A systems engineering environment for integrated building design

Yahiaoui, A., Sahraoui, A.E.K., Hensen, J.L.M. & Brouwer, P.J. (2006).
A systems engineering environment for integrated building design.
Proceedings of the EuSEC - European Systems Engineering Conf., 18 - 20 September, pp. 11.
Edinburgh: The International Council on Systems Engineering (INCOSE).

A Systems Engineering Environment for Integrated Building Design

Azzedine Yahiaoui[1], Abd-El-Kader Sahraoui[2], Jan Hensen[1] & Paul Brouwer[3]
[1]Center for Building & Systems, TU/e, Postbus 513, 5600 MB Eindhoven, Netherlands
[2]LAAS-CNRS, 7 av. Colonel Roche, 31077 Toulouse, (Also at IUT- Toulouse-II), France
[3]ProRail, Arthur van Schendeistraat 670, 3511 MJ Utrecht, Netherlands
Corresponding E-mail: a.yahiaoui@bwk.tue.nl

Abstract. Integrated building design concerns the whole building systems approach. This approach is based on a design support for the building life cycle, in which multiple disciplines and apparently unrelated aspects of design are integrated in a way to allow synergistic benefits to be realized successfully. In order to cope with factors related to tightening environmental requirements, reducing development cycle times and growing complexity, this paper aims to describe a comprehensive design framework vision for integrated building design. A more focused use of applying systems engineering approach to the building design support is presented in response to the ever-increasing complexity of buildings. In particular, this paper addresses all issues of interrelated dynamic optimisation, as local optimisations do not give a global optimisation. The paradigm used, here is to extend and particularly to adapt the work carried out in military and space systems to modern building services by taking into account the semantics of buildings in terms of different engineering fields and architecture issues.

INTRODUCTION

The systems engineering approach was primarily developed by the military industries as a process by which large engineering projects could be designed, implemented, and tested prior to deployment (Defense Systems Management College, 1990). This approach is based on a structured method towards specification, design, acquisition, integration, reengineering, and implementation of a complex system over its life cycle. Systems engineering (SE) has emerged as a distinct professional discipline since the late nineties in response to the ever-increasing complexity of new products and systems of different fields. Eventually, this emergent discipline has been applied with success mainly to scale complex systems and projects in the following industries: aeronautic (e.g. won et al. 2001), automobile (Loureiro et al. 1999) and space (Shishko, 1995), etc. For the building domain, there is a great interest in applying such a good practice in the building design process and particularly manufacturing and production systems.

In this case, real design projects typically require the systems-level cooperation of experts from several engineering disciplines. Nowadays systems-level considerations are recognized as being paramount in designing new product. In consequence, systems engineering is an interdisciplinary method that develops and exploits structured efficient approaches to analysis and design complex engineering problems. This focuses more on constructs of analysis and synthesis for problems involving multiple realistic aspects to enable the realization of successful products. Since systems engineering deals with the methodology rather than physical manifestations of science, its description considers both the business and the technical needs of customers with the goal of providing a quality product that meets the user needs. Therefore, Systems engineering covers a broad set of processes and methods for modelling and analyzing interactions among the requirements, subsystems, constraints and components that make up a product. Its purpose is to improve an organization's understanding of the product as a whole, and to use that total product understanding to better optimize the tradeoffs that drive detailed design, manufacturing, service decisions and so on throughout the product lifecycle. However, the following aspects of real time specification, for instance, have still not properly been addressed in existing building design methods such as:

1. Transformation of an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of evaluation aspects
2. Integration of related technical parameters and ensure compatibility of all related, functional and program interfaces in a manner that optimizes the total system definition and design.
3. Integration of reliability, maintainability, safety, survivability, human and other such factors into the total technical engineering effort to meet cost, schedule and technical performance objectives.

This paper deals with a tentative application of systems engineering (SE) concepts to the building design process. As SE is an open process, a major advantage for this application could be a proposed approach with various technologies, business and management aspects that could be efficiently evaluated. This is advantageous because an open process can be applicable to any application domain, as long as these applications adhere to fundamental principles.

SE standards have been preliminary successful because their concepts involve new technologies and requirements management means needed for:

- Definition of systems, including identification of costumer requirements and technological specifications;
- Development of systems, including conceptual architecture, trade-off of design concepts, configuration management during design development, and integrated product and process development;
- Deployment of systems, including operational test and evaluation, maintenance over extended lifecycle and reengineering (renovation).

Modern systems engineering, including both products and services, is often very knowledge intensive. In accordance with systems engineering, EIA-632 standard (EIA-632, 1998) a method for adapting the process of such a standard to the conceptual architecture for a building design is applied with implementation and evaluation of different phases defined in design process. As a result, building performance specifications, preliminary/detail designs, building prototype build, components tests and subsystem/system integration tests are conducted in sequence to apply the SE concepts to the building design process. A design development process can follow a systems engineering standard or a specific framework in sequence to realise successful integrated building design. Systems engineering is a generic term that describes the application of structured engineering methodologies to the design and creation of complex systems, like building.

The remainder of this paper is organized as follows: the next section describes building design process. Then it follows systems engineering and deployment. This is followed by an application of systems engineering to building design process, and finally conclusion.

BUILDING DESIGN PROCESS

Building design process is the acquisition of a system as an end product. The process begins with the necessity of a building requested by the customer. The process begins with a feasibility study. Financial budget, site conditions, compulsory regulations, clients needs together with the design requirements are defined during the feasibility search. The architectural program is structured at the end of feasibility. During development of architectural program, the issues that affect the design together with architectural aspects (building type, spatial requirements, etc.), environmental aspects (site, location, surroundings, climatic conditions, etc.), and regular aspects (codes and standards) are also taken into account. All-previous steps are considered as the pre-design phase. In other industries, including building construction, design plays an essential role in the efficiency of productive process and in the production of value to the clients (Fabricio et al. 1999). The design process may be divided into a few stages based on the level that each stage is expected. Nevertheless, whatever the stages are; at the end, the output includes the specification documents that satisfy all the requirements needed for design and construction. Based on this information, construction process executes till the building acquired. During the life cycle of the building in use, the feedback for maintenance and renovations are used for the expected modifications in daily necessities. The process is continuously cycling and never ends but feeds the new requirements for a new design problem and starts from scratch. Furthermore, each stage in the process is nonlinear and has feedback cycles, which strengthen the whole process with minimum uncertainty at the end product. Figure 1 shows the schematic illustration of the building design process with its different phases.

