Design Process Taxonomy: Notes on Design Theories, Methods and Instruments

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This presentation argues that the concepts of "tools" and "material", in relation to it use in contemporary architectural design education, can be understood as "instruments" within design processes. The difference between them relies on, its design knowledge abstraction levels, and its mechanisms to capture, manipulate and produce design knowledge. In addition, an initial exploration of Distributed Cognition concept, in order to redefine the use of instruments in design process as Cognitive Instruments, is presented. Furthermore, a more comprehensive framework for design knowledge is presented, including a specific examination of design instruments an its role in design processes. In the conclusions possible effects derived from the use of "instruments" in design processes are explored.

I. Introduction

From its origins, building production has been characterized by an intricate relation between construction techniques (tectonics) and a specific image of the building (aesthetics). Since the renaissance the production of drawings, or design activity, has been at the center of this process, and has delineated the architect's role within the building construction process[1]. Since then drawings have been the instrument by which architects have provided the information necessary to construct buildings, and it is in drawings where building descriptions and construction information happen together. By the eighteenth-century architecture had been profoundly affected by the demands for the reorganization of knowledge[2]. The questions that confronting architecture involved not only ontological queries regarding disciplinary boundaries or the matter that constituted architecture's body of knowledge but also a growing demand for an epistemology of architecture that would allow architecture to be taught as a formal discipline.

Changing social structures reinforced such abstract questions by requiring the removal of the vestiges of past practices. This new order provoked a deep and still open incision into the body of the discipline and was clearly noticed not only in the division of the practice according to design and construction activities but also in the division of the newborn formal architectural education following the distinction of architecture as a science or as an art[3]. As a result, we saw an increase in the division between the generation of information to describe buildings and the production of information to construct them.

Traditional design has been based on a clear-cut division between the generation of information to describe artifacts followed by the provision of information to construct them. Design can be thought of as a process of composition and refinement of concepts and technologies, while construction is the decomposition of design into its producible parts and its execution processes. If the units of construction also support later analysis and decomposition for construction, then the space of construction is greatly reduced, as well as the risk of later changes. In traditional design processes, a building is considered as a system composed of subsystems (structural, spatial and functional), and designers main concern is determine spatial location, interaction and coordination between these subsystems, guided by style and aesthetics. Construction has been traditionally based in on-site raw material shaping, assembly and sub-assembly processes. But lately it is increasingly dominated by the

component-assembly model, based in on-site assembly of components manufactured off-site3.

Traditional design documentation produces detailed systems and sub-system descriptions; interaction between them is assumed to be coordinated by the designer. Component production and assembly processes are implicit until bidding and sometimes until execution. The core problem is that designers are concerned with describing and placing systems and subsystems in space, while contractors are concerned with producing components and locating assembly processes over time, better integration is needed.

2. What is Design?

Design may be defined in two different and commonly confusing ways. One definition regards the process of design or the design activity and the second views design through the product that has been designed. The following discussion concerns itself primarily around design as a process and emphasizes the misconceptions that come from studying products as exclusive source of design knowledge. We would like to argue that the core issue in design is establishing a process that builds concepts, abstractions and knowledge representations that are manifest in the tangible product. Although many have focused on the manifestation of design, in multiple cases the real purpose of design emerges as the internal insights and the discernment of an effective process. This is specially true if we think of design as an idiosyncratic process.

We propose a change from a design knowledge based on objects to a one focused on design as process. Design processes draw attention to topics as well as artifacts and pose questions about the ways they might be composed, or reformulated, analyzed and built. Through a sequence of iterative operations along the different stages of the design process -- what we may call design rationale -- artifacts are manipulated as spatial systems involving dimensions that may be thought of as movements, acts, and events. These spatial systems can be further analyzed in subsystems, through different operational conditions (technical, economical, functional, visual, morphological, geographical, etc.). Furthermore, architectural design involves an ongoing negotiation or process between multiple actors (Client, Designer, Consultants, and Surveyors). These related aspects flow together into a conception-elaboration process through which the artifact emerges. Additionally, the design process involves the transformation of concepts and in to artifacts with a high level of physical complexity. Indeed, many of the parameters required to maintain coherence in the successful design process coherence remain ignored even though they are implicit within the process itself. It is quite appropriate to think of the architectural design process as the continuous elaboration of research, a process of successive approximations in which the designer achieves numerous departures and returns between the different stages (iterative process). As we will suggest, articulation of epistemological conditions allow us to understand the design process as the progressive displacement a theoretical body (abstract) with a physical object (concrete).

