We are Designers Because We Can Abstract

A. Adel[1], R. Djeridi[2]

[1] Magellan Research Center, I-Co-D, University Jean-Moulin Lyon 3, IAE Business and Management School, 6 cours Albert Thomas, B.P. 8242, 69355 Lyon Cedex 08 – France

[2] Laboratoire des Sciences de l'information et des systèmes (LSIS), 2 cours des Arts et Métiers, 13725 Aix-en-Provence - FRANCE

adel.aloui@univ-lyon3.fr; radhouane.djeridi@eurocopter.com

Abstract

Due to the increasing systems complexity, architecture design became an important issue. It gained interest and its importance was framed in three domains: as a way to understand complex systems, to design them, to manage their manufacturing process and to provide long-term rationality. The purpose of this paper is, firstly, to survey the existing definition approaches on architecture. Secondly, we propose a model for architecture design which articulates the potential linkage between two principle concepts: synthesis and abstraction. Our proposal model focuses on abstraction concept and permits an effective top-down design approach. It helps also designers to more respond to issues that characterize architecture design.

Keywords:

System architecture, Concept, Model, Synthesis, Abstraction.

1 INTRODUCTION

Research on system architecture design approaches is still in its progressing phase and several architecture design approaches have been introduced in the last years [1]. However, a consensus on the appropriate system architecture design process is not established yet and current system architecture design approaches may have to cope with several problems. We can also note a glaring lack of modelling and methodologies really used in practice [2].

System architecture design is generally considered to play a fundamental role in coping with the inherent difficulties of the development of large-sacle and complex systems [1] [3]. System architecture design includes the early design decisions and embodies the overall structure that impacts both quality and cost of the whole system. We maintain that the existing architecture design approaches have several difficulties in deriving the right architectural abstractions.

In the first section, we give a short background on architecture in which we present some existing definitions and our own definition of architecture. In the second section, we propose a model for system architecture design. The principle motivation for proposing this model is to help designers to manage complexity in designing systems. In the last section, we conclude by giving future work to operationalize our proposal model.

2 ABOUT ARCHITECTURE

In this section, we focus mainly on the meaning of architecture by analysing some prevailing definitions in section 2.1. In section 2.2., we provide our own definition of architecture based on the existing definitions and which considers architecture as a concept.

2.1 Definitions

Architecture is important in several fields such as building engineering, system engineering, software engineering, etc. The architecture design is a central stage of any system process creation or design. We think so that here would be thus certain joint points between these fields. In this section, we will refer sometimes, in particular, to software engineering.

The term architecture is not new and has been used for centuries to denote the physical structure of an artefact [4]. In tandem with the increasing popularity of architecture design many definitions of architecture have been introduced the two last decades, though, a consensus on a standard definition is still not established. Definition approaches are different and, often, they interact and have many joint points.

According to us, multitude as well as coexistence of various definition approaches notes a problem of comprehension and positioning as regards architecture. In this section, we are interested, first of all, with the approaches of definition of architecture in design.

Let us explain this considering the development of the definitions in the last two decades. The set of existing definitions is large and many other definitions have been collected in various publications [1], [3], [5]. We provide only the definitions that we consider as representative.

We can group definition approaches of architecture in three principal categories: a first category which lays the stress, mainly, on the internal composition of a system. The second extends the previous definition approach by including relationship with the environment and evolution over time. Lastly, a third category which is interested rather in the finalities of architecture by regarding it as sub-process of design process.

Architecture: an organized structure of components

In this definition approach, the stress is laid on the internal composition of architecture. Maier and Rechtin define architecture as being the structure in terms of components[1], connections and constraints of a product, a process or a system [6]. In this definition, three basic notions are to be raised: components, connections and constraints. These notions characterize the internal structure of architecture.

