INTEGRATION OF IT IN BUILDING DESIGN AND TECHNOLOGY: A SYSTEMS ENGINEERING FRAMEWORK

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ABSTRACT

Most concepts of systems engineering (SE) offer a systematic approach to the adaptation of procedures, tools, and standards toward an information-oriented problem in order to analyze, to design, to develop, to manage and to finally implement an effective and a pragmatic integrated information technology solution. This paper proposes a systems engineering framework for integrating information technology (IT) in building design and development. The system view is based on SE good practice and corresponding SE standards. All lifecycle for systems development is covered ranging from the operational concept to operation and maintenance and disposal. The paper is focused mainly at the requirement engineering levels and validation verification issues. In addition, this paper involves a case-study with an important setup where the simulated results are obtained within the use of distributed control and building performance simulation software by run-time coupling. The case-study is also developed in an effective way to illustrate the integration of IT in building design.

KEY WORDS

Systems engineering, information technology, verification and validation, hybrid systems, building performance simulation, energy consumption

INTRODUCTION

The technologies involved in building design and implementation covers many disciplines ranging from thermal, civil, electrical, mechanical engineering and so on. It involves also many processes from requirement process, design process, validation processes till implementation process and disposal process. If in the past many traditional methods have been effectively used with success, there is now a need for rapid development (agile development) but keeping the costs low. Mastering all processes and many interdisciplinary skills require a comprehensive approach. The informational technology is now applied in every aspect; for a building, it ranges from CAD software packages for architecture and civil studies to simulation of equipments for heating, ventilation and air-conditioning (HVAC) systems, of electrical and lighting components; and of control of such building equipments and components towards a desired comfort within a minimum energy consumption.

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There is a common agreement that social acceptant of IT (information technology) must take into account various technical aspect such comfort, security and safety. Integrating such a technology is not "yet another add-on artifact" but a balanced approach that preserves invariant properties with additional constraint as cost reduction: the tradition slogan here applies "faster, better and cheaper".

The remainder of this paper is organized as follows: the next section presents a brief description of context, problematic and state of the art. Then it follows the reasoning behind using system engineering and general deployment approach. This is followed by an application for a building model towards an integrated system. The next part elaborates case study demonstration, and finally conclusions and perspectives.

CONTEXT, PROBLEMATIC AND STATE OF THE ART

CONTEXT AND APPLICATION

The context in this work is related to building services. The integration of Building Science Engineering, Architecture, Construction Management and Risk Assessment Services for new construction projects and existing buildings becomes a must. Building a systems require a lifecycle of development as shown in figure 1.

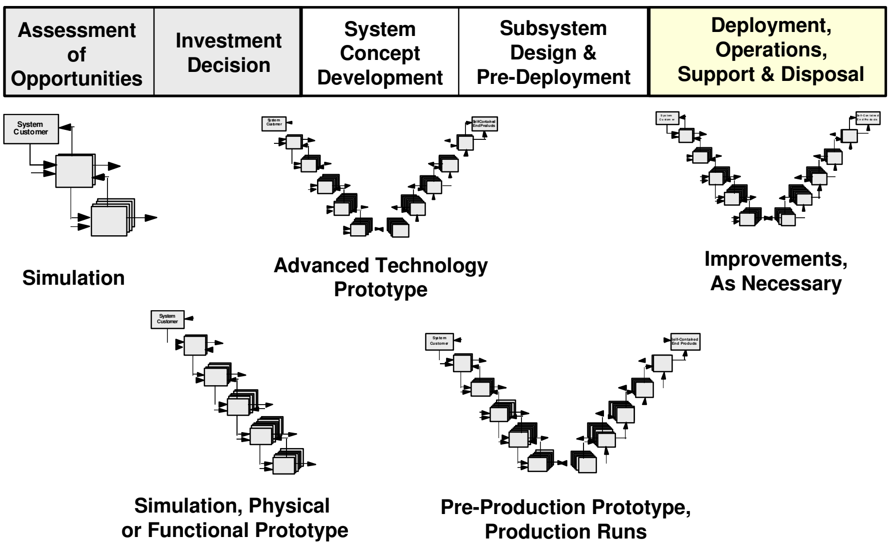

Figure 1: Enterprise-based life cycle phases

We are concerned in our context from the systems development (including subsystems design and deployment operation) the deployment operations concerns the multiple development and implementation of the initial systems as a final system or a prototype.

