Identifying Cognitive Operations of Conception Implied in the Uses of Parametric Modeling in Architectural Design: Toward Pedagogical Tools

Aurélie de Boissieu[1], François Guéna[2], Caroline Lecourtois[3]
MAP-maacc, Ecole Nationale Supérieure d'Architecture de Paris la Villette, France
http://www.maacc.archi.fr
[1]aurelie.deboissieu@maacc.archi.fr, [2]fguena@maacc.archi.fr, [3]clecourt@maacc.archi.fr

Abstract. *The research presented in this paper aims at identifying the cognitive operations implied in the uses of parametric modeling in architectural conception. The uses of parametric modeling in architectural design remain emergent and marginal. How can we teach these practices? The identification of the main cognitive operations of conception allows us to propose accurate pedagogical objectives. This paper presents: the research methods employed, the results achieved and propositions for pedagogical tools.*
Keywords. *Parametric modeling; architectural conception, CAAD curriculum, architecturology.*

INTRODUCTION

Parametric modeling is part of computer aided design process of industrial sectors, such as automobile or aeronautic, for over three decades. For a few years architectural sector has carried out parametric modeling.

Visual programming languages as Grasshopper [1] have certainly something to do with this amazing and growing adoption by architects. Popular among students and professionals, this plug-in of Rhinoceros 3D modeler enables them to build parametric models without any programming or scripting knowledge. However, the uses of parametric modeling in architectural conception remain emergent and marginal.

How parametric modeling is involved in architectural conception process? How architects can be trained to parametric modeling and visual programming language? These two issues must be clarified.

In order to address these questions, we search to identify the characteristics of the cognitive operations of conception implied in the uses of parametric modeling in architectural conception. We interrogate here architectural "conception" that we define as the cognitive aspect of design activity.

This paper presents: the research methods employed, the results achieved and propositions for didactic tools.

METHODOLOGY

Context of the research

Analysis of design practices in architectural contexts (our as well as Kolarevic, Picon or Lindsey ones (Kolarevic, 2005; Lindsey, 2001; Picon, 2010)) shows that parametric modeling is linked to various computer assisted tasks: complex form finding and representation, evaluation, optimization, fabrication, communication, collaboration, etc. We observed

that most often parametric modeling actors are not the architects who conceive the projects. Parametric modeling requires expert skills and knowledge that most architects have not yet mastered. How architects could be assisted for parametric modeling during the conception process and how they could be trained are thus crucial questions.

Different studies interrogate the role of parametric modeling in architectural design (Woodbury, 2010; Davis et al., 2011; Chein and Yeh, 2012). The laboratory MAP-maacc interrogates the uses of parametric modeling in architectural conception thanks to a cognitive approach. This paper synthesizes researches carried out in the context of a PhD in this laboratory. The purposes of these researches were to describe the use of parametric modeling in the architectural sector in order to identify the cognitive operations of conception involved. This knowledge on the cognitive operations of conception allows developing methods and didactics tools.

Corpus

In order to identify cognitive operations of conception implied in the uses of parametric modeling in architectural conception, observations and interviews were performed. We have analyzed conception practices carried out: in professional contexts (at Foster and Partners, Hugh Dutton Architectes and Ateliers Jean Nouvel among others); and in design studios of schools of architecture at Vienne (at the Universitat die Angewandte) and Paris (at the Ecole Nationale supérieure de Paris Malaquais, Ecole Nationale Supérieure d'Architecture de la Ville et des Territoires among others).

Methodology

In the cognitive science field, very few approaches interrogate the conception and especially the transformation of the conceived artifacts (conception is mostly interrogated as activity). Architecturology is a scientific field of research on Architecture that allows it (Boudon et al., 2000). This research field provides a scientific language for describing cognitive operations of architectural conception by which giving measurements to an artifact. These operations are described in terms of *dimensions*, *references* and *relevances*. *Dimensions* refer to the measurement supports, i.e. to what the measurement is given. *References* refer to the viewpoint from which measurement is given. *Relevances* refer to how measurement is given. The *dimensioning* operation is an elementary operation of conception that consists in linking a *dimension* to a *reference* through a *relevance* (Boudon et al., 2000, p.154).

