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Computing architectural composition from the semantics of the »Vocabulaire de l'architecture«

Abstract

Until a recent date, the scientific research was reticent to face the problems posed by the de-sign (creation) of sensuous forms; and indeed, everything indicates that the difficulties neces-sary to surmount in order to describe those processes are considerable. In the immense field of investigation, the thread that we propose to follow in order to penetrate into the mental uni-verse of the designer is the one of language. Furthermore: since our long term objective is more specific to comprehend the genesis of architectural forms, we are particularly interested in the means that language offers to express the space concepts that are requested from that point of view.

Bis vor kurzem war die wissenschaftliche Forschung zurückhaltend damit, Probleme, die sich durch Schöpfung und Design sinnlicher Formen stellen, zu bearbeiten. In der Tat weist alles darauf hin, dass die Schwierigkeiten, die zur Beschreibung solcher Prozesse zu überwinden-den sind, beachtlich sein werden. Den roten Faden, den wir innerhalb des gewaltigen Unter-suchungsfeldes zu verfolgen beabsichtigen, um in das geistige Universum des Designers ein-zudringen, liefert uns die Sprache. Da unser langfristiges Ziel spezieller darin besteht, die Genese der Formen der Architektur zu verstehen, sind wir zudem im Besonderen an den Mit-teln interessiert, die uns die Sprache anbietet, um die für eine solche Persepektive erforderli-chen Raumbegriffe zum Ausdruck zu bringen.

1. From the language analysis to the mental universe of the designer

Until a recent date, the scientific research was reticent to face the problems posed by the de-sign (creation) of sensory forms (Borillo & Sauvageot 1996); and indeed, everything indicates that the difficulties necessary to surmount in order to describe those processes are considera-ble as they will probably request not only the whole of the experimental cognitive disciplines, from psychology (for the exploration of the mental sphere) to neurosciences (would this be only for the sensori-motor components of the processes), but also their necessary formal, ma-thematical, logical and computational complements, without which there would be possible neither theorizations nor simulations. To tell the truth, the actual problems can only be posed after having operated a whole of adequate restrictions on a universe of such a complexity. In this immense field of investigation, the thread that we propose to follow here in order to pene-trate into the mental universe of the designer is the one of language (Jackendoff 1992). Fur-thermore: since our objective in the long term is, more specifically, to comprehend the genesis of architectural forms, we are more particularly interested in the means that language offers to express the space concepts that are requested from that point of view.

To define a »strategy of access to the mental universe of the designer by the analysis of the language …« is to assign to the latter the two functions:

- First, the analysis of language is conceived of as a medium giving access to certain characteristic mental processes involved in architectural design.
- In addition, insofar as the significance of the expressions in language can be represented formally, it could be possible to define and formalize in logico-mathematical terms the semantics of expressions of the architect‘s language.

Starting from these representations, it becomes possible to simulate, by ›qualitative spatial reasoning‹, some processes of design expressed in the architect’s language.

Our linguistic source of knowledge associated to the architectural elements and their composition is the classical *Vocabulaire de l’architecture* by Pérouse de Montclos (Pérouse de Montclos 1972).

2. A formal semantics of the vocabulary of architecture

2.1. Some principles of architectural design and composition

The principles of architectural composition are based on a set of very particular concepts that are revealed by the analysis of the terminological vocabulary of the elements of architecture (Goulette 1997). Among these concepts, one finds mainly:

- *whole/part relations* (known as meronomic relations): the purpose of the composition process is to gather in a unit a set of distinct components. The components are ›parts‹ of a ›homogeneous‹ whole.
- *cognitive spatial relations*: the spatial relations between objects, such as they arise from the interpretation of the language, exceed the framework of the traditional geometry. As a matter of fact, these relations have to express topological and qualitative information able to make exactly those distinctions necessary for expressing a relative arrangement of the values. Examples in ordinary language are given by the analysis of spatial preposition like *on* (the glass in on the table), *at* (the box is at the bottom of the wall), (Aurnague, Borillo et al. 1991). These relations do not exactly determine the complete geometry of the ob-jects. Only the relevant characteristics of the objects and the relations between them are involved. Their essential function is to induce a structural similarity between the represen-tations and the world represented.
- *models of composition*: they are regular descriptions of architectural compositions (i. e. spatial configurations of architectural elements). These regular descriptions implement rules controlling the relative positions and dimensions of a set of elements that make up an architectural entity such as defined in the vocabulary of architecture: from the elements to their composition.

