

# Role of System Architecture in Architecture in Developing New Drafting Tools\*

Arzu Gönenç SORGUÇ\*\*

In this study, the impact of information technologies in architectural design process is discussed. In this discussion, first the differences/nuances between the concept of software engineering and system architecture are clarified. Then, the design process in engineering, and design process in architecture has been compared by considering 3-D models as the center of design process over which the other disciplines involve the design. It is pointed out that in many high-end engineering applications, 3-D solid models and consequently digital mock-up concept has become a common practice. But, architecture as one of the important customers of CAD systems employing these tools has not started to use these 3-D models. It is shown that the reason of this time lag between architecture and engineering lies behind the tradition of design attitude. Therefore, it is proposed a new design scheme a meta-model to develop an integrated design model being centered on 3-D model. It is also proposed a system architecture to achieve the transformation of architectural design process by replacing 2-D thinking with 3-D thinking. It is stated that in the proposed system architecture, the CAD systems are included and adapted for 3-D architectural design in order to provide interfaces for integration of all possible disciplines to design process. It is also shown that such a change will allow to elaborate the intelligent or smart building concept in future.

**Key Words:** Software Engineering, System Architecture, 3-D Solid Model, Digital Mock-up, Architectural Design

## 1. Introduction

Technology, with all its scientific discoveries and engineering solutions changes/modifies the definition of existing fields or introduces new areas, with much new potentials to be explored. Information technologies, on the other hand, have a very strong impact in diverse field of applications. The complex tools and interdisciplinary nature of this technology, requires also new structures for proper and effective solutions where it is to be applied.

It is possible to consider 1940's as the beginning of history of software development together with the introduction of first digital computers. First generation programming languages serving software were developed to solve well-defined computational problems. But then starting from 1950's computers and so programming and software have found their applications in every field in a more sophisticated way.

In today's world, the IT becomes a crucial part of many fields, from engineering to architecture, from medicine to art, from house appliances to security. Although with the new developments in hardware and software, IT finds many new fields to be implemented and these new solutions facilitate our daily life and improve the qualities that are seek for, and yet the technology itself becomes more complex and more effort is required to provide appropriate systems for this technology.

IT in its applications has some problems or difficulties, either in terms of its hardware or software, peculiar to the field to be applied. The technologies serving for IT has been under a constant struggle to overcome all these problems and 'changing minds' for this technology is an essential issue of today's world.

The algorithms of 1950's to solve specified problems have been replaced by huge software with very complicated interrelations and user - developer relations. This rapid development in the scale and diversity of the programs/software led a software crisis at the end of 1960's as a result of the difficulties observed in development of software with a required level of accuracy, versatility, us-

\* Received 22nd December, 2004 (No. 04-5199)

\*\* Department of Architecture, Faculty of Architecture, Middle East Technical University, 06531 Ankara, Turkey.  
E-mail: arzug@arch.metu.edu.tr

ability, compatibility and flexibility for complicated problems<sup>(1)</sup>. This crisis resulted in the development of new field called 'software engineering'.

In this paper, it is aimed first to discuss the role of software engineering in developing new systems then, the idea of software architecture and how differs from software engineering is to be inquired, and finally the importance for software architecture in developing drafting tools for architecture is to be discussed aiming to provide basis for development of an IT model specified in architecture in general for further studies.

## 2. Software Engineering and Software Architecture

Engineering is defined as the practical application of science and mathematics, as in the design and construction of machines, vehicles, structures, roads, and systems<sup>(1)</sup>. The revolutionary developments in computers and informatics define a new engineering discipline named 'software engineering'. There are several different definitions for this new field. In general software engineering deals with handling complex programs by aiming to provide a structure to combine different parts of it. Parnas defined this new field as 'multi person construction of multi version software'<sup>(2)</sup>. Lamb states that software engineering is the synthesis and application of existing engineering principles to overcome problems observed in developing software<sup>(3)</sup>. It is possible to consider software engineering as a problem-solving act. Therefore, for a software engineer, the knowledge and methods provided by many different disciplines are implemented in a complex program/software in a structured way.

The definition of software architecture in literature has been varying from one researcher to another. Bass and his friends consider software architecture as high level design abstractions moderating and compromising requirements of different users/customers, providing suitable structures allowing development of the software by several different groups and disciplines, and also providing tools to evaluate and improve software<sup>(4)</sup>. Although there is no consensus in definition of software architecture, its importance in providing gross structures of software systems and their universal design principles are acknowledged by all those who involved in these tasks.