PROBLEM STATEMENT

There are numerous approaches to integration of technologies. However, a comprehensive approach where to see a building as a systems by itself. Such systems to be built needs requirements ranging from users/stakeholders requirements to institutions, standards, local, national regulations, etc, where is the limit of such integration if a global approach is not used. We focus in this work on the problematic of integrating advanced techniques in control supported by IT (information technology) tools to monitor an optimal design.

STATE OF THE ART

Up to our knowledge there are not yet establishment mythologies and approaches linking systems engineering (SE) and building HVAC (Heating, Ventilation and Air-Conditioning) systems and other components. Nevertheless, few energy research departments in America, like for example (EERE, 2006), use systems engineering to home building as advanced framing and insulation methods to increase efficiency and comfort while decreasing costs.

SYSTEM ENGINEERING AND GENERAL DEPLOYMENT APPROACH

Figure 2 provides a guide to the application of the systems design processes to a building block when the end products are either precedented or unprecedented. At this point, the main processes can be identified from initial requirements as safety, comfort, etc …

Without neglecting the various stakeholders (users and developers)

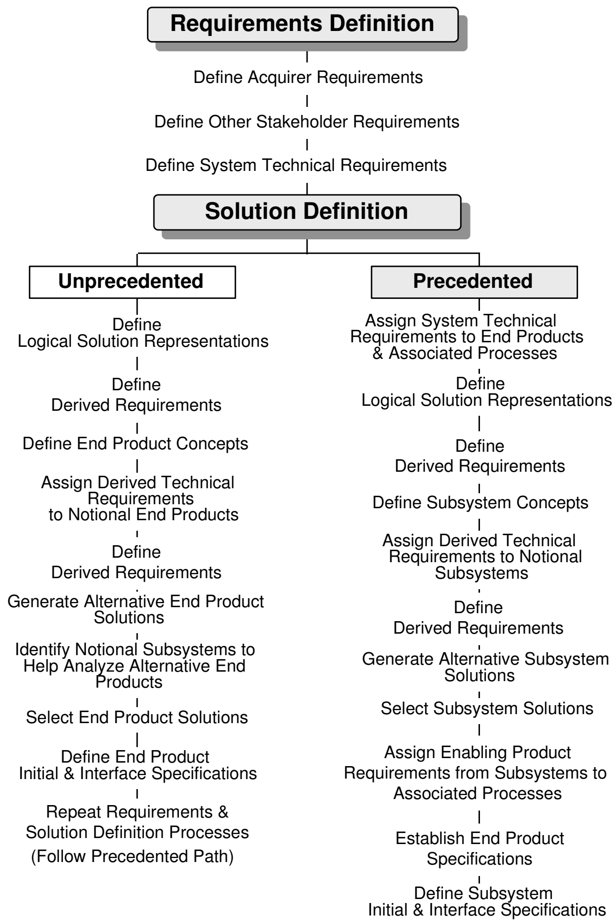

Figure 2: Approaches for unprecedented and precedented end products

The process of identifying key processes with respect to the application can be the most difficult task in deployment and customizing the SE processes for the application.

SYSTEMS ENGINEERING AND PROCESSES

SE practice is not new but the discipline is. It started to be with large-scale programs in USA in aeronautics (see e.g. Mathers et al. 2000), space (Shishko, 1995) and particularly in defense (see e.g. Defense Systems Management College, 1990 and Hoang et al., 1996). Furthermore, it is getting popular in country having a well-established aeronautic and military industry; it has been since the 1990's deployed in manufacturing, automotive (Loureiro et al. 1999) and recently in SME (Society of Manufacturing Engineers), see for instance (INCOSE, 2005). As a simple definition: *Systems Engineering (SE) is* an *interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and life cycle balanced set of system people, product, and process solutions that satisfy customer needs. Systems engineering encompasses: (1) the technical efforts related to the development, manufacturing, verification, deployment, operations, support, disposal of, and user training for, system products and processes; (2) the definition and management of the system configuration; and (3) the translation of the system definition into work breakdown structures Development of information for management decision making*

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. The generic modem is shown in figure 3 (i.e. systems engineering standard EIA-632).

