A HOLONIC APPROACH TO THE INTEGRATION OF AUTOMATED SYSTEMS

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Abstract. During several years building and residential automation was thought as a good test bed for integration methods applied to automated systems. A reason for that is the large response time of these systems and the fact that they assemble a set of very well known sub-systems (HVAC, security, elevators, etc.). Even recent innovations in residential environments are based on components based on solid and scalable technology. On the other hand the degree of integration did not improve as much as expected. In this paper we investigate this problem, first from a practical point of view, that is, based on the design and implementation difficulties that designers and vendors face everyday, and second from a technical and methodological point of view, which means finding a new control architecture that could lead to real flexible and integrated systems. Frame architectures could provide a better and modern approach relying on a heterarchic arrangement of sensors and actuators. Some years ago part of the authors proposed a similar architecture based on a generic element called integron. Now we revisit the same point with a new version of the same element focusing on the arrangement of the whole system and on the information flow instead of just distributing the control. We claim that such approach is more efficient. Also it will better fit the requirements in a heterogeneous environment such as residential automation.

Keywords: residential automation, integrated and flexible control, control architecture

1. INTRODUCTION

The introduction of integrated systems in automated process has being a challenge in mechatronics no mater what would be the application domain. It is widely agreed that integrated systems are far more complex to design and implement and there are also projection (not well verified) that such systems are also difficult to maintain, even if this statement is quite controversial as we would point later.

What is clear is that integration also means some kind of coupling what goes in the opposite direction then the basic recommendation in the Principles of Design proposed by Nam P. Suh (1990). By these principles a good design practice consist in identify parts uncoupled or as much uncoupled as possible. Somehow, and integrated approach for design create dependencies, information and/or data exchange between components that otherwise would be weekly coupled. The open space for modularity also contributes for that providing multiple ways of dividing a huge systems some of them strong or weak coupled. A trivial example for that in building and home automation is to design a system where there is an ascending system uncoupled from the security or presence detecting system. In hazardous situations elevators must be isolated and should close doors, except if occupied by people. That means to detect presence even with sensor that are property of the ascending system or that belongs to the security system.

Of course the first solution could lead to a duplication of equipment and programming. Therefore there is a cost associated to the uncoupling, the same way that there is a unavoidable design cost due to integration. The proper balance depends on the specific domain environment, that is, on the home or building environment where they have to be implemented, on the nature and performance of the different possible architectures. Of course the most efficient and easy to maintain would be the selected one. Thus, and important clue in that discussion is that the design process should in fact decide if the integration is really necessary and would bring good results. A good requirement elicitation is also a reference in that decision as pointed in section 2.

Roughly speaking the design process in home and building automation just follow the same paradigms and techniques used to automation and software engineering, where the design activity is product oriented. Even in software design where the final product is immaterial it is common, and even interpreted as a good practice, divide the process in deliverables that play the role of a sub-product or component. This approach also approximate the design process to a linear stepwise activity, very suitable to classical software approach.

We claim that for this kind of domain application a service oriented approach [Lush et al. 2008] , [Spohrer 2008] would be more suitable and potentialize better results for the clients. Lush at al (2008) presents the difference between a service-dominant approach and a product-dominant one, applied to information systems. In this paper we develop a similar argument for engineering projects, and particularly to home automation. The need to have a project that attend all requirements, specially the client and user viewpoint is a key point in home automation and make this application specially sensitive to product or service approach. In section 3 we discuss new trends toward a new architecture for home

automation based on these principles.

However the potential results would still depend on the accuracy of the design process, as pointed before, and specially on the capacity to analyze and verify the requirements. Therefore a formal representation must be provided that can provide a service-dominant approach. That means a formal schema to discrete events capable to model components and its dynamic relation at the same time, since the service-dominant logic is related to process and components equally. That would be responsible for the holonic approach, or for the capture of properties for the overall system that are not just an assemble of the components properties. Integrated systems could generate such properties.