3. Design Process Models:

As a result of an increasing demand for rational, predictive procedure within design practice, a host of design methodologies appeared during mid sixties[4]. In contrast to practices that appeared to many as neo-romantic appeals inspiration – really another version of black box models of design – there were multiple efforts to apply what was proclaimed to be a more scientific method that emphasized the rational and accessible but still omnipotent control of the designer. During the early seventies a second generation of methods appeared that often was taken from problem solving methods and participatory problem solving methods[5]. In the past twenty years, computational models have been added to problem solving methods[6]. Based on the visual manipulation of a represented object, a process was defined that focused on response to a sequence of restraints. More recently, we find ourselves exploring cognitive models that seek to approach design problems not only from the vantage point of the objective but from an understanding of the shared cognitive setting in which they would be used.

Several of these cognitive models have essentially been derived from the analysis of the design process and amount to articulation of micro aspects of the design process that are often black-boxed. For example, protocol analysis is the most used methodology of design process study. The analysis of design processes performed using protocols is based in two different approaches. The most common one refers to solving problem techniques developed by Simon an others. This model assumes an objective reality and defines design as an ill-defined problem in search of a rational solution. Constructionist interpretation offers a different approach by approaching the problem as truly unique and requiring in inquiry not simply into "science in action" but "reflection in action"[7].

Even though we can detect a clear evolution in design process models, most can be grouped under a sequential process paradigm. Sequential models assume design process as a sequence of stages and understand the design process as linear. Here the process resembles what in science is viewed as a Newtonian or mechanistic model[8]. At this point we can clearly identify the ongoing influence of science in design that in the broadest sense extends all the way back to the scientific revolution[9]. However, if we are even more precise, we can notice a remarkable connection not simply between architecture and science but between architecture and the philosophy of science. This relation is carefully noted by Philip Steadman[9] and others[2, 10, 11, 12]. For us, the main concern involves the active, dynamic relationship between science and architectural design. Rather than remaining fixed in obsolete models of science, design should give far more attention to research in the co-evolution of design in different fields. Indeed recent research[13, 14] – including our own -- points towards a non-linear interpretation of design processes. Designers mentally construct their view of the situation as well as the actions taken within it15. From such a perspective, we would emphasize the shift from ontological categorization to the consideration of a phenomenology of design and cognitive articulation of design experience in order to uncover underlying structures that relates one design move to other or one design alternative to another. Such aspects have been sketched by others[5, 16, 17, 18], including Suwa and Tversky who asked been interested in exploring the ways in which one phase of design establishes grounds for subsequent steps. Rather than considering the linkages between one "chunk" of design and another, we are interested in asking about the granularity of cognitive actions.

4. Design Knowledge

Design is a cognitive process that consist of consensual production of meaningful artifacts through a knowledge capture, manipulation and communication process. Design process brings up certain topics and through them artifacts are composed, decomposed, analyzed and built; those topics establish the design knowledge. Furthermore, the architectural design process is also a negotiation process between multiple actors and several related aspects flowing together into an artifact conception-elaboration process. Design process consists of the transformation of concepts and relations of high abstraction into artifacts with a high level of physical complexity. The parameters needed to guarantee design process coherence are many; while its conception mechanisms remains ignored.

Design knowledge can be classified in two classes declarative knowledge and procedural knowledge. Declarative knowledge similar to descriptive correspond to knowledge of objects and events and how these are related to other objects and events. On the other hand procedural knowledge is about tasks that must be performed to reach a particular objective or goal. It is characterized as knowing how. Procedural knowledge is often difficult to verbalize and articulate than declarative knowledge. Even accepting that design knowledge can manage and represent not only declarative knowledge but also procedural one, the use of procedural knowledge in design and in architectural theory is almost nonexistent[18]. On the contrary, and as we already revised, there is a prolonged architectural tradition in the use of declarative knowledge. This issue is very visible in research related to type based design[19] and it is evidence of one of the most striking problems in architectural theory, education and practice i.e. the preponderance of the discourse about design objects over the one concerning on design as process. The origin of this problem is rooted deep in to a dominant materialistic culture. Even though there is as increasing concern in design research about design theories, methods and instruments in architecture, this concern is gloomed by the lack of adequate taxonomies and design process models. In the other hand design research community studying design process tends to focus on the manifestation out of the process rather than in the process itself[18]. In some portion this phenomena is originated by the extensive use of knowledge taxonomies based on the Structure Function Behavior (SBF) scheme. Alternative knowledge taxonomies create schemes based on constrains, goals, and formal solutions. However research in design process point towards the idea of co-evolution in design i.e. that constrains or problem space evolve in the same way that solutions or solution space does[13]. In addition, this knowledge capture-elaboration-communication process involves different types of knowledge according to different stages in the process. at the early beginning knowledge is retrieve from previous experiences and also capture from the context The previous described situation obscure a possible understanding of design processes types or typology, and is in this point in where case based reasoning provides a stronger framework coming from the idea of considering design cases, episodes or stories as well as other design issues.