From these architecturological concepts, we have analyzed our corpus and identified several cognitive operations of conception by using the method of Applied Architecturology developed by Lecourtois (2011).

MAIN COGNITIVE OPERATION IDENTIFIED

Distinction between parametric model conception and architectural conception

Before presenting our architecturalogical research methods, we need to explain how we proposed to interrogated the use of parametric modeling in architectural conception. We didn't interrogate parametric modeling as assistance for a design, but as a conception activity in itself. We proposed to use the architecturalogical apparel to interrogate the architectural conception as well as the conception of parametric model. Does the conception of parametric model can be distinguished of the architectural conception? How these two conception process exchange or influence each other? These are the issues we interrogated in this research.

Elementary operations of conception

Our analysis shows that the elementary operations of conception built by architecturology can describe the conception of a parametric model. "Slicing", "referencing" and "dimensioning" are operations allowing the description of the conception of parametric models as activity of attribution of measurements.

The "slicing" operation is the activity led by someone when he decides to conceive a specific

part of an object. For example, when a conceiver decides to model a grid of circles and to drive the diameter of the circles thanks to their proximity to a specific point, he mentally does a "slicing" that focuses the attribution of measurement on the diameters of the circles.

The "dimensioning" is the operation by which a conceiver gives a measure to an object thanks to an activity linking a relevance and a dimension. For example, in the precedent case of the grid of circles, when the conceiver decides to measure the circles thanks to their distance to a point, he is doing a "dimensioning". We have developed more specifically this operation in a previous article (de Boissieu et al., 2011).

The "referencing" operation is implemented by a conceiver when he chooses a context or a family of relevancies to attribute measures. For example, still in the case of the grid of circles, if the conceiver decides to link the measure of the circles in an exact equality with the distance of each circle to the specific point, then he sets up the attribution of measurement in a specific mental world (a geometric one) which proceeds from "referencing".

If the analysis shows that these elementary operations of conception are useful to interrogate parametric models conception, the analysis also shows where the uses of parametric modelling in architectural conception overflow these elementary operations of conception.

A case of conception described thanks to the "elementary operations" of conception

Let's take a specific example from a student's work, in purpose to describe the cognitive operations that can be observed. The project "Topographies" has been developed by Aurea Rodriguez, Pablo Gancedo, Samya Pelloquin and Mathias Saboya in the course "Architecture Paramétrique" led by Nadir Tazdait and Francesco Cingolani in 2012 at the Ecole Nationale Supérieure d'Architecture Ville et Territoire. This project is an urban installation in the Parisian suburb "Cité des 3000". A topography is created to animate the public space and to allow different uses: parking, circulation, playing ground, sitting place, etc. (Figure 1).

In the parametric model developed in this project a surface is used as a reference to create a grid of points (Figure 2). Each of these points is moved in the Z direction in function of its distance to a set of curves. The more the points of the grid are closed to one curve of the set, smaller is the Z translation. All the Z translations are bounded by a maximum and a minimum values defined by the students.

The surface on which the point's grid is created corresponds to the easement of the public parking on which the "topography" is supposed to lean. The set of curves that controls the Z translations represents the main circulations ways and some parking places. The minimum Z translation value is zero to allow an easy access from the "topography" to the street. The maximum Z translation value is defined not to mask the view from the first floor apartments of the surrounding buildings.

// the "dimensioning" of the original grid points

- within an architectural conception:
  When the students have decided to conceive their topography on the parking easement, they have done a "slicing" operation linked with a "dimensioning" one: the measure of the "topography" fit with the existent public space.
- within the conception of a parametric model :
  It is also observed in the conception of the parametric model: to dimension the grid of point in Grasshopper (Figure 2) a surface on Rhinoceros is used as an easement for code.