Section 4 will present briefly how a unified object-oriented Petri Net could be suitable to represent integrated projects for home automation following the conceptual guidance mentioned above.

Finally, Section 5 will present a simple example for a hypothetical house were different rooms were independently automated as different and independent objects that should be integrated with the remaining system since the HVAC and security systems should not be replicated (with redundancy of equipment) just for these rooms. A mock-up of this experiment were built in our lab a couple of years ago and the data generated still supports our design approach. Section 6 presents final remarks and point for further research.

2. REQUIREMENTS VERSUS FRAME PRODUCTS

The called early phases in the design process is also the focus of a conceptual point to be discussed, concerning home automation. Available research about the market of home automation in the world shows that there is a gap in what is still characterized as the widespread adoption of the technology associated with this application [Moore 1991]. This what is called the crack in the bell curve as presented in the book of Geoffrey Moore (1991) that describe the cycle of adoption of new technologies.

Even if that is well accepted regarding the use of home automation, we should also consider additional points such as: if we consider the start point for home automation in the beginning of 80's, its early adoption cycle (considering the bell curve) would goes up to the firs years of this century. By this time, building automation was already experiencing a more widespread adoption in banks, military buildings, schools etc. Thus, it is important for any interpretation of this evolution to explain why home automation does not follow building automation in that cycle of development. Certainly both applications of automation evolve together and even some features developed initially to building automation were later reused in home automation.

In our opinion such detachment occurs because there a subtle difference between these markets: in building automation a stakeholder is identified that is absolutely independent of the users, even if sometimes the stakeholder assume also the position of a user. In home automation the stakeholder (the one who hires the project) is also the dominant user (the home owner who is supposed to live there). Such duality make the process of convergence of the viewpoints in the requirement engineering process a lot more complicated and the acceptance of the technology more difficult. That could explain why so much time were expend in to bridge the gap in the bell curve.

This duality constitute a great appeal to the customization of home automation projects, that is, if a set of component products were offered, it would be important that these components could be assembled in a multitude of ways to be adherent to each costumer. Therefore, flexibility is a key word in this market. That means pushing requirements with coupled viewpoints (stakeholder and final user) inside the design process.

However, what happens in home automation is just the converse approach: Guided by the need of reusing tools and techniques already successful in building automation, home automation inherit a lot of components that make such flexibility impossible or at least very difficult. Thus, a mix of service and components is disposed in home automation, what we will call a frame to other companies specialized in the proposition of a higher level integration project. Unfortunately that could not be enough to fit the demands of stakeholder/users as pointed above. On the other hand providing a granular service (dividing the frame in even small subsystems) could not be rentable.

We have then a good engineering challenge: to find a design process that would provide a flexible approach, customizing a frame of "products" that could be further assembled (as proposed for several specialized home automation institutions) and integrated. The rentability problem could be solved if a mass customization is envisaged instead of a personal one, considering that the further assembling could also make the necessary adjustments to the individual stakeholder/user. Note that we are not referring to market techniques or advertisements tricks but to fully engineering design of automated systems, where "fully" means taking in account implementation and deployment as well as affordability of the project.

A preliminary prospection in the home automation companies already show that the called early phases of the project are not completely observed, even because stakeholders/users are not patient enough to go through that process, and because of the duality of their position. Thus, although all the effort from designers a forced adaption of the frame described above is always the solution. In other words, the payoff of the majority of the home automation projects is questionable from the viewpoint of the stakeholder/user. Even attempts to show a good return by focusing in energy saving or in the security system is not as appealing as expected.

Our experience and accumulated work in engineering design points to a combined solution were mass customization

applied to group of users would result in frame based systems that could be integrated as the modern concept of service instead of products. We have a questionary based on Geoffrey Moore Chasm approach [Moore 1991] still in development were we try to have a better look of the companies and groups that offer home automation projects in Portugal and Brazil. Even if we are not ready for statistical analysis, the data available already shows that companies in this segment do not use requirements engineering techniques in the early phase of the project. In fact, so far there is not a unique company or group that make a requirement analysis. I we compare that with the strategic situation we have in this segment of automation, with a stakeholder/user very demanding, it is not difficult to understand why potential stakeholders do not find these projects reliable and consider them as superfluous, even if good and sound technology is available.