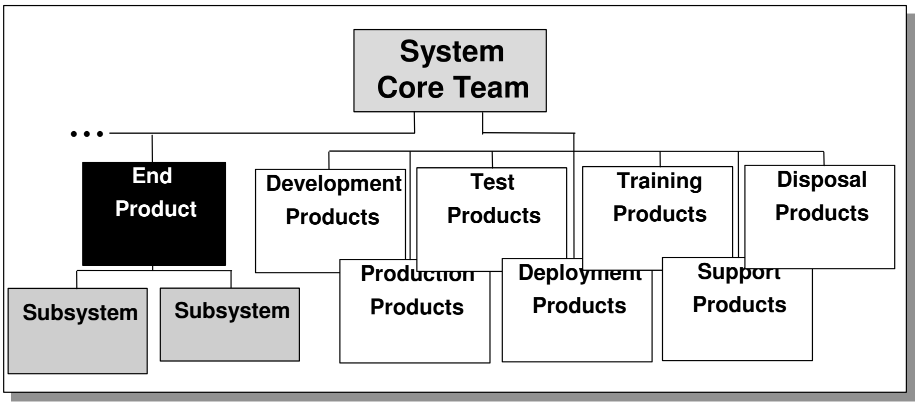

Figure 3: The Generic Framework

SYSTEMS OF SYSTEMS

The deployment of SE product can be carried out in a comprehensive approach by separating the final product (the building model) from the enabling product (production systems: crane, etc.) and development product (simulation tools, etc.) this can be best illustrated by the following figure 4.

A single block 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).

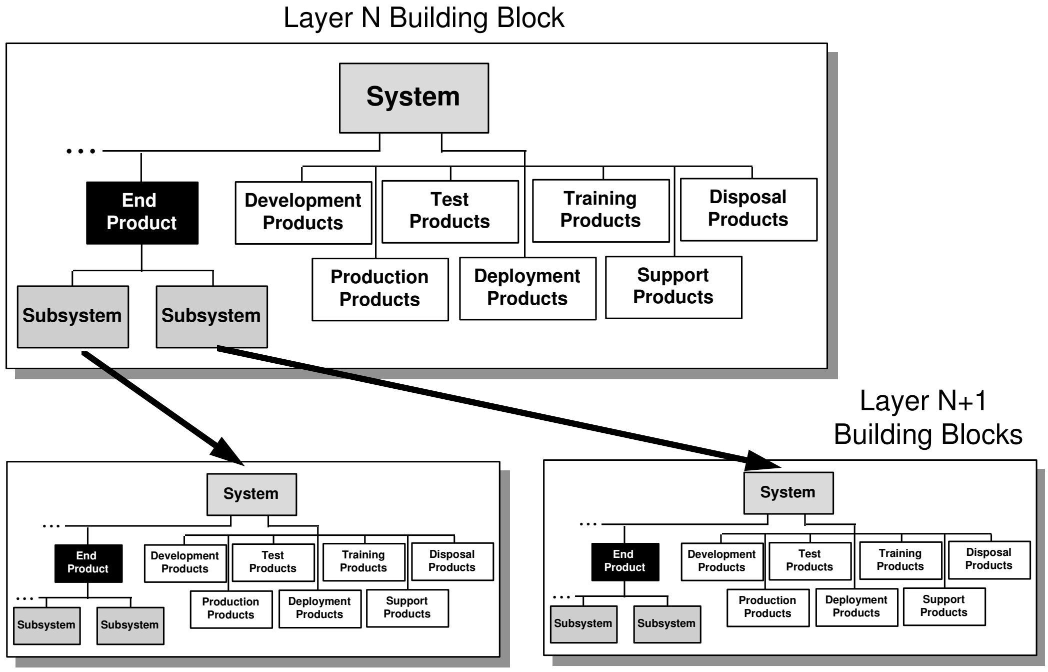

Figure 4: Hierarchy of building blocks

SE DEPLOYMENT AND STANDARDS

To deploy SE for a specific application for a building model, this requires to identify all sub systems that either contained in the final product (the building model) and subsystems that are part of enabling product for integrating building equipments and components (the control of HVAC systems, lighting, etc.). Although HVAC systems, lighting components, elevators and/or escalators, and fire and security equipments can be integrated within one building automation systems (BAS), the simulation modeling tools used for this context (BAS) play a leading role in enabling the current building model as a final product.