// the "dimensioning" of the Z translations

- within an architectural conception:
  The students conceive the "topography" project to allow different uses such as : circulation, playing ground, parking spaces: the topography of the project is dimensioned from the wanted functionalities of the project. For that, the slopes of the topography are conceived to: allow an easy walk, separate a parking place from a playing ground zone, etc.
- within the conception of a parametric model :

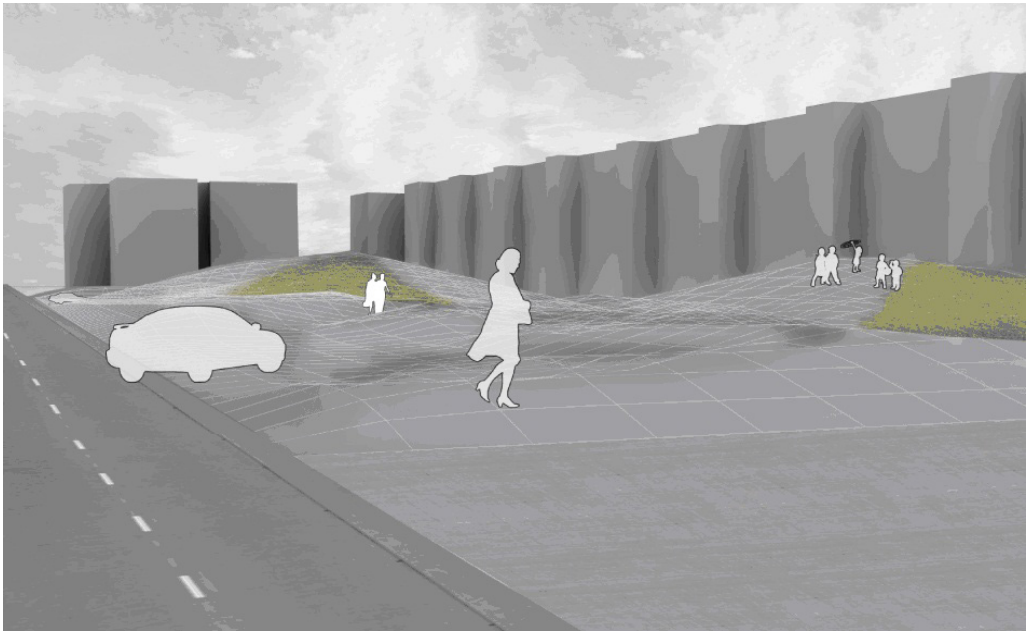


Figure 1
« Topographies » picture of the project from the students Aurea Rodriguez, Pablo Gancedo, Samya Pelloquin and Mathias Saboya (Ecole Nationale Supérieure d'Architecture de la Ville et des Territoires, Nadir Tazdait, 2012).

The Z translations of the grid points are linked to a set of curves. The curves are linked to the main ways observed in the existing public place and to the wanted parking places. The Z altitude of each point is dimensioned to be close to zero in proximity of a set of curves.