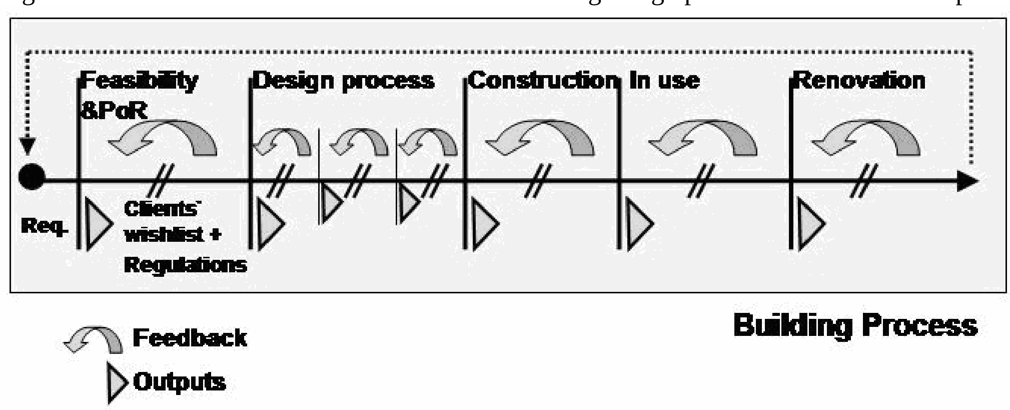

Figure 1. Building design process

In most cases, design process can be simplified as the function of the inputs, limitations, methodologies and outputs. Methodologies describe how to execute the process. In the building design process, the inputs can be outlined as ideas and necessities, and the outputs as products (usually buildings. It is shown in figure 2, that design process might be conducted of limitations relating to regulations, client's needs, cost, and time; and of methodologies in form of organizations, tools and techniques.

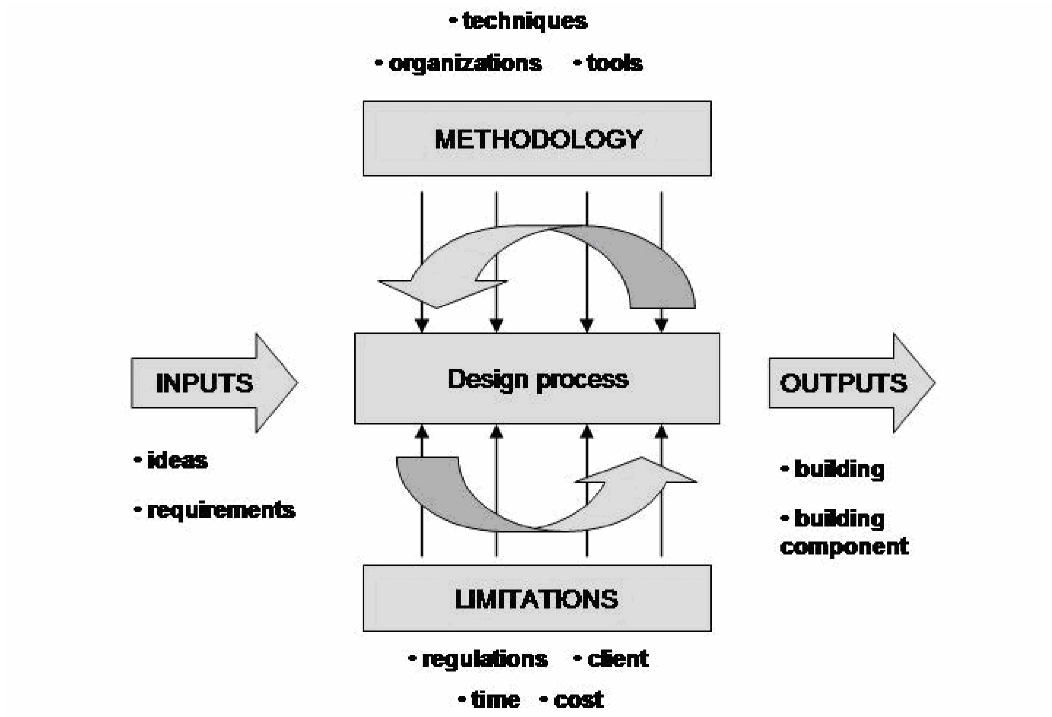

Figure 2. Simplified elements of building design process

For instance, Fabricio (et al., 1999) mentioned an important perspective on building. This has the purpose of characterizing the design process as a sequential conversion view that transforms the information from technical standards and requirements into solutions and product specifications.

SYSTEM ENGINEERING AND DEPLOYMENT

The efficiency of SE concepts is defined by methods, algorithms and tools used in the most complex of design problems. This methodology includes elements such as systems response functions, trade-off analysis, specifications and performance metrics, optimization techniques in the presence of various sorts of constraints, marginal and sensibility analysis, utility theory, scheduling, control databases, cost estimation, decision analysis, modelling and simulation, and software environments and tools. Although, SE model is an interdisciplinary area in which its conception affects all kinds of projects, a good description of systems engineering applies to systems as simple as a toaster and as complex as environmental restoration. The only difference between these two extremes is the degree of formality with which each process is used. Consequently, a model of systems engineering is a diagram that includes the known processes that we do. However, there are many models of popular systems engineering standards, such as: *ISO-15288, ANSI/EIA-632, IEEE-1220, SP-6105, ECSS-E-10A*, but their diagrams are similar to each other (Sheard et al. 1998).

The *EIA-632* standard is chosen, in this paper as an appropriate model for building design process; because it has an extra phase that involves the aggregation of end products. Technical Management Process – Processes that plan, assess, and control the systems engineering process.