It is seen that definitions of software engineering and software architecture can easily be confused due to overlaps in many of their principles and their goals to design optimized software.

The role of software architecture can be summarized as Ref. (4).

-Definition of components and interactions with each other. In this task, there is an abstraction of information by selecting some informations related with interaction, relation among the components.

-Designing modules compromising programs and

data that software in other modules can call or access, by allowing collaboration of different teams.

Thus, it is possible to claim that every software system has an architecture but the important issue is how well this architecture is. Moreover, the behavior of each component is a part of the architecture. Hence, interface specifications and providing rule(s) for this purpose are important issues.

Three main constituents of software architecture can be outlined as

-A style imposing set of constraints in the interaction of components and the pattern of interactions.

-A reference model decomposing the 'problem' to be solved mostly, through domain analysis.

-A reference architecture mapping reference model onto software components.

In the design of software architecture, first the architectural style and the reference model should be provided to yield the reference architecture. Then it is possible to consider the software architecture and consequently the system architecture<sup>(4)</sup>. There are several detailed models for software architecture. Tekinerdogan provided a detailed meta-model for architectural design approaches<sup>(1)</sup>.

This meta-model represents the common basic structure of various architectures and it is in consensus with many definitions existing in this field. It is important to clarify the concepts illustrated in Fig. 1 for further discussion of role of software architecture in developing new drafting tools for architecture.

First important step is to define 'client', who can be anyone involved in the development process, i.e., a customer, a programmer, an end-user or a system developer. In many cases, there are several clients contributing the architecture. The second step is to understand the concept of 'domain knowledge' which has a crucial role in different levels of the development process to provide the final architecture, consequently for every level; a different domain knowledge can be required. The first domain knowledge is related with definition of the problem imposed by the client(s). Solution domain knowledge is re-

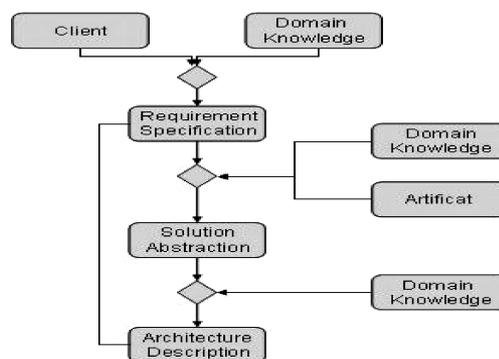


Fig. 1 Representation of meta-model for designing a software architecture

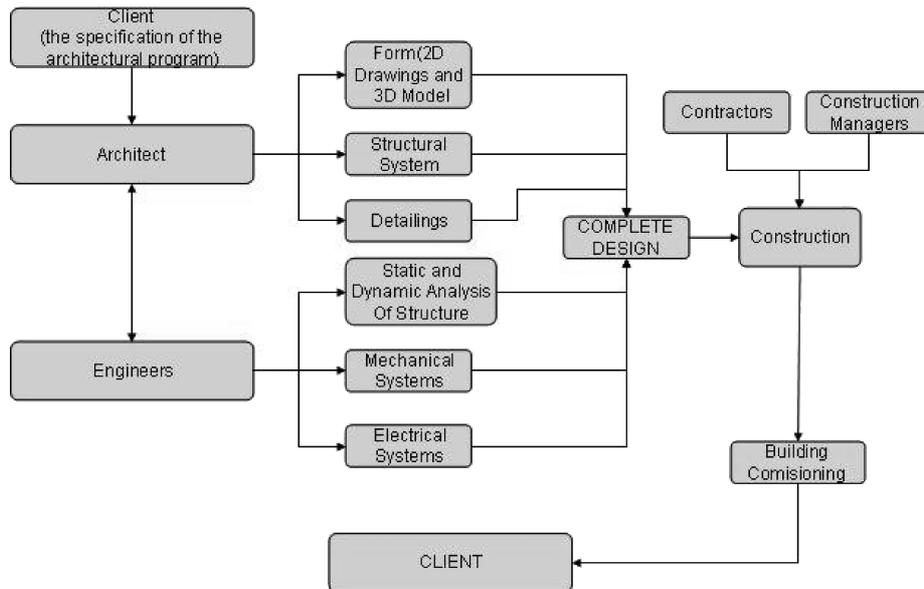


Fig. 2 The design process and practice in architecture

lated with several sub-domains like general expertise and knowledge serving for the solution, technical knowledge about software development, business domain knowledge concerning marketing, surveying and providing business tools. Requirement specification, solution abstraction can be considered as the synthesis and implementation of different domain knowledge to the final architecture description to yield the software architecture.