4.1 Object Knowledge

This is the most common form of declarative knowledge found in design processes. Correspond to object characteristics and properties

including material properties and is produce thoroughly the design process. Traditionally, design knowledge is produced and communicated using drawings. Drawings are just abstractions of planned artifacts and they are partial descriptions of future real objects. Architectural design process is supported by drawings belonging to three main groups:

- Paraline or axonometric projections.
- Converging line projections or perspectives.
-Diagrams.

The first two are methods based on a encoding process accepted as a drawing convention in an specific cognitive domain and both contains specific ways to describe objects. Sketches and diagrams are the most common drawings found in early design phases. Physical model are less used in architectural practice but more often found in architectural education. Probably because its use is especially relevant to design and rarely are used in construction. The most common physical model types are:

- Conceptual Models describing general spatial concepts or other abstract attributes
- Working or study models providing of alternatives or building parts visualization.
- Presentation models: Detailed model of the building

4.2 Fabrication Knowledge

Fabrication knowledge corresponds to knowledge about the different fabrication procedures used to realize or construct objects. Traditional design documentation produces detailed systems and sub-system descriptions; interaction between them is assumed to be coordinated by the designer. This knowledge it is normally assumed as implicit on traditional construction practices or in conventional constructive systems. In this way component production and assembly processes are implicit until bidding and sometimes until execution. The core problem is that designers are concerned with describing and placing systems and subsystems in space, while contractors are concerned with producing components and locating assembly processes over time.

4.3 Process Knowledge

Process knowledge relates to knowledge about the different processes used to design objects. Even though as revised previously design research community presented an increasing interest in theories of design process and design methods, this has not contributed to its use in design practice[20]. Normally the focus has been in describing sequential models of design process based on design stages along a time line i.e. according to what is produced. This is what we can call horizontal dimension of design process. What stays ignored, within those stages, are the theories, methods and instruments to produce objects or what we can call the vertical dimension I.E. how design is performed.

5. Design Environments

Design environments constitutes one fundamental concept in understanding an adequate taxonomy of design process. In fact is in the studio environment in where students acquire knowledge and expertise that later is developed in practice. Rather than approaching architecture as a discursive evolutionary practice shaped through an intricate set of theories, methods and instruments, design thinking remains under what it is known as the cognitivist approach i.e. the mind is in the brain. Formal education in architecture has been reduced to emulation practiced through apprenticeship with building masters assuming them as wells as building as models or types to imitate or instantiate from. Unfortunately this paradigm remains the dominant scenario in architectural education18. This ignores possible interaction between the designer and the design environment in what we can denominate a phenomenology of design processes. Looking at the place of theories, methods and instruments, we would like to think of ourselves as engaged in a design process involving continuous materiality[21].

5.1 Theories, Methods and Instruments

Theories are general statements that makes no reference to the specific problems or situations that they explain. Methods represent specific statements about action and organization of actions, generally based on a model or empiric knowledge[20]. Theories of design process are mostly based on two paradigms the cognitivist paradigm i.e. problem-solving process and the constructionist i.e. reflection in action[5]. Being the former the most popular in design research[5]. Mostly because the later has been not able to an adequate framework to describe how designer work.[22]

Furthermore the way in which the memory-brain relation is interpreted in both models influence fundamentally the way in which design process is understood[23]. Both approaches assume "memory" and "thinking" as processes localized in the brain and based on internal representations.

In here there are two alternative ideas, in providing alternatives to the previous assumptions, to explore from different areas of cognitive science. The first one is the concept of distributed or situated cognition[24] and the second one is considering memory as nonrepresentational[25]. Even though these concepts became important in to reformulating a possible theory of design

process, our attempt is explore the issue from the bottom up. Using concepts from the activity theory we attempt to clarify the role of design instruments in design thinking. Activity theory was originated from the work of Lev Vygotsky[26] and declare that human interaction with the world is mediated by artifacts. In addition post-cognitivist theoretical tradition in human computer interaction[27, 28, 29, 30] will provide with effective conceptualization for our hypotheses.