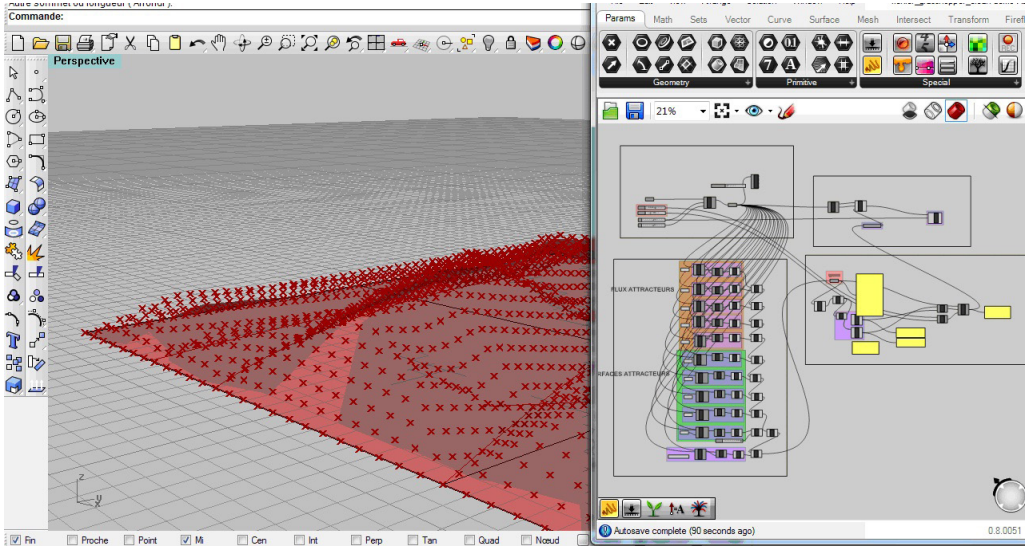
In these different operations we can observe that we can distinguish operations of conception of parametric model and operations of architectural conception. But we can also observe that these distinctions show how intricate and porous they are. The links and exchanges built between these two kinds of activity (conceiving the architecture and conceiving a parametric model) are interrogated in our research in terms of third operations: the "pragmatic operations".

Not an operation of architectural conception either an operation of parametric model conception …

"Pragmatic operation": In her research, Samia Ben Rajeb had identified some operations implied in collaborative conception that not give directly measurement to an object. She formalized these operations as "pragmatic" one (Ben Rajeb, 2012, p.281). The following operations that seem to be implicated in the uses of parametric modelling in architectural conception are kind of pragmatic operations.

Operations of collaboration: In our analysis, we observed the occurrence of two *pragmatic operations* identified by Ben Rajeb: the operation of "**pooling**" and the operation of "**interpretation**". The "pooling" operation is an operation by which collaborators with different point of view and different expertises, share information in purpose to attribute measurements to an object (Ben Rajeb, 2012 p.286). This operation operates in the use of parametric modelling in architectural conception when different collaborators (for example architects and model manager or parametric design experts, etc) share knowledge about the projects (the architectural intentions, the necessity or potentiality of a paramet-

Figure 2
« Topographies » picture of the parametric model.



ric modeller, etc) to link the architectural conception and the parametric model conception. The "pooling" is an operation by which a conceiver translate and negotiate his meaning in purpose to communicate it for a collaborator.

The operation of "**interpretation**" is an operation by which a conceiver gives a personal meaning to their collaborators discourse and information (Ben Rajeb, 2012 p.285). It operates for example when an expert of parametric modelling interprets the discourse on architectural intention in purpose to define constraints or parameters of a parametric model. The "interpretation" is an operation by which a conceiver gives a personal meaning to information shared by a collaborator.

Pooling and **interpretation** are operations aim at building some "référenciel opératif commun" (de Terssac and Chabaud, 1990) that we can observe in shared relevancies and references.

Elaboration of cognitive representation of the tools: From the case analysis, an operation of elaboration of cognitive representation of the tools can be identified. These representations are based on interpretations of a specific tool (its potentiality, difficulty, etc.). It operates in parametric modelling among other when an architect builds an understanding of the potentiality of the modeller to propose a specific way to conceive a space. It can be observed for example in the imaginary built by Frank O. Gehry about the parametric modeler CATIA (Lindsey, 2001).

Operation of translation in parametric geometry: The **translation in parametric geometry** is a pragmatic operation specifically observed in the uses of parametric modelling in architectural conception. By this operation, a conceiver shift from one system to another (from an architectural system to a geometric and parametric one and reverse). For example, in the case "Topography" previously described, we can observe a translation from an architectural relevance "answer with different slopes to the wanted uses" to a relevance for the parametric model "directly associate the Z positions of the grid points to a set of curves that position in the space the wanted uses".