It should be understood that every concept explained briefly above is a field of expertise and from one application field to other; a different architecture is to be end-up. The important question to be asked should be the suitability of the model of architecture regarding the problem and client.

At this point, the position of architecture in IT which comprises art, engineering and design, must be inquired more. Architects are also very important customers of various products of Information Technologies and their works create new horizons to be explored in civil engineering, in material sciences, in management, environmental issues, safety, comfort, innovations in tools and et al. But, it is seen that many of these tools borrowed from other disciplines and adapted skillfully to the field of architecture. Then it is possible to discuss the efficiency of these tools and/or the way to improve/adopt them for architecture.

### 3. The Role of Information Technologies in Architectural Design

As in many other disciplines, the impact of IT in architectural design is felt heavily and new paradigms are introduced in this field as well. The number of architects benefiting from all these tools is increasing every day and from the initial design i.e., from draft to final artifact, the process has been inquired. The design process and prac-

tice in architecture is illustrated in Fig. 2.

The scheme illustrating design practice actually should be modified by including the IT implementations at every level. Due to the involvement of IT in architectural design practice, new terms like computational design, ambient intelligence, artificial intelligence in design, virtual realities et al., have been introduced to architectural design practice and this involvement results in more complex interdisciplinary collaborations.

In this scheme for conventional architectural practice, it is seen that the role of architect is the realization of the design specifications and constraints of the client(s), and create a 'model' in terms of 2-D drawings and 3-D scale models or virtual models that can be handled by other engineering disciplines to provide a complete design of an artifact ready to be constructed.

However, it should be understood that computers and computer modeling is changing its role in architectural design from a presentation medium to a design medium itself. Moreover, inclusion of information technologies in design also yields new potentials for architects and the scheme becomes more complicated and yet the whole process has potential to be more interactive and optimized.

In this perspective the role of drafting should be questioned by concerning these potentialities provided by IT. One of the first involvements of IT through computers in design beside computations was the drafting/drawing.

Drafting/drawing can be considered as a graphical language expressing the ideas of designer concerning the problem interested in. Therefore, drafting is the keystone of design in order to be realized. The introduction of computers to drafting first in engineering and in architecture facilitate this process considerably responding for the requirement of fast-paced design, speedy revisions and the

need for more options to optimize the solution. Thus, the concept of Computer Aided Design CAD was born. Then, manufacturing technologies had their shares from the rapid developments of computer technology and Computer Aided Manufacturing CAM was introduced to production. Today, CAD/CAM is the usual practice for any design-production process.

Global spreading of CAD and CAM systems has revolutionary effects in many fields as it is already discussed. The first question that should be asked is how efficient these systems are employed by other disciplines. Then, it must be questioned suitability of these tools to the field of interest. Finally, the model i.e. architecture of the system peculiar to the discipline should also be discussed.

In this study, these issues are to be discussed for architectural design by focusing on drafting/drawing tools used concerning the crucial role of them in the whole design. Then, a system architecture for development of new tools of drafting/drawing is to be searched for further studies helping software engineers to provide compatible solutions for CAD in architecture.

#### 4. Present Situation of Applications of CAD in Architectural Design

One of the first popular areas of implementation of CAD systems is in architecture by replacing pen and paper with computers as a new presentation and communication medium, and today as new design media. The compatibility of CAD systems with other computation and database process systems also draw attentions to the integrated design concept, development of data bases, management systems et al. Then, new concepts like computational design, virtual reality and virtual spaces, ambient intelligence, artificial intelligence, smart buildings, virtual architecture and many others, are introduced as a result of the impact of these new media.

In discussion of the role of CAD systems in architecture, a common source of confusion due to the similarity of software systems used in the design process is about virtual architecture which speculates/inquires about architecture and design, and drafts and drawings of the projects to be implemented.

Concerning the drafts produced by CAD systems, beside the compatibility of the 2-D, 3-D models, their potential for data exchange, allows the interactive participation of the client to the design process without fully understanding the architecture. In this study, this compatibility is actually questioned for the whole design process illustrated in Fig. 2. considering the drafts as the center of design communication and the medium to collaborate over.