5.2 Distributed Cognition

The world in which we live is constituted by our perception, and it is our cognitive structure that enables us to have these perceptions. So, our world is the world that we perceive. If the reality that we perceive depends on our structure, there are as many realities as individuals. Such a position explains why what has been called "purely objective knowledge" is impossible[31]. Since the observer cannot be separated from the phenomena he or she observes, we are determined by a cognitive biological structure in which the environment can only trigger alterations shaped by the structure of the organism itself[32]. Our perception of the world leads us to understand ourselves as separate from the world that we perceive. According to Maturana[33], since we live in the field of our vision, we do not see the space of the world. Since we live in our chromatic space, we do not see the colors of the world.

If our perception constitutes only a portion of the whole, the same is true regarding our overall knowledge of the world. Maturana draws an even more challenging conclusion when he argues that that higher human functions do not take place in the brain[34]. For Maturana, language, abstract thinking, love, devotion, reflection, rationality, altruism, are not features of human physiology or the functions of the single body but social historical phenomena[35]. Instead of an emphasizing the importance of objects, they propose an additional emphasis on relations where an understanding of relations is indissoluble from process that constitutes the system[32]. Furthermore here we can affirm that design products and the cognitive process of design are intimately connected according to Varela, it is the network of interactions in its entirety that constitutes and specifies the characteristics of a particular cell, and not one of its components[33]. Distributed Cognition approach emphasizes the context distributed nature of cognitive phenomena across individuals, artifacts and external representations[29]. A main point of departure from the traditional cognitive science framework is that, at the "work setting" level of analysis, the distributed cognition approach explores how intelligent processes in human activity transcend the boundaries of the brain[36]. Consequently, instead of focusing on human activity in terms of mental processes acting upon internal representations the method seeks to apply the same cognitive concepts, but this time, to the interactions among a number of human actors and technological devices for a given activity[37].

5.3 Design Learning

Learning in children according to Vygotsky happen through interaction with others (typically adults) and with artifacts, concept found also in Piaget[37]. This is also true in design learning but not well understood in design education. Design education is mostly based on teaching approaches based on the professor as a master or role to imitate and design objects as types to imitate or instantiate. So teacher and building types became both model to instantiate from. Coming back to children along growth there is a evolution in the leaning process in where the children start his o her own learning through interaction in learning environments. This evolution can be exemplify as follow at the beginning parents are the "model" and the "judge", once in formal leaning environment children develop his or her own "personal model" that is judged by the teacher to finally as adult becoming his or her own "model" and "judge" of his or her actions in the world. This process do not happen in architectural education in where teacher keeps both roles along the educational process. What stays implicit and ignore within this process is the "learning by doing" or "thinking in action" process[18]. The problem in here is that procedural knowledge stays ignored and education is concentrated on declarative knowledge. Finally the value in learning from our actions in the design environment and through the artifacts that we use to perform those actions in pursuing our goals is ignored. Learning is not only learning as transfer of information or by creating, manipulating or structuring design knowledge. It also is a evolutionary process, in which new means and conditions for future design activity are built in the current situation.

6. Cognitive Artifacts

The notion of Cognitive artifacts was introduced by Norman: "those artificial devices that maintain, display, or operate upon information in order to serve a representational function and that affect human cognitive performance[38]." Cognitive artifacts are mental or physical devices that aid or enhance our cognitive abilities. This concept is quite interesting for design research. Specially in realizing that design activities are highly mediated by many artifacts i.e. drawings, methods, techniques, models, tools, instruments etc. In

fact last ten year an important portion of design research has been devoted to drawings and its use in design processes.[39, 40, 41, 42].

Mostly this research has been focused in what drawings represent i.e. content rather than how is represented i.e. media. Mostly the operational space in where this artifacts operates remains unknown. Is in this subject where activity theory from Vygotsky[26] open an interesting area of research. Departing from this theory, it is important to consider not only that designers interact with an artifact but also that they deal with an object of activity through the mediation of the instrument. in addition, designer adapt their activity to the artifact and they build new means and conditions for their future design activity[27].