GUIDE TO THE APPLICATION OF THE SYSTEMS ENGINEERING

Systems engineering and processes. The SE Framework Multidisciplinary teamwork ensures the accuracy and completeness of the evolving technical data package from which test articles, pre-production prototypes, and production products are to be manufactured or coded.

Systems of systems. The deployment of SE product can be carried out in a comprehensive approach by separating the final product (the building) from the enabling product (production systems: crane, etc.) and development product (simulation tools, etc.) this can be best illustrated by the following figure 3.

A single bloc k will really define the complete solution to a complex problem more typical of the design project. When an end product sub-system requires further development it will have its own subordinate building block.

Once the descriptions of the end product of the initial building block are completed, and preliminary descriptions of the end product subsystems are defined, the development of the next lower layer of building block can be initiated. If the building block has reached the "button", the design of these items requires no-development (i.e. all enabling product for that end product already exist and are all compatible with each other and with total solution).

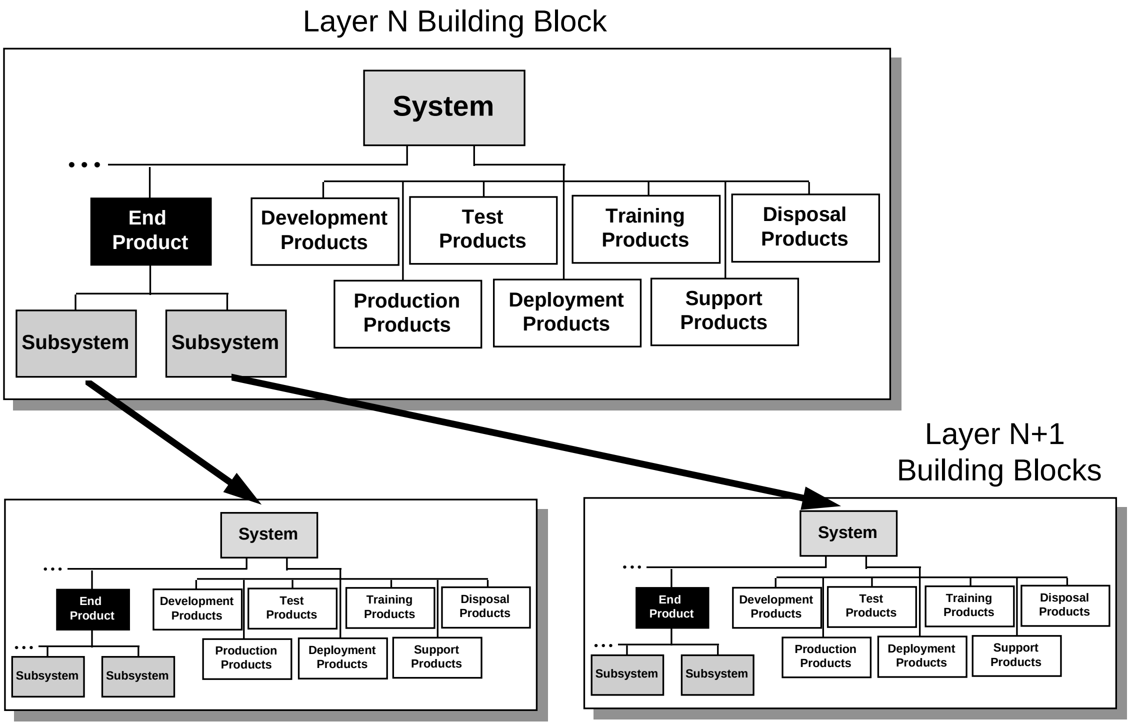

Figure 3. Hierarchy of building blocks

Systems engineering approach as analysis-synthesis. The systems engineering process, which specifies functions, sequence and the interrelationships between various stages of the systems engineering process is extremely imperative so that its application is successful. Although, there exists several diagram models (spiral, waterfall, V, etc.) that are used for applications, the V diagram, which relates systems engineering to project lifecycle, is probably the most popular one that is used for the application of processes for systems engineering concepts. Figure 4 shows a typical simple systems engineering process for the development of a system in a form of a V (or Vee), originally due to (Forsberg and Mooze, 1991).

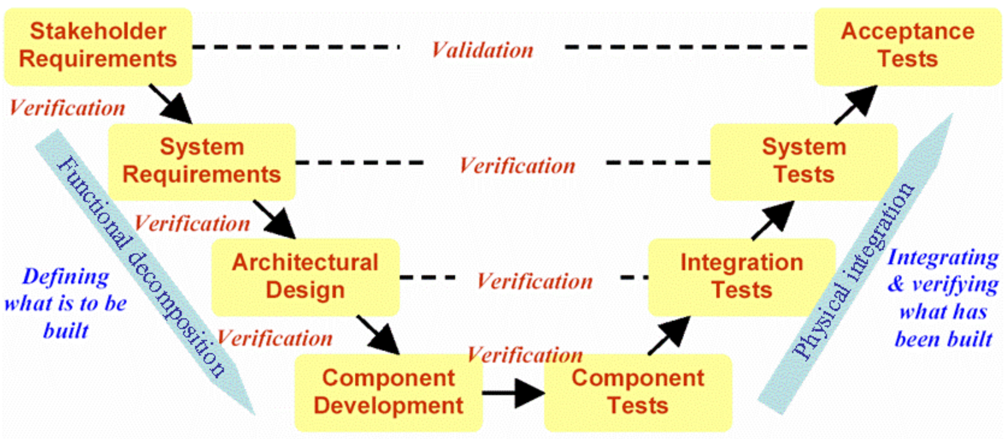

Figure 4. Typical SE process in form of V-shaped life cycle

During functional decomposition (or analysis), detailed design, and physical assembly; we can specify the building model as a whole, its parts, and their interactions clearly and at all decomposition scales. The subsystems at intermediate levels are fundamental for managing complex systems, for they enable us to establish complex details one step at a time. Outsized (or large) complex engineering parts are often decomposed into stages or steps and managed throughout the entire life of the product or system. This process of managing the system's life cycle (through concept, design, production, operation and disposal) is a bit like executing a series of interconnected engineering projects in a sequence, each building model on the results of the last until the end result is achieved.