Starting from the definition of a formal semantics of the elements of the vocabulary, we represent the spatial relations and the principles of composition that arise from the analysis of this specific vocabulary. This first step allows us to compute a process of composition.

We will try to test our basic assumption by the analysis of an architectural entity: *la baie – the bay.*[1] In the vocabulary, the bay is a generic term, which indicates the various types of open-ings, with various functions, that bear into the walls of our buildings. To study this architec-tural element, we refer to the *Vocabulaire de l'architecture* by analyzing the terminological descriptions it gives of this architectural object.

A conceptual analysis leads us to consider each architectural ›object‹, indicated by a term of the vocabulary, as the association of three meanings, distinct but interdependent: we name them the *architectural element*, its *spatial referent*, and its *geometrical representation*. The meanings of each component must be considered in the context of the role played by those elements in the composition process.

- *The architectural element* belongs above all to the field of the mental representation: it is a cognitive object, an object to think and conceive of a project of architecture, or to describe a building. Its essential characteristic is to be able to be named, to be indicated by a term that is associated to functional and geometrical characteristics (role, arrangement, proportion, morphology …) as we shall see later.
- The *spatial referent* of an architectural element is a ›qualitative‹ object. It results from the proper spatial characteristics (topological and geometrical) of the architectural

1 Thus, we actually relate in the following on the concept expressed by the French architectural term »la baie« as explained in the »Vocabulaire de l'architecture«, and use English expressions merely to simplify reading this text.

element. But it is important to notice that its characteristics specify only the ›distinctions necessary‹ to the correct classification and localization of the element.

- The *geometrical descriptions* of the spatial referents express the differential features and not the absolute or quantitative criteria. It is not a question of a volumetric specification that would prohibit any variation, but rather of distinctions that make it possible for a character to be recognized as such, while leaving free course to a creative interpretation.

At this point, it is important to recall that the theoretical framework of this study falls under a computational conception of cognition. That requires that we formally define the semantics of the components of our example, the bay. We exemplify one of those elements further, so as to illustrate our methodology. These definitions are based on the particular semantics of the me-ronomic relations (part-whole) and those of the functions associated with the spatial entities.

2.2. The bay and some of its components. A formal language to describe them, from the point of view of their composition

It is now a question of representing the definition of the architectural elements concerned in the terms of a formal language in a way that allows us to express their significant characteris-tics in the perspective of their potential compositions. Thus, the bay bears into a ›wall‹ (fr.: mur; itself pertaining to a ›building‹ (bâti)), and it has a single ›base‹ (assise), a single ›struc-ture‹ and a single ›embrasure‹. It is an architectural element (formally: Elt-archi) whose inter-pretation can be made at various levels (n), as a component (architectural element) or as a composed structure: In that second case we define:

$$\text{Bay}(b, m, n) \equiv_{def} \exists\, \text{building Wall}(m, \text{building}) \wedge \text{Elt-archi}(b, n) \wedge \exists!\, a, s, e\, [\text{Base}(a, b, n) \wedge \text{Structure}(s, b, n) \wedge \text{Embrasure}(e, b, n)]$$

There are about fifty components contributing to the determination of bay. Here is the definition of one of them: »the embrasure is an architectural element; it corresponds to the opening made in a wall and is an integral part of a bay for which it has a utility role; it is delimited by some of the other elements of the bay«.