Today there are almost 100 CAD packages applicable for architectural design with various complexity levels in terms of their compatibility with other software, their

capacity to data exchange and documentation, user friendliness, their flexibility for improvement and their graphical capacity, their need for minimum hardware profile and so on.

Some of these software packages are actually employed in engineering practices and architects employ only the drawing potentials of these software as graphical tools and drawings expresses the ideas of architect to client and to other disciplines taking place in the whole process shown in Fig. 2. Here, in most applications, CAD systems are only evaluated with their graphical potentials, and wire frame models, or solid models provided by them are mainly used to enhance the communication between architects and clients in graphical level. However, the potential of these 'drawings' to be a real 'design model' by providing information about materials, about static and dynamic load carrying capacity, performance of mechanical systems, construction costs and management are mostly ignored.

Today, in high technologies, these CAD/CAM systems are considered as a whole and the idea of 3-D mock-up gains more and more considerations. Software companies and engineers are developing new interfaces for this purpose. The idea of 3-D mock-up is to use 3-D solid models of the product/design before any drawing or prototype. Here, it should be understood that thinking in terms of sections and layers is replaced by thinking in three-dimensions and thus drawings are replaced by 3-D solid model as the master. Some of the advantages of 3-D solid models are

1. to have a model ready for further static and dynamic force analysis, thermal analysis, fluid flow and so on.
2. to generate programs for CNC machining process
3. to provide isometric and perspective drawings
4. to provide means for inspection
5. to allow making prototypes by rapid prototyping machines
6. to allow cost estimation, and manufacturing and resource planning

Besides the general advantages above, 3-D models can be used in producing 2-D drawings much easily and quickly compared with manual or computer aided techniques with high precision since all the views are generated from the master 3-D model. Changes to drawings can also be made quickly since the change in 3-D master updates all the drawings. Thus, modification(s) on the design at any level can be performed and tracked through the mock-up during the design process. Moreover, realistic renderings of the products facilitates the graphic communication between designer and client.

Aerospace, aeronautics and automotive industries demand for more efficient 3-D mock-ups, to control not only the design and production process, but also the product

life with proper management tools. The economic benefits of 3-D mock-ups compared with real physical mock-ups, is another advantage and these industries can heavily benefit from it. The first aircraft Boeing 777 designed and manufactured by using 3-D mock up has been recognized worldwide as the benchmark change in design process with the involvement of 3-D mock-up concept. In controlling the whole process from design to manufacturing of this aircraft Design Built Teams (DBT) were organized which can be considered as components of the architecture of the system<sup>(5)</sup>.

Today CAD/CAM systems, started to be known as CAX systems including these product life management systems as well. Leading software companies, software engineers and software architects like spend effort to provide better tools to serve CAX and improve the existing software by adding new modules. Some of the well-known CAD systems developing 3-D models are CATIA starting from version 4, Pro/Engineer, Unigraphics NX, SolidWorks, Solid Edge, AutoDesk Inventor, CoCreate Solid Designer, and VX CAD. The number of studies in this field increases rapidly with the advances in IT. The awareness of the companies and clients for the advantages of 3-D mock-ups and increase in the number of implementations also forces the software and hardware developers and software architecture becomes an important part of all these researches.

Regarding the brief discussions about the role of 3-D modeling in engineering, it should be questioned about the present situation of such 3-D models in architecture where such models have potentials to serve in a similar way with engineering. It is already stated that, although architects uses the same tools, the way those 3-D models are provided is for better graphical communication. However, even with the present level of technology, the role of

these 3-D solid models can be replaced by 3-D mock-ups and the design process can be modified accordingly.

**5. Role of 3-D Models in Architecture and a Proposal for Designing a System Architecture Design**

Although architects have started employing CAD systems almost at the same time with engineers, still the 2-D drawings are common practice in architectural design and 3-D solid models serve for better graphical communication, yet not as real 3-D models. It is possible to list out several reasons for this time lag in conceiving 3-D mock-up concept. One of the reasons is to perceive design as a stand-alone activity between architect and the client, and other components are considered as post-design activity. However, inclusion of IT with all means of computation and communication, the architectural design scheme can also be more interactive and collaboration of different disciplines over the 3-D model results in better results in terms of process, labor and final artifact. It is possible to modify the design scheme illustrated in Fig. 2 as follows.