In short, figure 4 highlights the interactions that take place between the links of decomposition or analysis (\) and construction, which means physical integration, or synthesis (/) of the system. When the cycle V is applied to all the components of a system (see figure 5), the number of loops can easily be deduced by decomposing and reconstructing the design concept. The systems approach is analysed with details of parts in order to know the whole design process. The systems approach as analysis and synthesis focus on internal structures along with a set of functional requirements given. Systems engineering goes one step further to establish what functions are required to design and built the successful system (or a product).

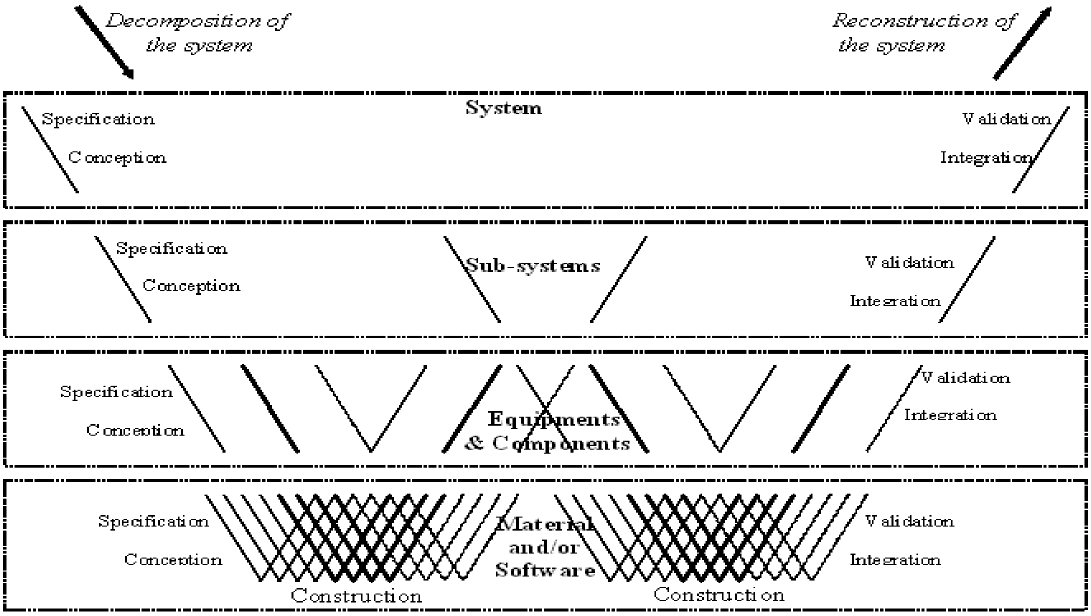

Figure 5. Sequences of V cycles for the development of a system

The SE process begins with eliciting stakeholder requirements and ends with acceptance tests where the final system or product is validated against the original stakeholder requirements. During the system development, verification is carried out at every stage to ensure that the intermediate developments meet the requirements and specifications, which have been set at the previous stages.

It should be noted that System Engineering defines the requirements for components, but it does not produce or manufacture components (Stevens, et al. 1998). Typically, traceability will be from the lowest level of user requirements to an intermediate level in system requirements. Figure 6 illustrates how many user requirements can be traced one system function.

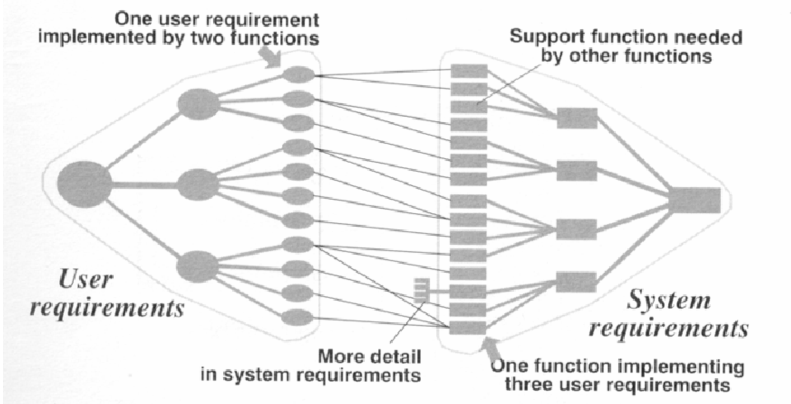

Figure 6. Traceability between user and system requirements

A large range of different types of requirements is needed for defining a system, and there is a complexity of inter-relationship between them. To organise the different types together, it is mentioned in (Stevens et al.) to choosing one type of requirement as the framework, structure that as a hierarchy and organise the other types of requirements around it. This framework is usually supported by the functional breakdown.

OPTIMIZATION IN DESIGN PROCESS

Optimization is a very useful and practical procedure for conducting trade studies when the cause and effect relationship between parameters and results can be specified mathematically or through simulation. From the mathematical point of view, optimization means techniques and algorithms with the help of which is calculated minimum or maximum of the target function (or the objective function), usually with many variables, observing additional requirements, expressed by equations or no equations way. These optimization procedures typically use gradient methods, which find the next local optimum. However, it is obvious to obtain information about the complete design space. Figure 7 describes an example of the grand unsolved problem in analysis local optimisations do not give a global optimisation. Although the problem is when non-convex objectives or constraints (wiggly contours) are necessary to distinguish local information from global optimization, issues of this interrelated dynamic optimisation are necessary to be driven by optimization algorithms so that the design space investigation is determined toward optimum or near-optimal solutions. The distinctions between those optimization applications are as follow:

- Local optimization - this optimization performs on a basis of block by block within a system of all basic blocks. A basic block is a sequence of statements where its optimum might represent the maximum, i.e. its derivatives might not be distinguished.
- Global optimization - this optimization is performed on a system over all its basic blocksin which it can perform analysis for an entire system. Therfore, all loops can easly be detected and optimized.

