited, given the conceptual character of the demanded project, we evaluate that it is possible to see the evolution. While the only one model created by direct description evolves strictly linearly (by modifying locally the ‘digital material’), the generative objects receive numerous iterations and regenerations with new rules and/or parameters (Fig. 4). What is even more interesting is that the finally selected object remains dynamic and can be subsequently modified if needed. This way, a potentiality of solutions is created. This confirms the findings of the first observation where parametric models were considered more as ‘principles’ to explore than as solutions.

5.2. On dialogues, vocabulary and attitude

The partial transcript of the design-session recordings unveiled interesting aspects about the design process, on the attitude and the creativity of the students when working with each of the modeling methods.
5.2.1. Architectural meaning

Even if the production of variances with generative methods seems formal, it was found that this process was accompanied by a conversation on architectural aspects of the project, and with architectural terminology: on structure, constructability, functional and esthetic properties. Manipulating digital parameters and rules was giving the possibility to evaluate the proposal and to consider architectural dimensions of the project. The visual exploration of the object is quite fluent even if sometimes numerical values are manipulated. New ideas were emerging stimulated by these variations. When manipulating a digital model, conversations with architectural terminology (about the program of the building, on structure, on light and materials) were taking place. Inversely, use of ‘digital terminology’ was noticed even when sketching a possible solution on a piece of paper. So there was a constant process of conversion and exchange between the real and the digital worlds.

5.2.2. Rapidity

Speed and efficiency were frequently evoked when talking about generative methods. Even at the very beginning of the observations, when deciding with which method to start, some students were saying: "let’s start with generative, we’ll finish this quickly”.

One of the teams had to start-over the model created by generative method when they were already rendering some presentation images with lights (and the computer crashed because of reasons not linked to the observation). Even starting-over was not much regretted in their dialogue because the students were aware of the rapidity of re-creation of the model (this took 3 minutes and even variations were made).

The rapidity had an implication on the consideration of more architectural aspects of a design object created by ‘generation’ (if we consider only the first 3 stages of the observation): i.e. structure, pedestrian flow. In some cases, though, if the parameters and the generation rules go out of control, much time can be lost to find an appropriate solution.

5.2.3. Possibility to go back and modify an object

Another thought which was recurrent in the dialogues of all the teams was the possibility to go back and modify an object. Other than the flexibility provided by this characteristic of models created with formation, and especially with generation methods, this makes fixation difficult. This is the reason for the non-linear evolution of models created under these paradigmatic classes, as well as for the many variances generated for them.
5.2.4. Unimportance of the form created: can be further modified

The previous point and the ‘non-fixation’ provoke an attitude of ‘unimportance’ of the form created. On one hand, this might be good because it removes the fear of the white page, but on the other, it creates conditions to design forms without giving them deeper consideration, which might lead to bad designs (if one never comes back to reconsider them).

That is why it seems important to always start a design by clearly stating some general architectural concepts that will be the basis of the formal development. Such a process was clearly declared at the beginning of the session by one of the teams (who generated concepts for all the methods at the very beginning), and was less explicit for the other two teams who declared their architectural intentions, but without giving names to the concepts, for example.

5.2.5. Communicating the process

While working with generative methods and communicating intentions about a project (without manipulating the model), the students were frequently figuring-out and describing the procedure or the digital method to be used for its creation, instead of the final look of the form. This seems to be a major difference in communication compared to traditional design methods and compared to direct description methods.

5.2.6. Motivation and enthusiasm vs. boredom and anxiety

Discovering the moments of positive emotions partially coincides with the ‘aha-event’ of unexpected discovery. During natural verbalization through dialogue between two team members, they can be expressed by exclamations such as ‘Ah’ or ‘Oh’ (Iordanova 2006). Positive emotions and enthusiasm are expressed by louder voice, laughter, faster speech or direct statement of attitude.

This evaluation though, accounts for the satisfaction (or not) of a student with her own work. In order for it to be more objective and scientifically acceptable, the evaluation of the researchers has to be in the same direction (i.e. a very irrelevant idea can create enthusiasm in a team, but an external evaluator may judge it completely inappropriate). On the other hand, innovation often starts with ideas that are at first considered ‘crazy’. On these bases, we consider both student’s judgment and expert’s opinion.

During the observations, considerably more ‘aha-events’ were found when working with generative methods of modeling. They were occurring mostly during the exploration period: when the model was created and variations were performed. Enthusiasm was very often perceivable when finding a generative rule by which to represent design intent. One such moment, for example, was
the concretization of the concept of the train-stop as a ‘cloud of smoke’ (created by the passing train). It evolved from ‘cloud of smoke’ through tunnel and cloud, to ‘train in movement with its wagons’. Often during the design session, positive attitude to generative methods was explicitly expressed (even while working with the other two methods), and inversely, negative attitude to direct manipulations of faces and points was declared. One of the teams though, was declaring fascination to direct modeling methods, but in fact, the method used by them was not purely direct, but rather parametric as well.

6. ON THE DESIGN PROPOSALS (THE RESULTS)

Two types of evaluations were done: one by the researchers (also architects and teachers) and another one by the students themselves (implicitly, by choosing which of the three initially developed solutions to continue in the last phase of the design session).