The scheme proposed in Fig. 3, emphasizes the role of 3-D modeling as a collaborative/interactive design medium in which the whole design and post design processes can be carried on, i.e. a model substituting the 3-D mock-up concept, in engineering design.

It is possible to consider this scheme as a meta-model for the architecture of an IT system in architecture in which the system is centered in 3-D modeling and all possible interactions are through that model. The question of ‘how a real 3-D model for architecture can be developed’ should be answered not only by software engineers developing CAD systems, but also by the software architects who should provide complex structure for the whole components of the system and their interactions.

Present high-ended CAD systems are on the way de-

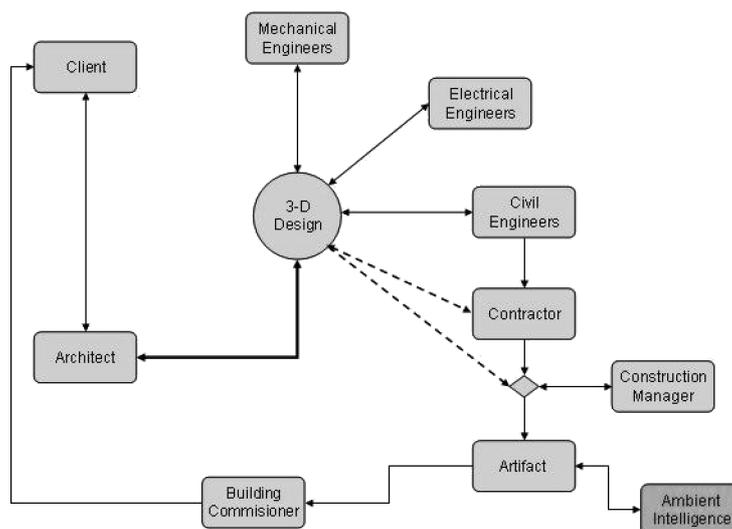


Fig. 3 Improved model of design process in architecture

veloping technology capable of producing 3-D models as discussed. Thus, the question is how these 3-D models employed in engineering can be adapted in architectural design by replacing thinking in 2-D with thinking in 3-D.

Comparison of a 3-D model in engineering and a 3-D model in architecture shows that in most cases, engineering models are more complex than 'models' in architecture in terms of information stored in these models. Yet, since the engineering processes are well defined as well as the initial problem, it is easier for software engineers to develop a proper tool for engineering applications. Today, conventional design and manufacturing in engineering uses these 3-D models and product life management systems are also demanded by clients from software companies which can be illustrated with a scheme similar to the one in Fig. 3.

In this study, it is seen that one of the reasons why architects do not employ yet those systems to provide 3-D models, besides 2-D thinking, is the lack of interfaces serving to share data among the contributors of the whole design process. Therefore, the important issue is to clarify the architectural design process in order to propose a general architecture as it is stated in the discussions above. Major characteristics of components of an architecture coherent with the proposed meta-model shown in Fig. 3 can be listed as

1. The software required to provide 3-D model is not more sophisticated than software used in engineering. Thus, modeling tool for architecture can be developed based on existing ones like AutoCAD, CADKEY, CATIA, MAYA and other high-ended ones having 3-D modeling capability.

2. The dimensionality of the 3-D model in terms of information that should be stored is not higher than information dimensionality of engineering 3-D models. Although the end-products of designs in architecture and design in engineering appear to be different, all these models should provide data for force analysis, material specifications, geometric specifications, cost analysis, mechanical systems, electronic systems, quality control and monitoring of the process during the production/construction and some others depending on the need. Therefore, the present CAD systems can easily be modified to be implemented in architecture.

3. The model should allow the interactive design as in engineering and documentation of all modifications should be performed through that model.

4. Compatibility between 3-D model and construction management software is important for the implementation of the design. Management process appears to be more complicated in architectural design due to nature of construction and model-management tools should allow construction managers to plan the process or update it. Contributors from various disciplines should provide feed-

back to each other over the 3-D model and model should support all these modifications accordingly.

5. 3-D model can be employed to develop smart buildings and more than that it can support concept of intelligent ambience providing database for this purpose.

These characteristics listed above also imply the components of the structure of architecture. Although, definition of these components in literature exhibits some slight variations, they are arisen from definitions provided by Bass and friends<sup>(4)</sup>. In this study, following structural components in consensus with definitions provided by Bass and friends are considered as the candidates to form the basic system architecture for architectural design process or in a more general term, system architecture for IT in architectural design process.