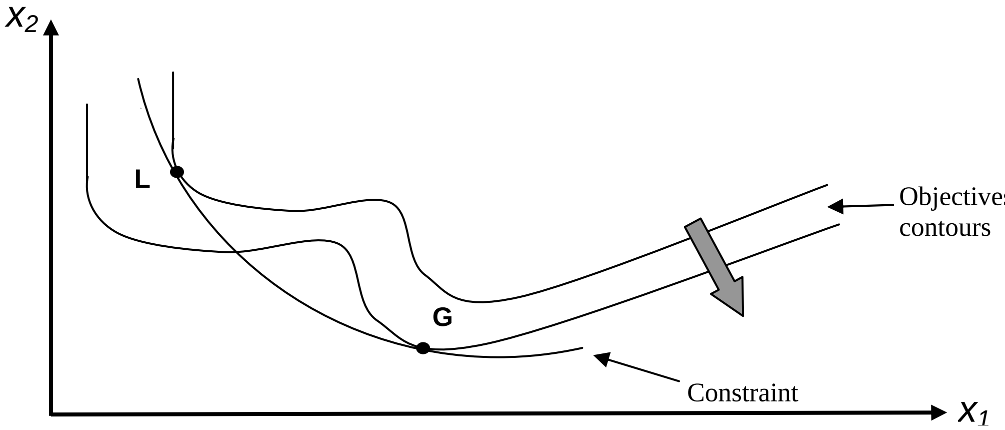

Figure 7. Example of the grand unsolved problem in analysis

Optimization techniques are extremely constructive for investigating sensitivity to key design parameters in order to find an optimal design. The objective of an optimal design is to select design points according to some criteria. Nevertheless the optimum design, with respect to structural building materials is extremely difficult to be built because of various constraints from other requirements. Therefore, trade off studies, which are part of the larger systems engineering environments, become very essential in building design, i.e. by comparing optimum models of design with different level of constraints. Those studies need results from several optimization tries for which the constraint definitions should be automatically produced. Figure 8 shows which cross-sections are considered in the entire project phasing, from the early phase to the disposal phase.

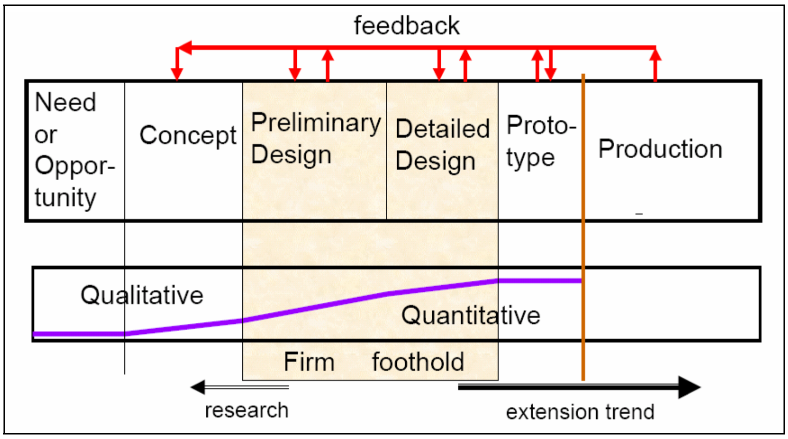

Figure 8. Decomposition for optimization in design process

Although Systems Engineering (SE) is a discipline created in order to be able to cope with the growing complexity of technical systems, this is recently recognised as a multidisciplinary approach to enable the realisation of successful systems (INCOSE, 2005). It focuses on defining and dealing with all phases required in the development of system life cycle. In accordance to all phases of design process from the beginning and predefined review activities at the end of design phase, qualitative and quantitative methods of optimization can be identified following the extension tend of design process. However, optimization is very useful where quantitative content is high. Issues necessary are given for both local and global optimisation while there are many different types of optimization routines to be determined.

For application in building design, it is essential to depict the trade-off between the objective function and constraint value as specified by a key parameter. This is often quoted as finding the “knee in the curve” that refers to the Pareto optimal curve. Optimization seeks to mathematically minimize (or maximize) an objective function of many parameters in the presence of one or more constraint functions. While there are many different types of optimization routines, the answer one receives can be no better than the specification of the objective and constraint functions. A bad objective function will, at best, result in an optimally bad design! For that reason, a simple decision tree analysis is useful for diagramming possible results, and probabilities associated with the outcomes can easily be added if known or postulated. Further extensions from utility theory can specify preference (or aversion) to known possible outcomes, and quantitative techniques can be applied based on either optimistic or pessimistic functions. These techniques can allow us to formulate courses of action based on maximizing the best outcome (maximax) or maximizing the utility from the worst-case outcome (maximin). Decision tree analysis can be useful when the probabilities associated with known outcomes can be specified or may be uncertain in their own way, but it is less suited to cases where there are unknown outcomes.

Previously, an example scenario described by Kim (and Szykman, 1996) illustrates the use of the refinement tool for assembly design. In this example, the conceptual assembly-modeling framework (CAMF) is proposed to enable the procedure of designing a television remote control assembly. However, the objective of this scenario is not limited to the conceptual assembly issues only but also to the optimization driven refinement results in materials being selected for design process. The choice of those materials was determined by the optimization performed by the tool and the deficiency defined early was considered without constraints. Alternatively, optimization can be used to improve a point solution in a design space, at a given design stage, in the latter phases of the building design process. Furthermore, a given decision (like e.g., the choice of materials to use) plays an important role on optimization techniques to use in order to find an optimal or near-optimal solution. Therefore, the use of optimization here can be described as an aid to explore the design support through the space integration and iterative design process.

EXTENSION TO BUILDING DESIGN PROCESS

From previous sections, it is clear that engineering a system using systems thinking and systems approach is the right way in analysing and resolving a problem or in developing a product (or a system). in contrast, the systems engineering process, which has been proved successful in other industries, is believed to be applicable to the management of this systems issue.