TOWARDS AN INTEGRATED SYSTEM

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 objective of this research is to apply the deployment strategy to a building model and refine the SE architecture (EIA-632, 1998) to the level concerned. By taking up such the approach illustrated in figure 5, this SE concept, which has been proved successful in other industries, is believed to be applicable to the management of a building control system issue.

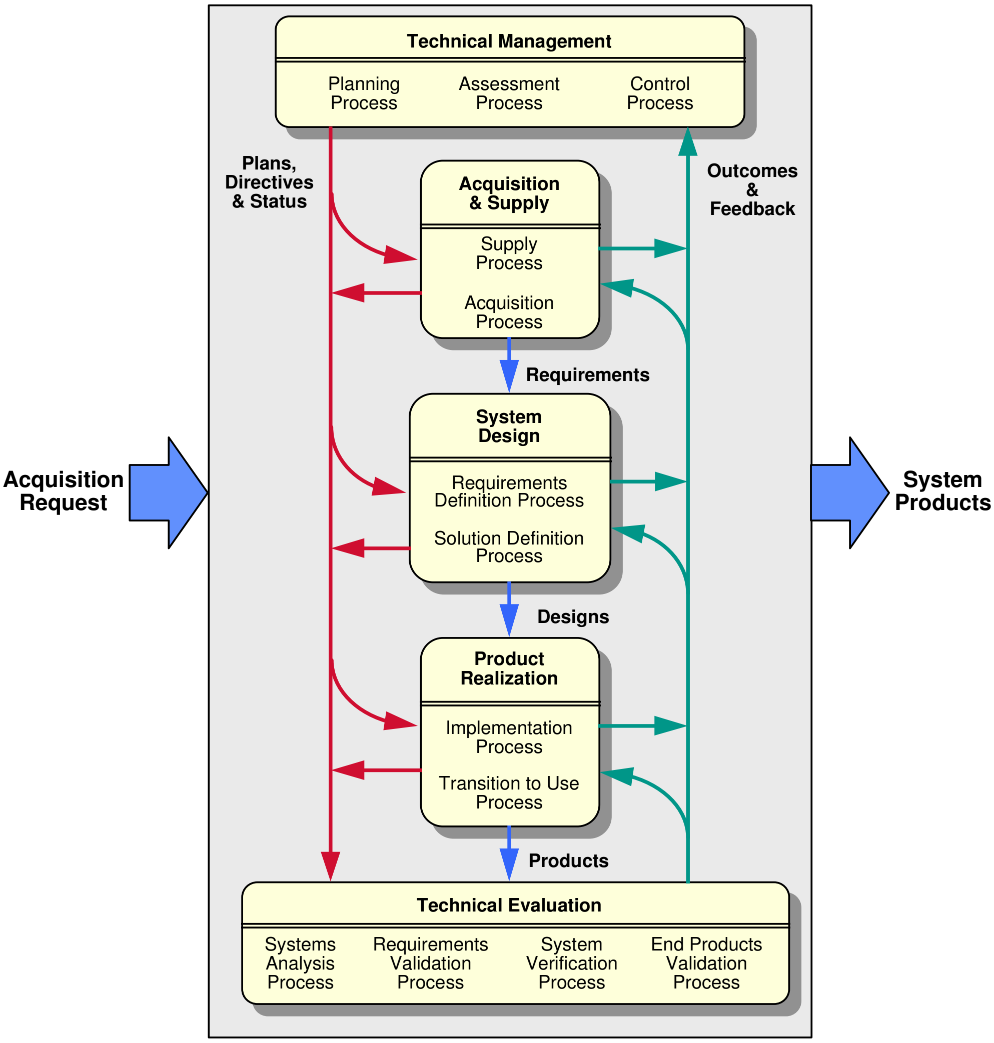

Figure 5: Relationship processes of systems engineering

BUILDING SYSTEMS AND SE

There are many systems in the building model: the building design itself is as the final product and its subsystems but all systems that enable this building model are as a product. Concerning the controller for example, the enabling product is domain dependent control modeling environments (CME), like for instance (Matlab/Simulink, Labiew, etc.); and for the building design, the enabling product is domain specific software for building performance simulation (BPS), like for instance (ESP-r, TRNSYS, etc.). Although, our current work starts from specific BPS and CME simulation environments, an approach to distributed control and building performance simulation software tools by run-time coupling that is developed and implemented, have much wider and more general applicability. ESP-r and Matlab/Simulink were selected as BPS and CME software tools respectively. Consequently, ESP-r is used for building modeling only and Matlab/Simulink is considered as a controller that can be configured remotely. It is felt that this type of technology development will enable design and evaluation of advanced building control applications that are currently not yet possible.