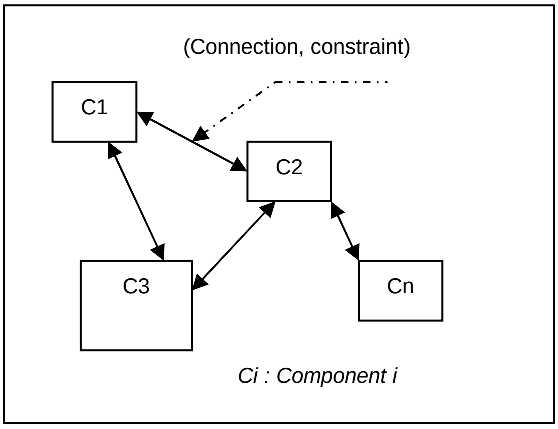

Figure 1: Architecture: an organized structure of components

According to this approach, architecture contains, primarily, the composition of the system in components; It is an abstract description of the entities of a system and their interactions [1]. The approach of definition of architecture system relates to three levels then: first of all, a first level which consists in determining the components of architecture system to conceive. Components of architecture should not be selected arbitrarily and they should participate on the satisfaction of the overall requirements and help the architecture evolution over time. A second level of architecture focuses on interactions between these components. Lastly, the third level relates to the analysis of the constraints resulting from these interactions. In this approach, the organization of components and their interactions are, primarily, question of optimization (performance, size, cost...).

Architecture: an organized structure of components in relation with environment and in evolution over time

In this definition approach, architecture is defined, not only, as abstract description system components and their interactions but also in its relationship with the environment. Thus, an important notion comes to be added; this notion is that this structure of components evolves in and by its environment. Evans emphasizes this by defining architecture as being the conceptualization, the description and the design of a system, its components, their interfaces and the interactions with the various internal and external entities and their evolution over time [7].

This definition approach emphasizes the dynamic notion of architecture in addition to its static one. As regards software architecture, Lawson defines architecture as follows: "... *we define architecture as a system design model that captures system organization and behaviour in terms of components, interactions, and static and dynamic configurations* » [8]. According to this definition, we release the following basic notions associated with system architecture: composition, interactions and interfaces, performance and evolution. These key notions show the importance of architecture in the design process and especially in the future evolution of the system over its life cycle. This evolution is guided for example by maturity of technology.

[1] The term component here is used as an abstraction of varying components; it may refer to abstract concepts, subsystems, physical components, etc.

Architecture: a sub-process of system design process

This definition approach is quite different from the two other approaches. Indeed, instead of attempting to define architecture by its entities, it considers architecture as a problem solving process in which the problem represents the requirement specification and the solution the structure of the architecture in terms of entities and interactions. Ulrich defines architecture as being: "*The scheme by which the function of the product is allocated to physical components*", or also "*the mapping from functional elements to physical components; the interactive specification of interfaces among physical components* "[9]. In other words, architecture is the process by which the designer starts the process of concretization of the solution on the basis of system's functional definition.

According to this approach, architecture is regarded as a process of abstraction of the physical solution using representations, models and syntaxes. It is the scheme by which the structure of the system is determined and the concrete physical solution is, simply, an instantiation of this abstract representation of architecture.

2.2 Architecture as a concept

According to all these definitions, it is clear that architecture can be defined basically as arrangement of components or entities and relationships between them. However, architecture is sometimes defined as the scheme by which this arrangement of components is obtained and so confused with architecting. According to us, the multitude of definitions on architecture is due, essentially, to the multitude of perspectives. As Van Wie, we conclude that architecture is an ill-defined design concept, and there is a need for a definition that captures all those perspectives which are important in helping designer [2].

Designers face continual challenges to deal with complexity of system. Consequently, it's often required to provide aids to them.These aids may be provided in many forms; computer-based aid systems, co-worker networks, pertinent approaches and methodologies and essentially suitable general framework to guide them in their solving problem tasks. Architecture is one of the most important concepts in management complexity in engineering design. It must be defined with consistent and overall definition including various perspectives and viewpoints. For this we provide our own definition:

Architecture is a concept forming a set of abstractions, perspectives and viewpoints of a system structure

We think that this definition is general and covers also existing definitions on architecture. It synthesizes disparate existing definitions from many domains into a new framework for understanding architecture. We consider architecture as a concept that gives an abstraction of the corresponding domain knowledge. It represents a high-level structure of a given system including, in addition of components structure, its behaviour and the scheme by which is obtained.