The ultimate of building design is to build a successful high-performance building. To achieve this goal, an application of the integrated design approach to the project during the planning and programming phases is mandatory. The fundamental challenge of buildings design is that all building systems are interdependent. To closely interact throughout the building design process, it is necessary that the building design process comprise the following steps:

1. Define and identify the customer’s requirements (or stakeholders)
2. Create alternative design concepts that might satisfy these requirements
3. Build, validate, and simulate a model of each system design concept.
4. Select the best concept by doing a trade-off analysis.
5. Update the customer requirements based on experience with the models.
6. Build and test a prototype and update the customer requirements.
7. Build and test a pre-design Update the customer requirements based on experience with the prototype.
8. Version of the building and validate the process.
9. Update the customer requirements based on experience of last analysis.
10. Build and test a design version of the building
11. Deliver and support the product.

Figure 9 illustrates a schematic approach of adapting a systems engineering model to the building design process. Then a typical systems engineering layout, which is the basic concept of the EIA-632 standard, for the application of the development of, systems design engineering, is used to expand the building process.

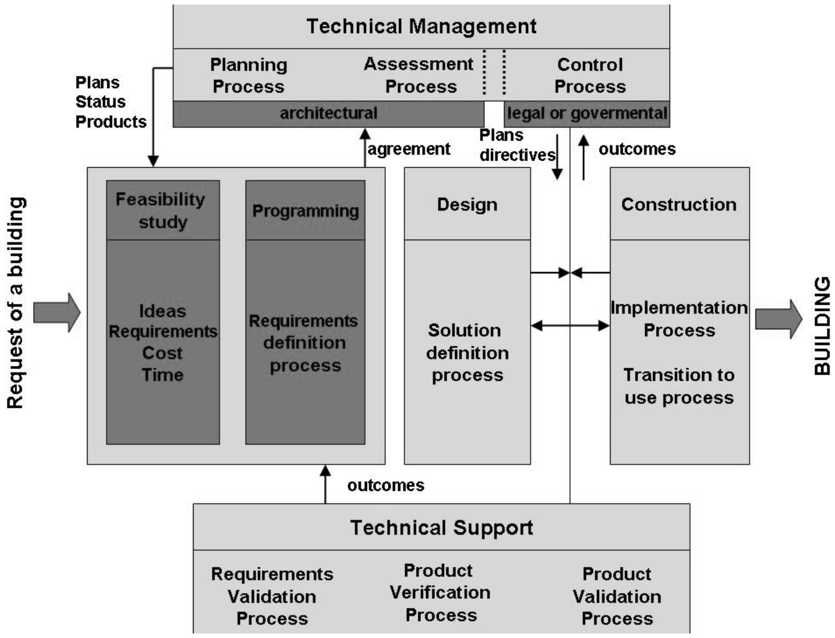

Figure 9. Systems engineering process in concurrence with building design

All steps described above can be depicted graphically on a Spiral diagram, a Waterfall model, a V cycle, etc. Indeed, the V-shaped life cycle is a sequential path of execution of processes. Each phase must be completed before the next phase begins. Testing is emphasized in this model more so than the waterfall model though. The testing procedures are developed early in the life cycle before any coding is done, during each of the phases preceding implementation. Figure 10 shows the schematic diagram of systems engineering combined with different phases based on the development of the building design (Yahiaoui and el., 2006). This illustrates a complete understanding of applying systems engineering concept to building design process.

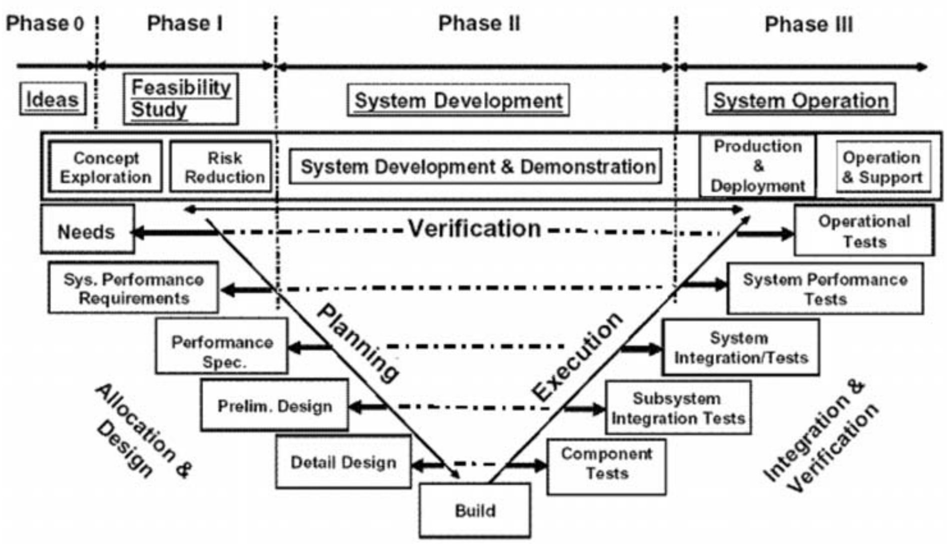

Figure 10. Building design process in form of V-shaped life cycle

A building architecture is a hierarchical framework for the structure of a system (building). Since a building can be a complex system, this system is decomposed into sub-systems and eventually component-level "chunks" that can be handled by individual team. Each phase in every V cycle is reviewed and finalized before handled over to the next design team. The system is then physically reconstructed from its individual components into sub-systems and eventually integrated into a complete system (building). Plans are in fact created to ensure that the sub-systems and the overall system perform as designed (verification) and ultimately meet the desired intent of the costumer (validation) by performing the desired functions.

On verification and validation. This step requires firstly determining whether the system built satisfies all system requirements. V&V processes are conducted during the project life cycle to ensure that a project meets the defined mission by fulfilling the identified functions and requirements (e.g. Sahraoui at al. 1999). This involves two different approaches:

- Validation focuses strictly on the requirements analysis and ensures that the right problem has been defined correctly.
- Verification focuses on the design solution for the validated requirements and ensures that the problem is solved.