GENERIC PROCESSES AND INSTANTIATION

A generic process has evolved into a well-established reuse approach in systems engineering to support a vast variety of applications. Basically, the generic processes are closed to the primary systems engineering concepts and patterns that are widely recognized and reduce domain complexity in system production and system use. At the same time, the generic solution must provide a powerful, extensible construct on which the design of distributed control and building performance simulation can be effectively based. Hence, two most important steps are considered in our context. The first step concerns to address systems concepts by indicating system components, system boundaries and the system universe of environment. As the second step, engineering concepts that must be supported by the generic model are problem solving and structured distributed solution development. Figure 6 illustrates the generic processes, which are applied in the context of our current work.

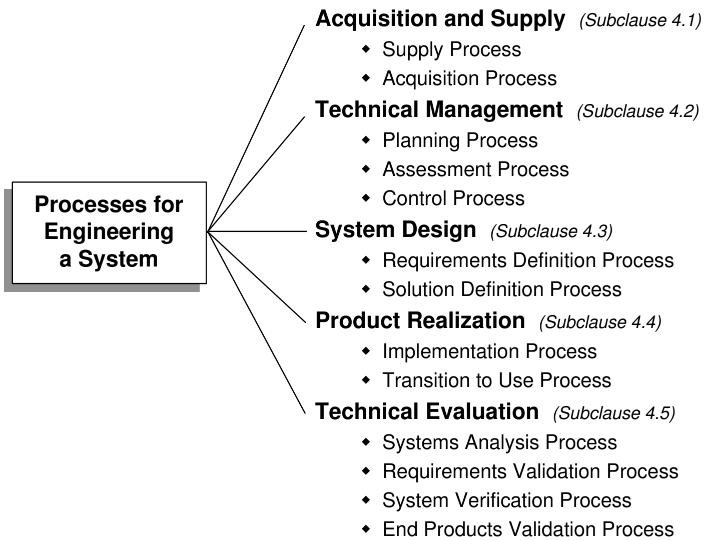

Figure 6: Generic processes for developing building control systems

THE FRAMEWORK

From previous sections, it is clear that engineering a building control system using systems thinking and systems approach is the right way in analyzing and resolving a problem or in developing a product. Therefore, the framework developed for run-time coupling ESP-r and Matlab/Simulink is based on the natural information found in the systems engineering activities (e.g. Lightfoot, 1996). Figure 7 shows a complete understanding of data exchange between building model and its controller. The exchange is performed via TCP/IP protocol. More details, see (Yahiaoui et al., 2003, Yahiaoui et al., 2004 and Yahiaoui et al., 2005).