3 HOW ABSTRACTION WORKS IN ARCHITECTURE DESIGN

Architecture design can be considered as a problem solving process in which the problem represents the requirement specification and the solution represents the architecture. A well-known concept in engineering to solve problems is synthesis. This concept is often considered as the process by which a problem specification is transformed to a solution by decomposing the problem into loosely coupled sub-problems that are independently solved and integrated into an overall solution.

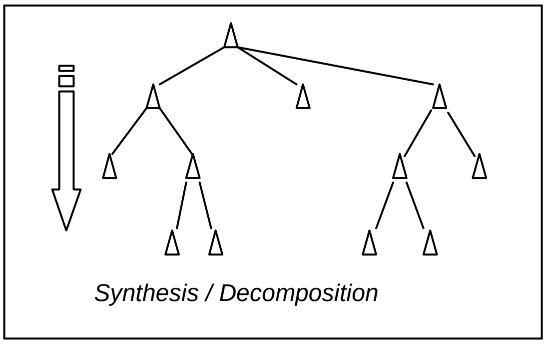

Figure 2: Synthesis principle of problem solving

During the synthesis process, designers need to consider the design space that contains the knowledge that is used to develop the design solution. Resolving design problem is more and more cognitive in nature. Often, the total amount of conceptual and factual knowledge that ideally should be commanded in order to deliver desired (ideal) solution exceeds the average worker's mental capacity. In product design, Van Wie note that the stereotypical engineer is famous for solving problem in a logical and rigorous style, but its modelling and analysis capabilities are not generally used in architecture design [2].

Recent cognitive research indicates that human decision making and problem solving is mostly non intuitive and based on associations and abstract mental models [10]. Translating these generalized and abstract representations to a concrete solution is complex. To manage this inherent complexity in problem solving, synthesis can be performed at different higher abstraction levels in the design process. A higher level of abstraction reduces the difficulty in dealing with both problem and solution or function and form. This approach reduces the complexity in particular of the design of larger systems. In addition, higher level abstractions are closer to a designer's way of thinking and such increases the understandability, which on its turn facilitates to consider various solution alternatives more easily.

Using mainly synthesis and abstraction concepts, we propose the following model for architecture design.

Requirement specification represents the requirements of stakeholders who are interested in the project of system development. This set of requirement is used to *formulate* the technical problem. This formulation can be considered as the process by which functional description of the system is obtained. This functional description can be represented by a functional diagrams or function structure [11]; [12]. The functional description has hierarchy aspect representing the decomposition of principal functions into sub-functions which can be decomposed further into lower level sub-functions [12]. It can also crated at different levels of abstraction [13].