The formal expression of the definition of »embrasure« includes some of our architectural knowledge of this element. It is given below:

$$\begin{aligned}\text{Embrasure}(x, b, n) \equiv_{def}\ & \text{Elt-archi}(x, n) \wedge \text{Empty}(x) \wedge \exists\, m\, [\text{Bay}(b, m, n) \wedge \text{Pierced}(x, m) \wedge \\ & \text{Total-In}(x, b) \wedge \text{Function}(x, b, \text{utility}) \wedge \\ & \exists\, a\, [\text{Base}(a, b, n) \wedge \text{Limit-below}(a, x)] \wedge \\ & \forall\, c, s\, [(\text{Cover}(c, b, n) \wedge \text{Soffit}(s, c, n)) \Rightarrow \text{Limit-above}(s, x)] \wedge \\ & \forall\, c, i\, [(\text{Covert}(c, b, n) \wedge \text{Intrados}(i, c, n)) \Rightarrow \text{Limit-above}(i, x)] \wedge \\ & \forall\, p, t\, [(\text{Pier}(p, b, n) \wedge \text{Panel}(t, p, n)) \Rightarrow \text{Limit-Side}(t, x)] \wedge \\ & \forall\, p, e\, [(\text{Pier}(p, b, n) \wedge \text{Ebrasement}(e, p, n)) \Rightarrow \text{Limit-Side}(e, x)]\end{aligned}$$

It's very important to point out that some of the spatial relations that are included in the definition of the elements of architecture as »to limit, to delimit, to support, to cover…« have to be interpreted in a specific way in the context of the vocabulary of architecture. Consequently, they have a quite particular semantics, different of their use in ordinary language.

2.2.1. A topology for the cognitive space of the architect

The geometry implemented in descriptions of elements and compositions of architecture is a complex and original geometry. Indeed, these descriptions do not refer to an absolute and ortho-normal space: it is rather about a space of perception and experiment, a cognitive space of which the structure rests mainly on the functional aspects and symbolic systems of the de-scribed objects, and also on the point of view of the actor/speaker, which is here the point of view of the objects‹ composition. With regard to the particular case of the vocabulary of ar-chitecture, that space has two major characteristics, the taking into account of which is essen-tial to express the most significant properties of architectural space: *delimitation* and *relative positioning.*

These characteristics do not agree with the principles of a traditional topology or a geometry, as traditional topology does not grant an explicit place to the border of the objects, and the relations of geometry are at the same time too precise and too general to be able to apply di-rectly. To study and specify the mechanisms of this particular spatial reasoning, we take as a starting point the ›alternative‹ representations of space proposed in work raising mainly of the study of formal semantics of the expression of space in the natural language, work that aims at defining principles of reasoning on these particular representations.[2]

We are thus brought to base our topology (which is a mereotopology) on two independent primitives, the relation of »*part of*« (to be part of a whole) and the relation of »*border of*« (to be the border of an object). From a mathematical point of view, the axiomatic system that we have defined then makes it possible to structure the following eight relations of which we have showed that they constitute a complete set of mutually exclusive relations:[3]

- DC disconnected
- EC externally connected
- PO partial overlap
- TPP tangential proper part
- NTPP non-tangential proper part
- EQ equals
- NTTPi opposite of NTTP
- TPPi opposite of TPP

2 See in particular: (Aurnague, Borillo et al. 1991), (Borillo 1991), (Aurnague et Vieu 1993), (Asher & Vieu 1995), (Borillo & Pensec 1996), (Goulette 1997), (Vieu 1997), (Goulette 1999), (Borillo & Goulette 2002), (Borillo & Goulette 2005).

3 This structure is named Rcc-8 in » Randell, D. A., Cui, Z and Cohn, A. G. 1992. « »A space logic based on areas and connection« in Proceedings of KR‘ 92, Knowledge Representation and Reasoning, Los Violas, Morgan Kaufmann, pp 394-398. However, those relations are here defined in an original axiomatic system that respects the constraints of the qualitative space of the architectural composition.

2.2.2. A geometry for the cognitive space of the architect

In this geometry, we find the basic concepts of *part* and *border*, but now associated with me-chanisms of orientation and provision that make it possible to qualitatively define the mor-phology of the elements and the spatial organization of their compositions. Intuitively, it is a question of representing three principles of definition of the limit of a volume in a given di-rection. These three principles rest on relations of: *geometrical part, geometrical delimitation*, and *geometrical border*.