It proves to be quite difficult, even to a specialist, to evaluate conceptual design proposals, especially in situation of design experiences which are not part of the term projects. According to Smith and Koselyn (2009), the assessment of an architectural design can be done through the Criteria Reference Assessment matrix. Its criteria include: “An understanding of design elements and principles, integration of theory and practice, responsiveness to context, quality of physical setting, ability to abstract ideas, ability to interpret social and cultural issues, and ability to communicate ideas.” All these criteria cannot be applied to our situation because of the relative simplicity of the task and the limited time for its realization. The co-authors of this paper (who did not assist to the design session) were asked to evaluate the mini-projects according to practical and creative aspects. Two of the generation-model designs were considered as the most creative from a team (Figure 4 and Figure 5-c), and one of the direct-description designs (Figure 5-a). In terms of practicality, two of the direct-description models, and one generation model were evaluated as ‘winners’. Logically enough, the generation model which was evaluated at the same time most creative and most practical from one team, was perceived as the overall ‘winner’ (Figure 4). The most innovative one was a generative model as well (Figure 5-c).

As far as the students’ judgment about their projects is concerned, two of the teams continued the generation models and one, continued the direct-description one. We are aware, though, that in a learning situation it is more important to develop appropriate design process than to obtain a good result.
7. DISCUSSION

On the basis of the observations described in the previous point, it is possible to notice that creativity was enriched by the parametric methods of modeling of the design object, and especially by the generative methods, even if there were not conditions for ‘intermittent divergence’, as stipulated by Talbott (2004). In fact, this author refers to the predecessor of Generative Components–Custo-
mObjects (by Bentley), which offers a completely parametric environment and an interface quite difficult to control by non-expert users (as of 2008) and unusual for the ‘architectural culture’.

In respect to the four principles operationalizing creativity, ‘abundance’ was found to be positively influenced by ‘formation’ and ‘generation’ modeling paradigms. ‘Flexibility’ and ‘evolution’ were supported by ‘generation’ in a way different than by the other types of figuration.

The observed exploration processes were different when working each of the three proposed modeling paradigms. This leads to the idea that different cognitive mechanisms might be solicited too. If a conventional model (real or digital) advances linearly, step-by-step and by static representations; a generative model evolves in less number of ‘steps’ but with dynamic figurations. Intermittent processes might be limited by the possibility of the working memory to keep track of ‘steps’ (normally 4-5), while in dynamic generation models the cognitive support might be different if a transformation rule is established as a mental model (Smith and Kosslyn 2007). Importance of procedural knowledge for the creativity was underlined by some authors, and evidence about explicit discussion on the generation process (and not the result), were found in the dialogues, as already mentioned.

Another difference can be seen in the objects or the notions manipulated: if in direct-description model, the designer manipulated objects and makes a ‘composition’ with them, in formation models, there are already some links between the objects since their creation, and in generative models, mostly rules and processes are manipulated. This offers many more alternatives (in type and in degree) with a tiny effort. It is not possible though, to say that each variation is a new idea: it remains a variation and will become an idea only if it leads to a new concept semantically expressed.
These observations are consistent with the opinion of Lyon (2005) on the digital design process. He proposes to rethink the architectural design process on the basis of non-linear conceptual processes, where dynamic emergence stimulates creativity. Wilden (1980) finds even that the mapping of continuous and discontinuous (intermittent) methods is necessary for the design process.

The enlarged conceptual space when working with generative models might be due to the balance between convergent and divergent thinking, as prescribed by Lawson (1980). These are exactly the activities used when modeling by generation: convergent when a team has to decide how to model a concept in order to create an initial prototype, and divergent when generating variations on it. This can be reflected upon from teleological point of view as well: modeling a mentally ready solution vs. free parametric explorations guided by some principles only (as seen during the observations). The first one needs control over parameters (sometimes leading to impossibility to represent a concrete intention because of too many parameters); while the second gives relative freedom of manipulations and may use dynamic intermediate states to stimulate creativity.

According to the questionnaires, a controlled random effect is much cherished by students. It is true that its effect might be destructive, but in fact, it brings unforeseen results, which may provoke unexpected discoveries. And in creativity, not everything is under control. According to Csikszentmihalyi (2006): “For original ideas to come about, you have to let them percolate under the level of consciousness in a place where we have no way to make them obey our own desires or our own direction. So they find their way, their random combinations that are driven by forces we don’t know about. It’s through this recombination that something new may come up, not when we try to push them directly.” Without willing to take away the creativity from the human brain but only to additionally stimulate it, it might be possible to compare the effect of a random modification with the effect described above, and which takes place in the non-conscious.

8. CONCLUSIONS AND FUTURE WORK

This research showed that affinities of students to one or another modeling paradigm can be different when in non-controlled design environment. This could be an indicator of different cognitive processes being solicited. It was also demonstrated that generative modeling can contribute to creativity and therefore should be proposed to students from the beginning of their projects when intentions can be explicated and formalized, and after this, explored.

The two types of indicators used to evaluate creativity: abundance, flexibility, evolutions and originality of ideas, as well as the level of engagement in the design work, proved to be efficient and coherent.
In order to have a rich ideation environment, generative methods of modeling should be combined to all other methods (direct, formation and performance), as well as be complemented by a context providing access to analogies. A possible solution might be given through interactive models of referents (metaphors and precedents) proposing named parameters, functional, structural and performance knowledge and thus, serving for analogical transfer. A library of such kind of objects was created and the results of its use in a design studio were reported in previous work.

In future research, we would like to include in the design task a method associated with performative modeling paradigm, and to give the students longer period of time for work.

According to Oxman (2008), the theory of design has to be reconsidered in order to include the new digital methods and strategies of creation. This article tries to make a step in this direction by reaching further on and investigating the question of creativity in relation to the context in which parametric approaches are used, as well as depending on the paradigm to which they belong.

ACKNOWLEDGEMENTS

This study was sponsored by a SSHRC research grant on pedagogy with digital means, lead by Prof. De Paoli.

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