Although the EIA 632 standard is applied for building design process in this study, about eight requirements for V&V are contained and evaluated in this standard. Figure 11 illustrates different V&V activities with respect to development of the V diagram. Specialty engineering functions participate in the systems engineering process in all phases. Those functions might be responsible for reliability, maintainability, testability, producibility, parts control, human factors, safety, design-to-cost, etc.

During requirements verification, systems engineering and test engineering verify the completed system design to assure that all the requirements contained in the requirements specifications have been achieved. Tests conducted to verify requirements are performed using hardware configured to the final design.

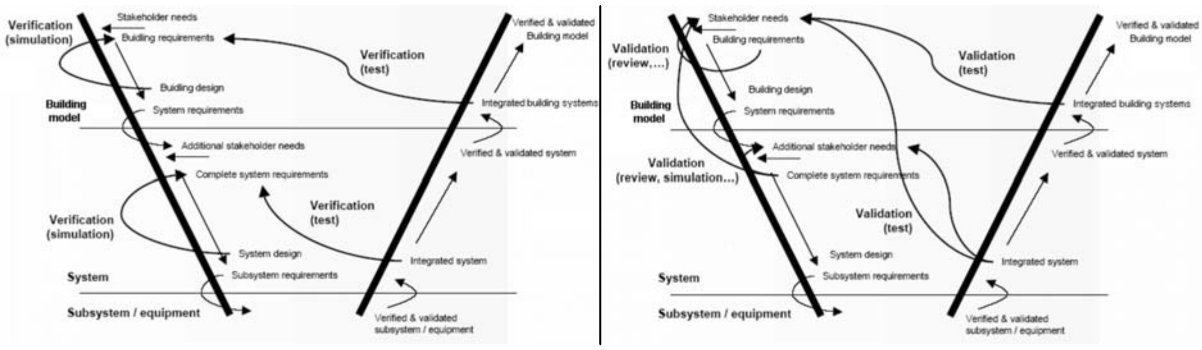

Figure 11. Verification and Validation activities

Traceability Issues. Another way of describing V&V is that verification is “constructing the building model right” and validation is “constructing the right building model.” It is important to recognize that every requirement should be traced in the system to its realising component(s), and vice versa from components to requirements. One-way to do this is through a requirements traceability matrix, as shown in figure 12.

Req.	Spec.Si	Design Di	S/w modules	
R1				
R2		X		
Rn	N/A			

X : relational link between a requirement and a design

N/A : Non applicable *(no apparent link)*

Figure 12. Traceability table between requirements and functions

EXAMPLE OF APPLICATION

This section illustrates how the SE concept can be used for the implementation of the total view approach. For example, if a building model is considered two operational functions are sub-systems of this model and heating, lighting power, waste, water and security are components of this model. To build the building model capturing all the necessary information an expressive modelling technique supporting hierarchies (abstractions) and several different views of a design are required. “Systems decomposition” skill, a method based on breaking the building model down to smaller and smaller parts until they can be easily understood and their performance easily modelled and subsequently verified. In figure 13, a classical functional analysis for systems decomposition is applied to breakdown a building model in order to detail specifications and design development followed by components, sub-systems and systems verification. An optimized design for conducting trade studies when the cause and effect relationship between parameters and outcomes can be specified, in this case mathematically or through a simulation. In fact, optimization techniques are extremely useful for investigating sensitivity to key building design parameters.