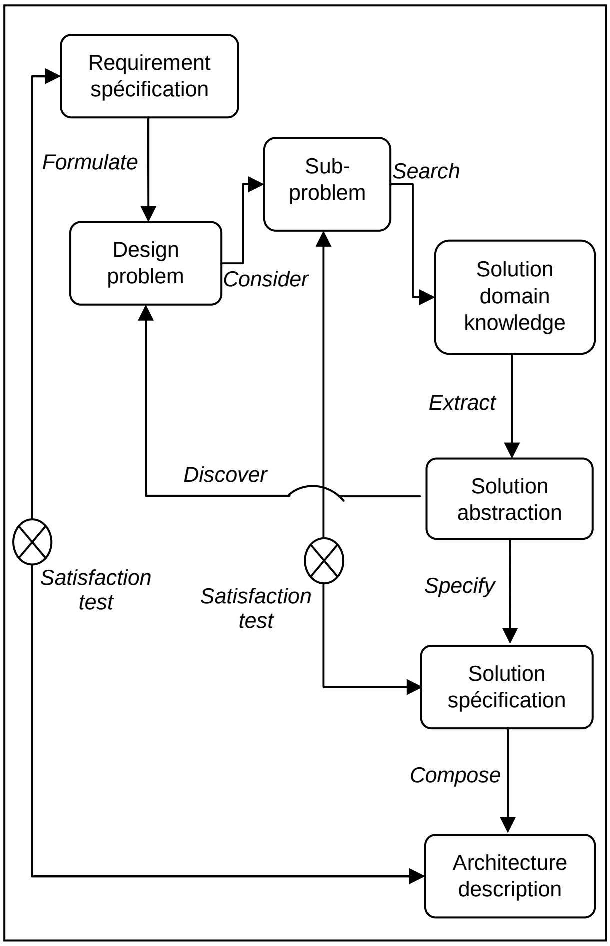

Figure 3: Model of architecture design

The process of design of architecture begins by considering a sub-problem of the hole identified problem represented by the functional description. For a given sub-problem, designers will search the solution domain knowledge. Then, solution abstraction must be extracted from this solution domain knowledge. This step is called also concept generation. When abstracting solution, we can discover new sub-problem which must be integrated to the whole design problem to be solved later. Finally, the abstract solution must be specified; in other words, this step consists to allocate components to the sub-function considered. The specified solution must be tested with regard to sub-problem formulation.

These steps must be conducted with all sub-problems and specified solutions obtained must be integrated to compose or to build the whole architecture. In this way, architecture generation process consists of a series of divergent and convergent steps, completed of at different levels of solution abstraction [14]. The architecture resulting from integration must be tested in regard the initial requirement specification and can be modified to improve satisfaction by refinement using optimisation techniques. This process of architecture design is inherently iterative and therefore feedback loops are not shown explicitly in the model although they certainly exist both within and between steps.

This meta-model can help designers in practice and improve their abilities to more respond to issues that characterize architecture design. It permits an effective top-down design approach to generate system architecture. It clarify in a practical way the process architecture design and try to eliminate (or at least minimize) the need for design recursion.

4 ARCHITECTURE DESIGN USING MORPHOLOGICAL ANALYSIS METHOD

4.1 Principle

Architecture, considered as “*the mapping from functional elements to physical components*" [9], is obtained by arrangement of physical or organic solutions. In the case of complex systems, the conventional approach would be to break the system down into a set of sub-functions. This process is called functional decomposition or also analysis process (Figure 4). In a given level of abstraction, we can allocate to each sub-function a weight which indicates the contribution of the considered sub-function in the fulfilment of the principal function.

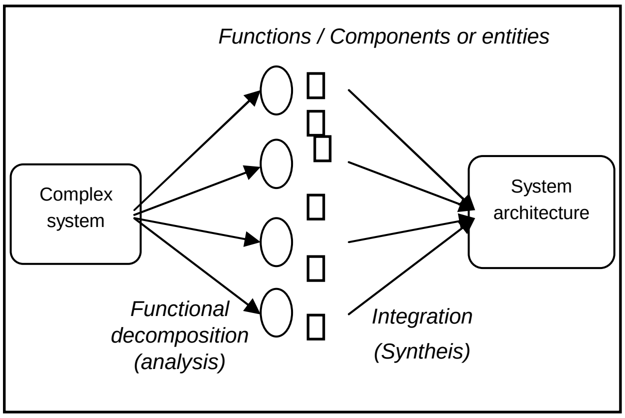

Figure 4 : Architecture as the mapping from functional elements to physical components

Architecture is obtained by allocating physical solutions to functions. It is clear that many alternative solutions are possible. To explore all these possibilities, we can use morphological analysis method. Morphological analysis was developed by Fritz Zwicky for exploring all the alternative solutions of a multi-dimensional complex problem.

Figure 5 shows the principle of morphological analysis using to generate system architecture. As shown by this figure, architecture is obtained by combining possible solutions of sub-functions. Depending on the outcome of solution generation phase and the level of functional decomposition, the use of morphological analysis method can generate a huge number of possibilities.

4.2 Quantification architecture method

It is impossible to study all solutions obtained by using morphological analysis method. Somehow, we must be able to reduce the number of alternative architectures generated. However, considering only constraints and preferences is not sufficient to help designer to select appropriate architectures. This step of reduction may reflect true impossibilities also combinations that seem to be unrealistic. With constraints and preferences we can reduce by up 90 percent the initial morphological field [15]. This reduction leaves us with an enough important number of alternative architectures called candidate architectures. So the question is: how to reduce the number of these candidate architectures to keep only viable and interesting ones?