2.2.3. A meronomy for the cognitive space of the architect

Our analysis leads us to identify four types of meronomies between elements of architecture. Their short abstract definition is given here:

- *Piece/Whole:* this relation applies to an element of which the space referent is a piece of volume. It cannot thus be dissociated from a sound whole.
- *Member/Collection:* we indicate by this relation the membership of an element to a whole set of elements that is the reference of a term of the vocabulary.
- *Sub-Collection/Collection:* it is about a collection included in another collection.
- *Component/Assembly*: the component has a role (›Constructive‹, ›Utility‹ or ›Plastic‹) compared to the whole.

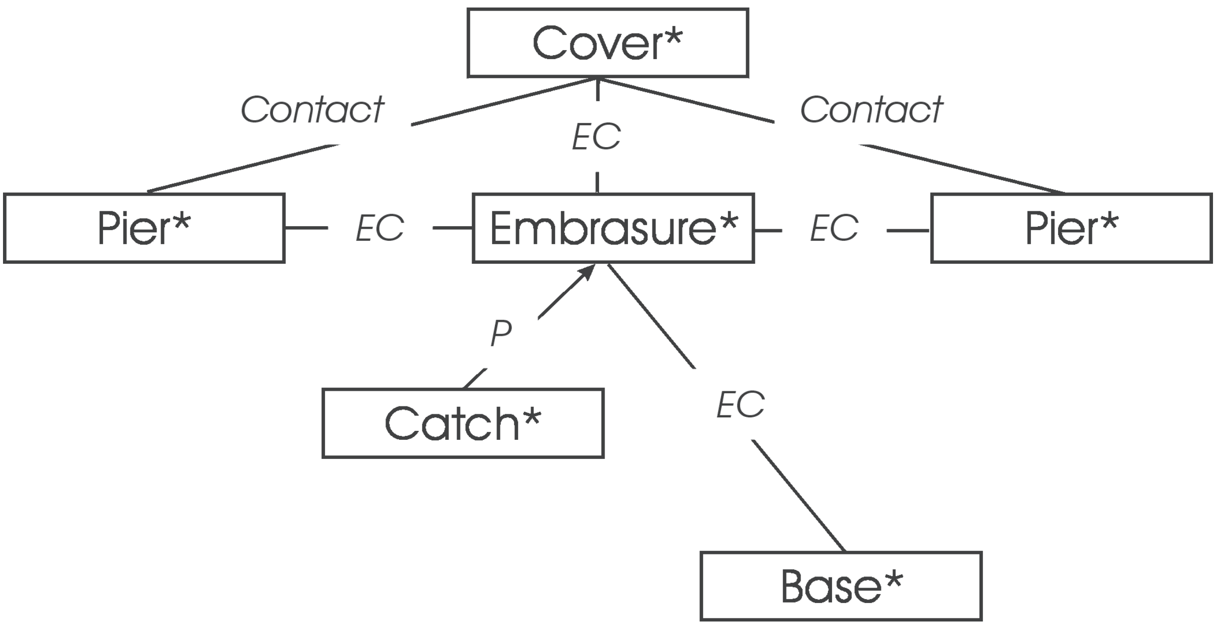

Fig. 1: Mereotopological relations between the spatial referents (marked by '') of the elements of 'bay'*

P: part of;

EC: externally connected;

Contact:contiguity without border sharing

These relations are defined on the basis of an axiomatic system that supplements those of topology and geometry.

The topological, geometrical and meronomic relations (and their combinations within the formal language thus defined) make it possible to represent more complex relations between elements, these relations ›being anchored‹ in the vocabulary of architecture. One can thus formally define ›To crown‹ (›To form the horizontal ridge or the pyramidal top of a rise or part of rise‹), ›To be aligned with‹, ›To be recessed‹, ›To limit‹, ›To delimit‹, ›To decrease‹, etc. One sees how much this type of relations describes qualitatively and functionally the objects of the architectural composition. The graph below expresses the mereotopological organization characteristic for the essential elements of the bay:

3. Representing some principles of the process of architectural composition

3.1. The fruitful ambiguity of the linguistic description of compositions

The term of ›composition‹ is ambiguous. It can indicate the process by which the components of a more complex structure are associated and located in space. But this term, ›composition‹, can also refer to the spatial entity that results the process of composition. In this second mean-ing (the spatial entity), the reference of this term must present a unified aspect, in the sense that its reference constitutes one element of the architectural universe.