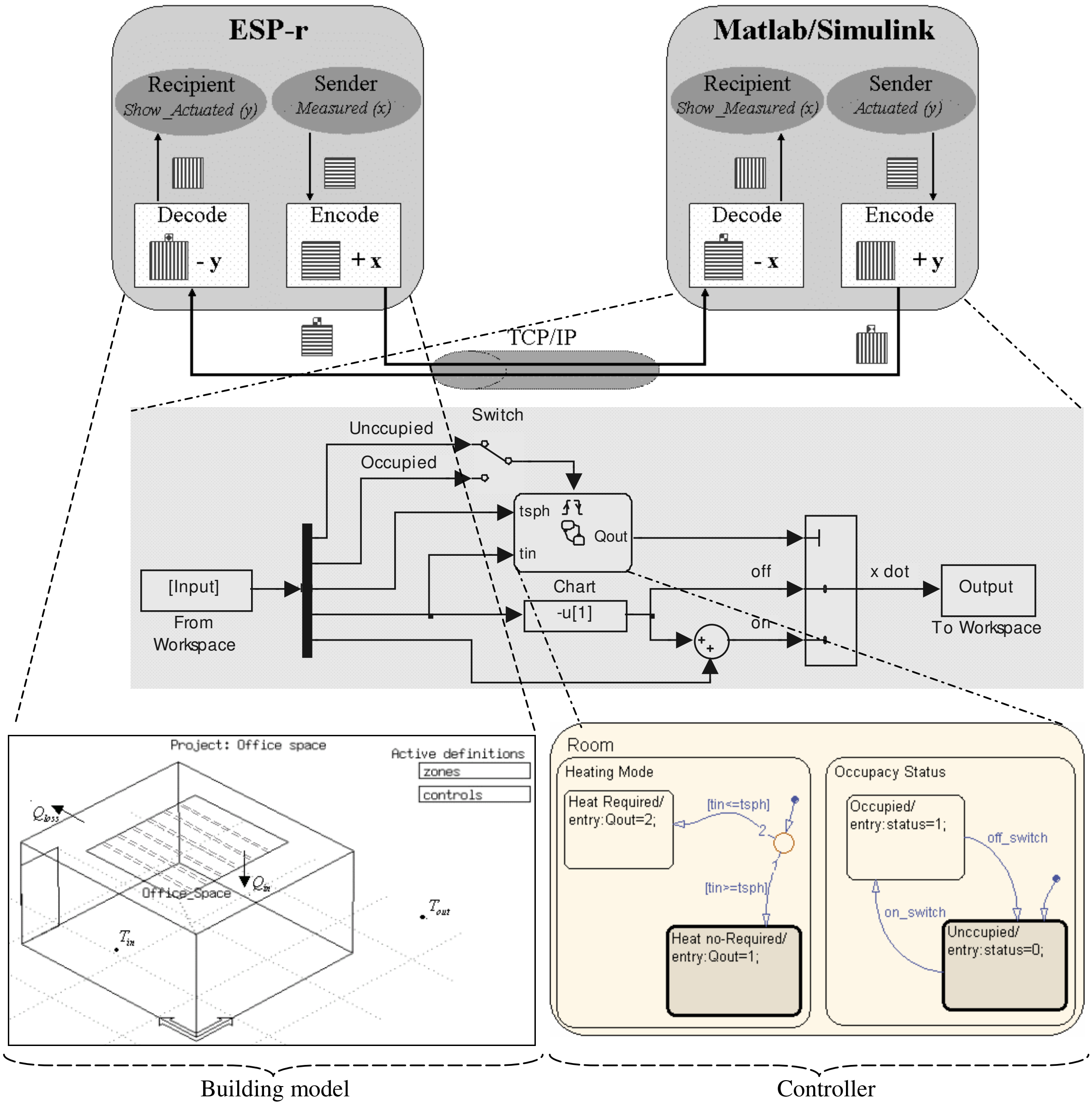

Figure 7: Distributed control and building performance simulation environments

During simulation, commands and data are transmitted between ESP-r and Matlab/Simulink. If for instance the building model (i.e. ESP-r) has to send its actual measured process to its controller (i.e. Matlab/Simulink) with TCP/IP-stream, a method called encodes them first and then transmits them with a defined control sequence via TCP/IP to a method received. This receives the control sequence, decodes data from TCP/IP format and sends them to the recipient (Matlab/Simulink). When the controller has to send back the actuated process to its building model via TCP/IP, the same procedure is followed in this case, as shown in figure 6.

The concept of distributed control modeling and building performance simulation by run-time coupling is widely accepted within both software engineering domains. However in this concept, t is ESP-r, which starts the simulation. Indeed, Matlab is launched at every ESP-r time-step as a separate process. If the connection between ESP-r and Matlab/Simulink breaks down the data cannot be exchanged until the communication between them is reconnected.

CASE STUDY

BUILDING HEATING SYSTEMS

A requirements document for building heating system is well documented and described in (Booch, 1991). On the assumption proposed in this paper, it demonstrates that a model-based design provides numerous advantages over the traditional design approach. In that actual fact, a number of the limitations or shortcomings presented in traditional design using classical or conventional control methods can be avoided. As a result, model-based control design can provide a time- and cost-effective approach based on the development of simple dynamic control system when a single building plant model is used.

However, an application for a building case-study model is presented on the left side of figure 7. The application comprises a working office space unit (4.8*4.2*2 m3) with two radiant-ceilings used for both heating and cooling mode. A controller is used to regulate the appropriate temperature inside the room by opening or closing the valves on pipelines. The constructions used in this office space are internally insulated cavity walls and internally single glazed walls. The office is sited around the atrium. The walls facing south and the atrium are in a single glazed structure. It has a thermostat in which the user is allowed to set a temperature at five degrees higher or lower than the common set-point, which is 21 °C.