1. Module structure that includes problem definition/assignment, and products like code(s), specifications and etc. as well as allocation of project resources during whole design process.

2. Conceptual or logical structure which are abstractions of functional requirements.

3. Process structure controlling the running units.

4. Physical structure which determines the hardware profile according to the software developed.

5. Data flow structure which allows to trace data flow and to allow sharing the data.

The structural components like uses structure, call structure, control flow structure, class structure can also be employed in the system design. These components have been employed to develop different system architecture design approaches classified by Tekinerdogan into four main categories<sup>(1)</sup>.

1. Artifact-driven architecture design which is mostly object-oriented analysis methods.

2. Use-Case driven architecture which attempts to model systems's required functions and its environment.

3. Domain-driven architecture which is based on the identification domain knowledge of the problem domain to provide data for developing new systems.

4. Pattern-driven architecture which is based on pattern language concept of Christopher Alexander in architectural design setting principles for designing software, patterns repeating themselves at every level of software.

Proposing a system architecture to develop a software system for architectural design replacing 2-D drafts/drawings by a 3-D model yielding a new design scheme with the help of IT is discussed above. Here, it should be pointed out that, the first issue is not to develop totally new CAD tools for this purpose, but to modify/adapt/improve the existing CAD tools for architectural design process which can be realized by carefully designing a software system architecture covering all design process.

It should also be stated that the design attitude in architecture will be changed from 2-D thinking to 3-D as

discussed in previous sections and architectural design and consequently the 3-D model will be the center of the process as the common medium for all design participants. The new role of architect and 3-D model will also result in the new development of technologies involving the whole design process illustrated in both Fig. 2 or in modified form Fig. 3.

A model has been developed by the author and her co-workers from her department, Middle East Technical University, Department of Architecture. The goal of this study is to provide a system architecture including IT systems in the architectural design process and present a pattern for integrated design. The system to be proposed is then implemented by participants from professional software development companies. It is aimed to test the proposed system on the intelligent building to be built by the faculty of architecture.

## 6. Conclusion and Future Remarks

In this paper, the present status of architecture is discussed by considering IT systems. The role of software architecture in architecture to improve the design process is discussed. A model of design process centralizing 3-D model in architectural design, which can be considered as a counterpart of 3-D model/mock-up in engineering is proposed. The basic definitions that are believed to be employed in the system architecture are briefly discussed. Then, a meta-model in system architecture in architectural design is proposed.

It is pointed out that the existing high-ended CAD systems with 3-D modeling/mock-up can be used in architecture but the system architecture including all levels of design and post design processes should be provided. Therefore, for further future studies, the effort is to be spent to develop a system architecture rather than to develop new CAD software systems or new analysis software. In developing the system architecture, a detailed structure of the system architecture is to be presented in order to clarify the requirement of interface software combining different components of the design process compat-

ible with the existing software employed in the process.

The proposed system architecture centered on 3-D architectural model can be considered as a considerable change in design attitude in architecture. Besides, the scheme shown in Fig. 3, yielding the basis for system architecture can be thought as a new pattern for the design process under the impact of IT systems. It can be expected that as the CAD systems become more sophisticated the role of the 3-D model in architectural design as in other disciplines will be more emphasized.

In developing the system architecture in architecture design, the intelligent building that has been designed by Department of Architecture, and the construction process will allow to test the proposed system and identify the deficiencies of the existing tools and clarify the characteristics of interfaces as binding tools of the existing systems. It is planned to carry out this research by collaborating with software companies, informatics and other disciplines involving the design process. The results of the proposed model is to be presented through that building to encourage thinking in 3-D in architectural design and to illustrate the importance of pattern of new design process under the impact of IT systems. It is also expected that these conscientiousness will force software and hardware developers to design and develop new technologies participating these new design attitudes with more efficient and economical solutions.

## References

- (1) Tekinerdogan, B., *Synthesis Based Software Architecture Design*, Print Partners Ipskamp, (2000), Enschede, The Netherlands.
- (2) Parnas, D.L., *Some Software Engineering Principles*, (1978), pp.237-247, INFOTECH International.
- (3) Lamb, D.A., *Software Engineering, Planning for Change*, (1988), Prentice Hall.
- (4) Bass, L., Clements, P. and Kazman, R., *Software Architecture in Practice*, (1998), Addison-Wesley.
- (5) Bauer, E., *Boeing, the First Century*, (2002), Tabla Publishing Inc.