3.2. To compose compositions: levels of interpretation

Under some conditions, some associations of bays can, in the vocabulary of architecture, be named a bay, as well. That means that a bay can be composed of several bays. The description of the components of a bay reflects, in language, the diversity of the levels of interpretation that can be associated to an architectural object. A component can then receive various deno-minations according to the level of interpretation adopted.

The possibility of variation in interpretation has as its consequence that the same object can be classified, according to the adopted level of interpretation, in various terminological categories of architectural entities. This leads us to define two distinct levels for the interpretation of the terms being used to refer to the elements of architecture: the *Neutral* level and the *Composition* level. The transition from the first level to the second one reveals the process of compo-sition, which we seek to describe.

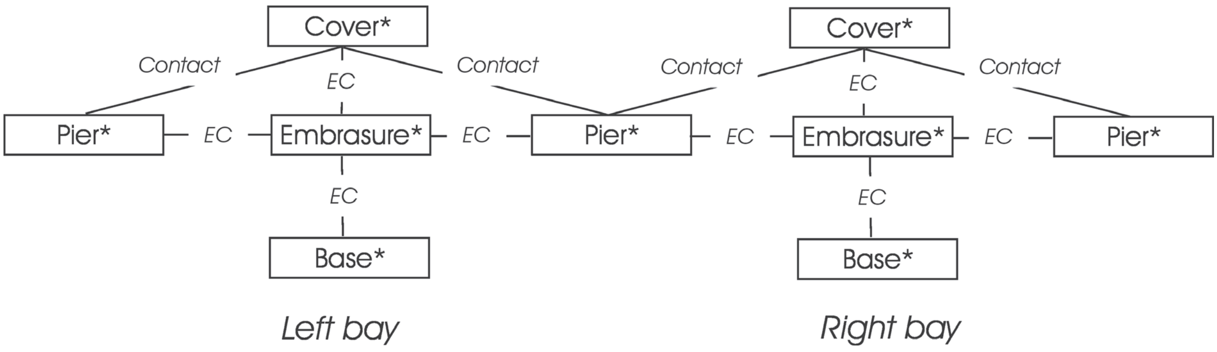

Fig. 2: Mereotopological graph of 'semi-detached bay' (level of interpretation: Neutral)

3.3. Elements for the formal description of a process of composition

We have defined the formal procedures for the treatment of compositions of bays, starting from the semantics of the elements that constitute them. We here illustrate very briefly the kind of computations that are carried out on the formal representations of the architectural entities. Theses computations allow the transition, in our example, from ›semi-detached bays‹ (›baies jumelées‹; Fig. 2) to ›compound bay‹ (›baie composée‹; Fig. 3).

The followings remarks can help to understand the method. Of course, the operations we evoke here in graphic form are carried out by computations operating on the formal definition of the various elements:

a) The ›semi-detached bays‹ consist of simple bays sharing one of their ›piers‹ (piédroits). Consequently, the graph of Figure 2 consists in the composition of two graphs isomorph-ous to Figure 1 by sharing the space referent of one ›pier‹.

b) To interpret ›semi-detached bays‹ as a composition, i.e., as a single element named ›compound bay‹, it is necessary ›to reduce‹ the structure of the graph of Figure 2 to the struc-ture of the graph of Figure 1.

c) This ›reduction‹ of one graph to the other one results in the graph of Figure 3 (which is isomorphous with that of Figure1 insofar as Figure 3 represents one unique ›compound bay‹).