6.1 Artifact-Instrument Relation

Ours actions in the world are not direct, but mediated by socially and culturally constructed objects. These objects are artifacts, which are mediators of actions performed by an operator in pursuing activities[27, 28, 43, 44]. Socially and culturally loaded, they are shared and transmitted through communities in a continuous evolutive process. Artifacts already exist, but they need to be mobilized by users in their activities in order to become instruments, i.e. means in the service of goal oriented activity. The appropriation of artifacts as instruments in use situations performed through "utilization schemes" and is conceptualized as an 'instrumental genesis', which transforms not only activity organization "instrumentation" but also the artifact's characteristics "instrumentalization". Using this ideas in design opens an interesting way to analyzes design activities. Specially thinking about drawings, drawing instruments and drawing techniques. The knowledge that they displace and the knowledge that they produce trough its manipulation. Even though the use of drawings and its implications has been under theoretical discussion over time. The historical perspective about the role of drawings in architecture has been a permanent focus in this research[1, 41, 45]. What has been also permanently ignored is the role of instruments in design thinking.

6.2 Utilization Schemes

If artifacts are conceived as sets of negotiated, sedimented and embedded rules, their relevance in design thinking is extremely important and comprises many issues that until now remain ignored by design research. First, artifacts can be understood a means to improve design thinking, Second, artifacts can be also interpreted as way to structure knowledge not only at organizational level but also at operational[46]. Social schemes of artifact utilization. Reorganization of activity leads to the emergence of instrument "utilization schemes"[27, 30, 47]. Using Piaget definition of scheme[48]; utilization schemes can be understood, as a structured set of generic descriptions of artifact utilization activities. They enable the subject to develop the activity necessary to perform the functions he expects from the association of the artifact with his action. They thus form a stable basis for his activity. The utilization schemes can be considered as representative and operative invariants, corresponding to classes of instrumented activity situations. But in a long term perspective they evolves in the way that knowledge evolve. This is specially visible in the use of digital tool in architecture. At the origins of CAD use in architecture utilization schemes were inherits from previous practices i.e. electronic drafting tables. Later new utilization schemes were originated and implemented in newer CAD software versions. With the ubiquity of 3D modeling, totally new schemes were generated and are being absorbed, specially at the academic environments49, 50. Same thing will happen with the availability of 3D prototyping. In the other hand, design processes stay unaltered and attached to old practices and obsolete paradigms.

6.3 Types of Mediation

The instrument's intermediary position makes it the mediator of relations between subject and object. It constitutes an "in between" world whose most distinctive characteristic is being adapted to both subject and object[28]. This adaptation process takes place in different levels, at the material, at the cognitive and in the semiotic level.

Two main types of mediation are identified:
- a mediation from object to subject that we describe as an epistemic mediation in which the instrument is a means allowing knowledge of the object;
- a pragmatic mediation from subject to object in which the instrument is a means of a transforming action directed toward the object[27].

The instrument is thus not only an intermediary world. It is a means of action and more generally, of activity. This is the second relevant characteristic. Actions are very diverse in nature[30]:
- transformation of a material object with a tool: material instrument;
- cognitive decision making: cognitive tool;
- organizer of own activity: psychological instrument;
- semiotic interaction with a semiotic object: semiotic tool.

Finally as mentioned before two processes contribute to the emergence and evolution of instruments; instrumentalization and instrumentation. Instrumentalization can be defined as process in which the subject improves the artifact's properties. Instrumentalization is based in the artifact's intrinsic properties, and gives them a status in line with the action underway and the situation concern the emergence and evolution of artifact components of the instrument[27]. A good example of this process is the evolution of drawing instruments in architecture51 and not only on reference to the analog-digital evolution but also within each category. Also the evolution of external representations in architecture is a very good example of this process[1, 45]. Instrumentation processes are relative to the emergence and evolution of utilization schemes and instrument-mediated action. This is particularly evident in the incorporation of digital technologies to architectural practice and education[52].

6.4 Instrumental Genesis

This approach is based on activity theory, which deals with purposeful interactions of active subjects with the objective world[43]. Interactions, or activities, are understood as social, hierarchically organized, developing, and mediated by artifacts. The instrumental approach focuses on integration of artifacts into the structure of human activities. The instrumental genesis approach, mainly developed by Bardel, maintains that genuine appropriation of artifacts by human beings is an outcome of developmental transformations of artifacts, individuals, and social interactions30. Not only do individuals change artifacts and adjust them for their specific needs and conditions, but they also become proficient in how to operate a tool, what tasks can be accomplished with the tool, and which methods should be applied to accomplish these tasks effectively. In other words, an artifact becomes an instrument through instrumental genesis[27].

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