It is clear that quantifying architectures can helps to reduce significantly the morphological field (Figure 6). As shown by Figure 4, the quantification of architecture can be given by Equation (1).

$$Q = \sum V_i * Pj_i \qquad (1)$$

Where Vi is the weight of sub-function F_i ($i \in \{1, n\}$) and Pj_i is the weight of the solution Sj_i. This last weight gives the satisfaction degree oh the considered sub-function by the solution *Sji.* In the case of the example given by Figure 7, the quantification of the considered architecture is given by Equation (2) :

$$Q = V_1 * P1_1 + V_2 * P2_2 + V_3 * P4_3 + V_4 * P2_4 \qquad (2)$$

5 SUMMARY

Design architecture includes the early design decisions and embodies the overall structure that impacts quality and cost of the whole system. Throughout this paper special emphasis is placed on practical difficulties of understanding architecture concept giving a multitude definition approaches. We have focused in this article on the development of a model of architecture design based on the two principle concepts synthesis and abstraction. The proposed model and quantification method guide designers’ reasoning but they must be more operationalized by tools in order to be easily used to improve the practice of generating system architectures.

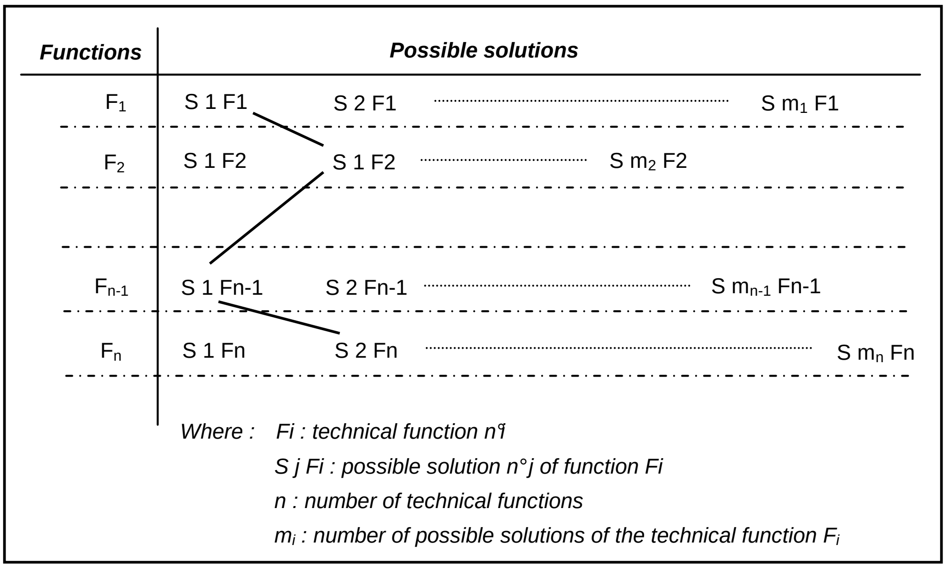

Figure 5: principle of architecture generation using morphological analysis

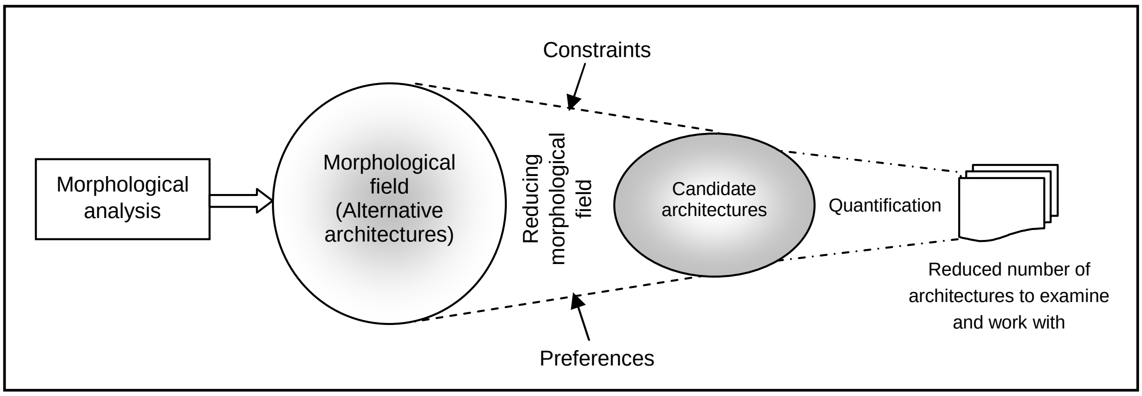

Figure 6: Steps of morphological field reduction

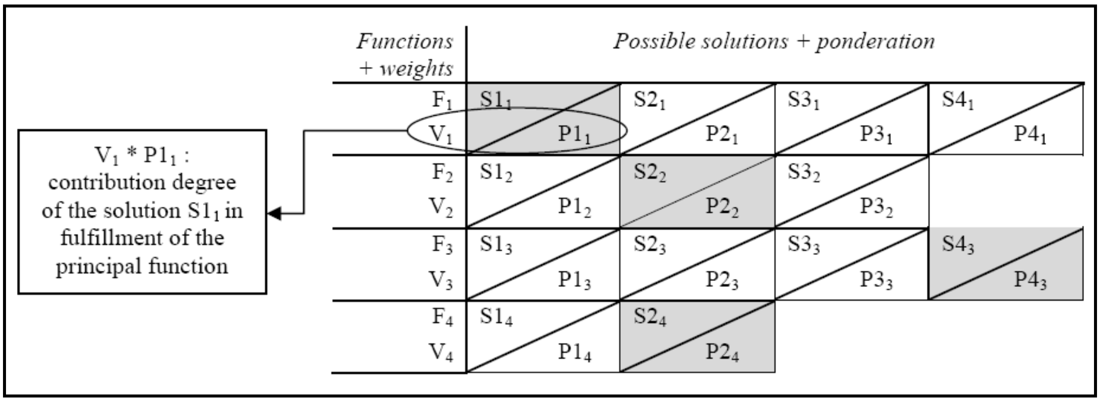

Figure 7: principle of architecture quantification

6 REFERENCES

[1] Crawley, E., and al., 2004, The influence of architecture in engineering systems. Engineering Systems Monograph, The Engineering System Department (ESD) - Architecture committee, MIT, March 29-31.