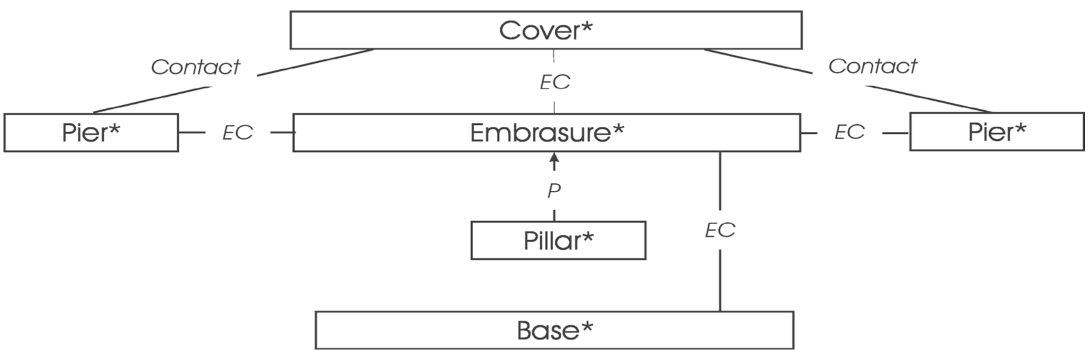

Fig. 3: Mereotopological graph of 'compound bay' (level of interpretation: Composition)

d) We illustrate the operations constitutive of this ›reduction‹ by the computation of the spatial referent of the ›embrasure‹ of ›compound bay‹. This spatial referent is defined in me-reotopological terms by the fusion of the spatial referents of the two ›embrasures‹ and the ›piers‹ of ›semi-detached bays‹. We have here an example of the consequence of the change in levels of interpretation (from *Neutral* to *Composition*). It will be noted that in this interpretation, the spatial referent of the ›pier‹ of ›semi-detached bays‹ is included in the spatial referent of the ›embrasure‹ of ›compound bay‹. Being included in the spatial re-ferent of an ›embrasure‹, it cannot still be associated to a ›pier‹ in that new level of inter-pretation: it must be associated to an element of ›catch‹ (cf. Fig.1), a ›pillar‹ (›pilier‹).

4. So many problems in prospect…

In the framework of an activity like the architectural design, the technical language specific to that activity has accumulated and expresses a whole set of relevant knowledge. The systemat-ic and rigorous analysis of the information conveyed by this language allows us to reveal at least part of this knowledge. As a consequence, the analysis of this technical language can be considered as a way to access some of the mental processes that are involved in architectural composition. This is our basic cognitive assumption.

But, rooted in some linguistic and logical developments, the philosophical research has opened the way to the definition of a formal semantics of natural language. Applied to the vocabulary of architecture, these developments enable us to represent in a formal language a significant part of the architectural knowledge involved in architectural design. At a theoretical level, these representations permit us to compute some architectural compositions described in the *Vocabulaire de l'architecture.*

The conjunction of those two fundamental assumptions allows us to define a rigorous metho-do-logy for the description – and in some respect, for the computer simulation – of the archi-tectural design.

In this conceptual and theoretical framework, the research can explore some new complementary and strongly connected axes. To give some of them:

- Extension of the actual research to the definition of new semantical structures associated to new elements and compositions.
- Association with experimental studies of *creative* behaviors based of cognitive psychology; exploration of the heuristics of the creative activity.

In fact, we think this type of investigation can be extended to other domains of artistic crea-tion where the expression of space, associated to time, has generated notational systems, i.e., choreography and von Laban notation (Fig. 4). *It may also be fertile in order to formalize the analysis of pictorial composition, in particular concerning the pictorial representation of spatial objects and the creative organization of space.*

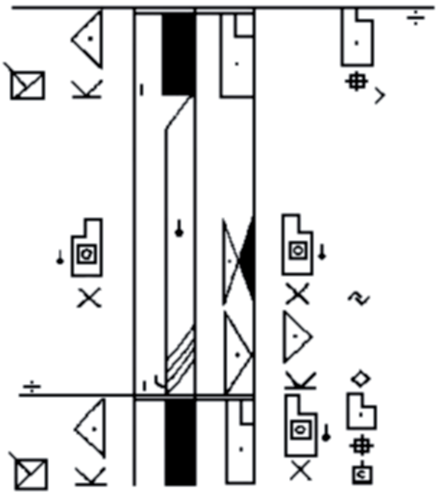

Fig. 4: A 'Fouette-en-Tournant' in Laban notation, taken from Don Herbison-Evans: 'Symmetry and Dance', Technical Report 329, Basser Department of Computer Science, University of Sydney Australia, 2003)

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