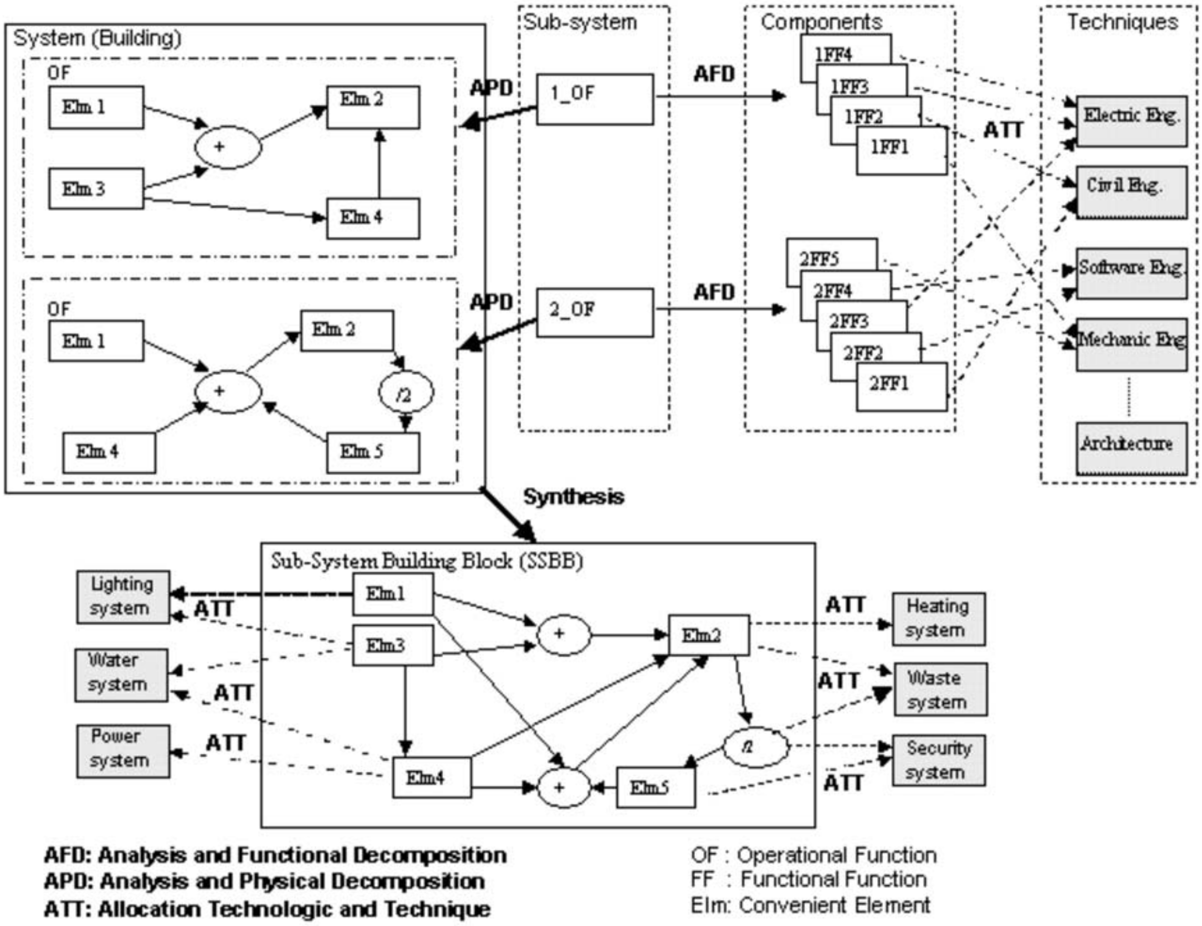

Figure 13. Building model functional breakdown

In the case of design space, the systems engineering uses an iterative process, from top to down (or top-down), hierarchical decomposition of system requirements, supported by trade studies that record the basis for significant decisions and the options considered. This iterative, top-down, hierarchical decomposition methodology includes the parallel activities of Functional Analysis, Allocation process, and Synthesis. The iterative process begins with system-level decomposition and then proceeds through the major subsystem level, the functional subsystem level, to the hardware/software configuration item or assembly/program level. As each level is developed, the activities of functional analysis, allocation, and synthesis will be completed before proceeding to the next lower level, as described in figure 5.

In consequence, functional function may be achieved by software, hardware, a human interaction, etc. The goal at this stage is to address what functions needed. Convenient function is an operation of the action that system must perform to accomplish its purpose. Functional analysis is the interactive process of breaking down, or decomposing requirements from the system level, to the sub-system, and as far down the hierarchical structure as necessary to identify specific components of the design space.

CONCLUSION

In general, the complexity of design process is rooted in generating alternatives and directing search towards optimal design process. One of the preliminary issues is attempting to describe how to exploit the structure of the design problem to apply systems engineering environments to the building design process. As an example of applying systems engineering in building design, a design procedure used consists often of decomposing the (complex) system into a set of sub-systems, which may further may be divided into equipements and components, and so on. This leads to a design space, which is based on a hierarchical structure that concerns the entire system development life cycle. However, the design iterations are driven by optimization, systems engineering with assistance from the other engineering disciplines can establish the baseline system design by optimizing design process across multiple levels of abstractions in a decomposition methodology. Additional research is necessary to provide insight into how knowledge problems of building design can be used to define useful optimization techniques to consider in different phases of the design process.

The results of the building design process serve to define good requirements. Then, a conceptual building design can be used to develop a technical specification (usually called a document of specification requirements). This is important issue concerning this perspective in building; there may be benefits in making a common document of specification requirements based on a trade-off between cost, schedule and requirements in order to realize a building project with at least both significant aspects: lower cost and customer satisfaction. In fact, this documentation would be the principal source of building design process used for developing, updating, and completing all systems and subsystem specifications, interface control requirements, specification trees, and test requirements that concern the design space.

REFERENCES

Blanchard, B. S., 1998, Systems Engineering Management, 2nd Ed. John Wiley and Sons, Inc.

EIA-632, 1998, Processes for Engineering a System, ANSI/EIA-632, EIA.

Chapman, W. L., Bahill, A. T., and Wymore, A. W., 1992, Engineering Modeling and Design; CRC Press, Boca Raton, FL.

Defense Systems Management College, 1990, Systems Engineering Management Guide. Fort Belvoir, VA

Fabricio, M. M., Melhado, S. B. and Baia, J. L., 1999, Brief reflection on improvement of design process efficiency in Brazilian building projects, in Proceedings of IGCL-7, University of California, pp. 345-356

Forsberg, K. and Mooz, H., 1991, The Relationship of System Engineering to the Project Cycle, Proceedings of the 1991 INCOSE Symposium

Hunstad, A. and Hallberg, J., 2002, Design for securability-Applying engineering principles to the design of security architectures, Prococeedings of WAEPSSD, Massachusetts, USA.

Hoang, N., Jenkins, M., Karangelen, N., 1996, Data Integration for Military Systems Engineering, Proceedings of IEEE Sump. & Work. on Eng. of Comp. Based Systems, USA.

INCOSE, 2005, International Council on Systems Engineering, INCOSE's website, http://www.incose.org/about/hall/fellows.aspx

Kim, G. J. and Szykman, S., 1996, Combining Interactive Exploration and Optimization for Assembly design, in proc of ASME Design Engineering Technical Conferences and Computers in Engineering Conference, No. 1482, Irvine, CA

Loureiro, G., Leaney, P.G. and Hodgson M., 1999, A systems engineering environment for integrated automotive powertrain development, Society for Design and Process Science, Vol. 3, 4(41), USA.

Shishko, R, 1995, NASA Systems Engineering Handbook, NASA,USA

Sheard, S. A. and Lake, J. G., 1998, Systems Engineering Standards and Models Compared, Proceedings of 8th Symposium of INCOSE, Vancouver, Columbia.

Stevens, R., Brook, P. Jackson, K. And Arnold, S., 1998, Systems Engineering - Coping with Complexity, Hertfordshire: Prentice Hall Europe.

Sahraoui, A.E.K. and Jones, D., 1999, Validation & verification: towards a system engineering framework, Proceedings of 13th of ISCE, Las Vegas, USA

Won, C.H., Sale, D., Schultz, R.R., Johnson, F. and Semke H., 2001, Spacecraft Systems Engineering – The Initiation of a Multidisciplinary Design Project at the University of North Dakota, Proceedings of ASEE-ACE, pp. 8951-8963

Yahiaoui, A., Ulukavak Harputlugil, G., Sahraoui, A.E.K and Hensen, J., 2006, The Application of Systems Engineering on the Building Design Process, Proceedings of the 1st International CIB Endorsed METU Postgraduate Conference, Ankara, Turkey, pp 205-218