[2] Van Wie, M.J., 2002, Designing product architecture: a systematic method. PhD in mechanical engineering, University of Texas at Austin, December.

[3] Ulrich, K.T., Eppinger, S.D., 2000, Product design and development, 2nd ed. New York, McGraw-Hill.

[4] Merriam Webster on-line Dictionary, http://www.m-w.com/cgi-bin/dictionary, 2000.

[5] Ullman D., 2003, The mechanical design process, 3rd edition, McGraw-Hill, New York.

[6] Maier M.W., Rechtin E., 2000, The art of systems architecting, CRC Press.

[7] Arciszewski, T., 2004, Design and Inventive Engineering.

[8] Lawson H.F., Kirova V., Rossak W., 1995, A refinement of the ECBS architecture constituent**»,** Systems Engineering of Computer Based Systems, pp. 95-102.

[9] Ulrich, K.T., 1995, The role of product architecture in manufacturing firm, Research Policy, N°24.

[10] Bechara, A., Damasio, H., Tranel, D., and W. Anderson, S., 1998, Dissociation Of Working Memory from Decision Making within the Human Prefrontal Cortex, The Journal of Neuroscience, January 1, 1998, 18(1):428-437

[11] Vladimir Hubka and W. Ernst Eder, 1988, *Theory of Technical Systems* (Springer-Verlag, New York.

[12] Phal, G., Beitz, W., 1996, Engineering design – A systematic approach, Springer, London.

[13] Theodore Fowler, Value analysis in design (Van Nostrand Reinhold, New York, 1990).

[14] Salonen, M., Perttula, M., 2005, Utilization of concept selection methods – a survey of finish industry, Proceedings of IDETC/CIE, Long Beach, California USA.

[15] Ritchey, T., Modeling Complex Socio-Technical Systems using Morphological Analysis, Adapted from an address to the Swedish Parliamentary IT Commission, Stockholm, December 2002.