Hugh Whitehead and some of the actors of the SMG and ARD teams at Foster and Partners talk about such an activity of "interpretation" (Whitehead, 2009; Freiberger, 2010). We use the term "trans-

late" in this research because if interpretation is needed (as giving a personal meaning [2]) it seems that this last activity implies to transpose from one system to another one [3].

These different operations show that if activities of architectural conception and activities of parametric model conception can be distinguished for the analysis, they are also porous and intricate thanks to different third operations. These operations are, to some extent, already proposed by architecturology such as operation of collaboration (with the operations of "pooling" and "interpretation") and the interpretation of the conceiver about the tool. But there is also specific operation to the uses of parametric modelling in architectural conception: the transposition of relevance or reference from a system to another one (the operation of translation in parametric geometry).

Logical operations and knowledge

Logical operations: Logical operations of induction and verification can also be observed in the uses of parametric modelling in architectural conception. Some induction operations appear when a conceiver establishes few cases of his object to then induce some rules or a system able to define these different cases. An operation of verification appears when a conceiver tests his parametric model in different particular cases. By induction, the conceiver thinks from the instances to the parametric model. In verification, the conceiver thinks from the parametric model to the instance.

Knowledge for parametric modelling in architectural conception: The elementary operations of conception as well as the pragmatic operations described need some specific knowledge to be implemented. The analysis of the different operations helps us to define this needed knowledge. As part of this knowledge we can list among others: architectural knowledge; geometric and mathematical knowledge; knowledge in computer science and more precisely propagation based system (Aish and Woodbury, 2005; Woodbury, 2010).

TOWARD PEDAGOGICAL TOOLS

The results of the research presented above, led us to propose didactics tools for assisting architects to parametric design. These didactic tools are: accurate pedagogical objectives for parametric modeling training and training resources.

General training objectives

Parametric modelers are constantly updated: new versions are regularly proposed as well as new plug-in. Furthermore, research is active in this field: new explorations are regularly published. Practices of parametric modeling seem to be in a demanding situation: fundamental knowledge is needed (as we formalized above), as well as a continuous update of the knowledge and practice of the field.

To answer to this specificity, a training of parametric modeling in architectural conception should focus on :

- fundamental knowledge,
- learning abilities in this specific field,
- relevant didactic tools that can be used to improve specific issues even when the training is over.

General skills that training in parametric modeling should aim to develop are:

- abstraction (logical and geometrical);
- organization and anticipation;
- participation to a community of amateurs, a network linked to the students interest, work as a team;
- curiosity, self-motivated.

Pedagogical objectives

Thanks to the results previously built on cognitive operations implied, we can also define specific requested behavior and know-how that are, for the moment, specifics to parametric modeling experienced experts. As Hugh Whitehead says « *I think the changes are more about attitudes than about technology and that comes with experience* » (Whitehead in Kocaturk and Medjdoub, 2011, p.238).

For each cognitive operation previously identified in the use of parametric modeling in architec-

Table 1
Pedagogical objectives linked to cognitive operations.

To implement these operations:	**A learner should be able to :**
slicing operation	Decompose an intention of parametric model in terms of logical and geometrical chain of dependencies
dimensioning operation	Decompose an intention of parametric model with proper and specific relevancies, especially linked to his architectural intentions
logical operation of **verification**	Test the viability of his parametric model in extremum instances of his solutions domain
logical operation of **induction**	Define general rules from particular sketches
operation of **translation in parametric geometry**	Interpret an intention in terms of propagation systems, hierarchy of the dependencies and geometrical constraints
operations of **collaboration** (**interpretation** and **pooling**)	Give a personal meaning to a collaborator discourses, find information specific to a new problem

tural conception, we can propose some pedagogical objectives (Table 1).