SIMULATION RESULTS

A building model represented on the left side of figure 7 is implemented in ESP-r by carrying out the same material proprieties as used in the construction, and its controller shown on the right side of figure 7 is realized in Matlab/Simulink.

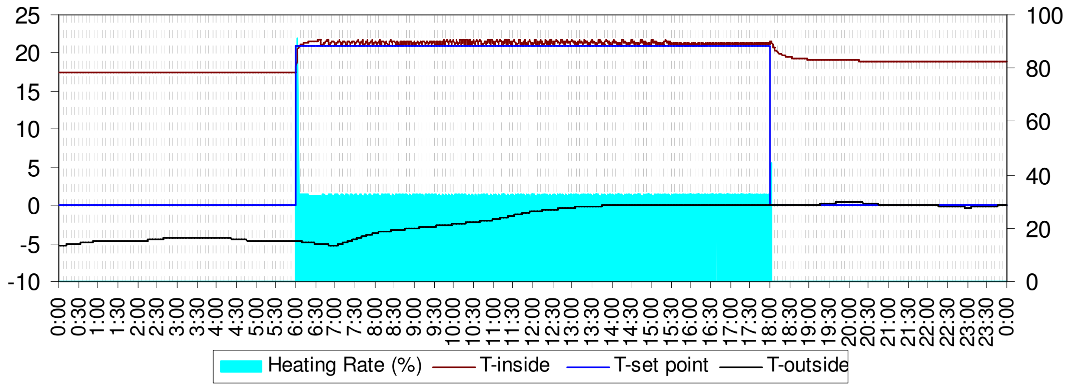

Figure 7: Simulated results obtained with distributed simulation

The simulated results, obtained in Figure 8 show small oscillations of the controller response around the set-point in working period (6:00 to 18:00 o'clock), this is due to the disturbance variation as controller capability used in hybrid automata can not prevent errors early. In addition, hybrid systems can be easily coupled with model based modern control techniques (see e.g. Sazonov, 2003). This can aid in the elimination of errors early in the control design phase resulting in a more robust control system and stability notions that refer to appropriate formalisms of their correctness. As a result, many practical applications can be modeled accurately using a simple hybrid models and two main advantages of such models are an important design tool for rapid prototyping of controller designs for real-time systems, and for a greater confidence for their functioning according to requirements specification.

Although dynamic simulation involves the calculation of the performance of the building processes (e.g. temperatures with time), using time-varying climatic variables, occupant and control strategies as boundary conditions; the role of information technology (IT) is very important in the design and evaluation of buildings. With the domain based approach to distributed control modeling and building performance simulation environments by run-time coupling described previously, the simulation of a building control system can now evolve with the complete design process considering both building model and its controller.

CONCLUSION AND PERSPECTIVES

A conceptual architecture framework for integrating information technology (IT) in building design and development of distributed control modeling and building performance simulation by run-time coupling is presented throughout the use of systems engineering processes (principles, techniques, and practices). This work has demonstrated a procedural design approach to the development of simple or complex dynamic control systems for either single or complex building plant model. Hence, the importance of integrating information technology (IT) in the building design evolves distributed control modeling and building performance simulation environments by run-time coupling over TCP/IP. Consequently, distributed control modeling and building performance simulation environments by run-time coupling has evolved into a well-established reuse approach in software engineering to support a vast variety of applications that can be qualified with any model-based control system can now be used for any integrated building plant model. Sorter concept that offer a systematic approach to the adaptation of control modeling and building performance simulation software tools toward an information-oriented problem has been analyzed, developed and implemented with an effective integrated IT solution. With this approach it is now possible to achieve better building performance and handle larger systems.

Among perspectives, the complexity of information technology solutions requires an effective application of distributed control and building performance simulation by run-time coupling tailored to the specific issues concerning a design process reflecting both the building model and its controller. The current challenge is to apply systems engineering framework for integrating information and communication technologies by developing an approach, which matches the required utilization to the requirements specification in an orderly manner so that the simulation results can be used effectively in the development of a solution which meets all the occupants' needs. Future work includes a mature design system of distributed simulation that would be able to run on a wide range of computing platforms.

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