Didactics resources

We defined then a pedagogical framework of web resources that architects can exploit during design process and for training. This framework includes a general knowledge support and a specific knowledge support for the visual programming language Grasshopper. The general knowledge support [2] provides resources on geometry, computer graphics and more broadly on applications of computer sciences to architectural design.

The Grasshopper resources are gathered into a library of samples presented with images of possible produced shapes, a describing text with keywords and obviously the corresponding *.ghx code [4]. This library is proposed as mediation for the use of Woodbury's patterns (Woodbury, 2010) by non-expert in parametric modeling.

CONCLUSION

This paper presents some of the main result we obtain on the identification of cognitive operations implied in the uses of parametric modeling in architectural conception. We have interrogated parametric modeling as an activity of conception in itself (conception of parametric models). Our analysis shows that elementary operations of conception proposed by architecturology (*slicing, dimensioning, referencing*) are accurate to describe the conception of parametric models. We identify as well some porosity between conception of parametric modeling and architectural conception. These porosities are allowed by third operations: operations of collaboration (*interpretation* and *pooling*), an elaboration of a cognitive representation of tools and a specific operation of parametric modeling (*translation in parametric modeling*).

Thanks to the identification of these characteristics of the uses of parametric modeling in architectural conception, we proposed accurate: -general training objectives, -pedagogical objectives and -didactics resources.

REFERENCES

Aish, R and Woodbury, R 2005. 'Multi-level Interaction in Parametric Design'. In *Proceeding Smart Graphics, Lecture Notes in Computer Science*. Springer, Berlin.

Ben Rajeb, S 2012. *Modélisation de la collaboration distante dans les pratiques de conception architecturale : Caractérisation des opérations cognitives en conception collaborative instrumentée*. PhD Thesis, Ecole d'Architecture de Paris la Villette, Paris.

Boudon, Ph Deshayes, Ph Pousin, F and Schatz, F 2000. *Enseigner la conception architecturale, cours*

d'architecturologie. Paris, Editions de la Villette.

Chein, S and Yeh, Y 2012, 'On creativity and Parametric Design', *Proceedings of 30th eCAADe conference*, Prague.

Davis, D Burry, J and Burry, M 2011. 'Untangling Parametric Schemata : Enhancing Collaboration through Modular Programming'. *Designing Together*, CAAD Futures. Lièges, Belgique.

de Boissieu, A Guéna, F and Lecourtois, C 2011. 'Operation of parametric modelling and/or operation of architectural conception ? Expressing relationships in parametric modelling'. In *Proceeding 29th eCAADe*. Ljubljana.

De Terssac, G and Chabaud, C 1990. 'Référentiel opératif commun et fiabilité'. In *Les facteurs humains de la fiabilité dans les systè mes complexes*. Toulouse.

Freiberger, M 2007. 'Perfect buildings: the maths of modern architecture'. In *plus.maths.org*. available at : http://plus.maths.org/

Kocaturk, T and Medjdoub, B 2011. *Distributed Intelligence in Design*, Wiley-Blackwell, London.

Kolarevic, B 2005. *Architecture in the Digital Age: Design And Manufacturing New*, Taylor & Francis Ltd, London.

Lecourtois, C 2011. 'Architecturological and epistemological research on collaborative design', in *International Journal of Design Sciences and Technology*, Volume 18 Number 1, Europia productions, p. 31-46, Paris.

Lindsey, B 2001. *Digital Gehry*, Birkhäuser, Basel.

Picon, A 2010. *Culture numérique et architecture, Une Introduction*, Birkhauser, Paris.

Whitehead, H 2009. Interview with Aurélie de Boissieu. Delft (not published)

Woodbury, R 2010, *Elements of Parametric Design*, Routledge.

[1] www.grasshopper3d.com
[2] cnrtl.fr/definition/interpretation
[3] cnrtl.fr/definition/traduction
[4] dnarchi.fr
[5] www.parametric-ressources.com