Our proposal is to work in the introduction of a sound requirement engineering analysis, not only because it is a good general practice in projects for distributed (and hybrid) systems, but also because it is specially strategic in home automation. In other words, it is not possible to explores deeply the potential of this area without this early analysis.

Recently we propose a method to approach requirements analysis by using Petri Nets [Silva et al. 2005] and developed a tools to build requirements models in UML and translate to Petri Nets called itSIMPLE [Vaquero et al. 2005] which is today in the version 2.1. In figure 1 we show a small example of the requirement of an elevator system that is translated to Petri Net (figure 2). In the next section we will discuss further that is very important if we are going to consider home automation projects based on processes instead of product. In the last section we revised an example developed in 2003 in our Lab in a generalized situation and applied with the new approach presented here in a real application located in Famalicão, Portugal.
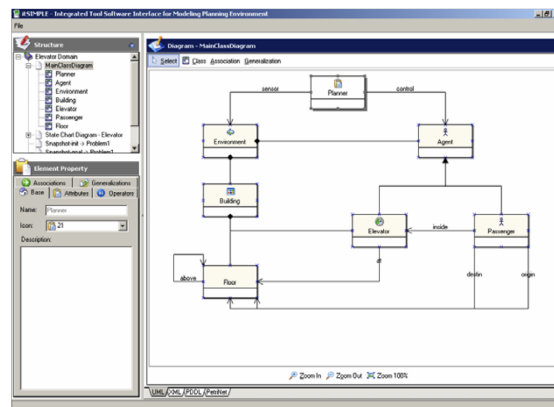

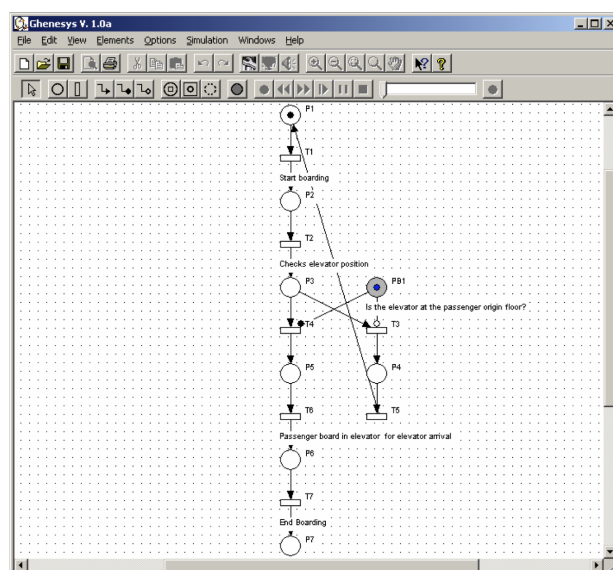Figure 1. UML modeling for a simple elevator system

Figure 2. The same model translated to Petri Nets by itSIMPLE.

3. A NEW SERVICE ARCHITECTURE FOR HOME AUTOMATION

As pointed in the previous section, the proposal presented here is based on the fact that the crack in the bell curve that avoid home automation to gain maturity and goes to the major acceptance phase is located in the way the project is made and in the relation that developers tend to maintain with the stakeholder/client. The proposal is based first in the inclusion of a careful requirement elicitation and analysis as a condition to evolute to a successful project that really fulfill the stakeholder/user needs.

However, there is another important point that denotes the very nature of home automation projects: the legacy system components which came from building automation and that influence the market. Of course there is no way to argue against the gain in scale manufacturing components. On the other hand, some basic components are in fact common to both areas and that is in fact a good point. The only drawback is in the flexibility such components really have, and if this flexibility is not inherent to the component itself than it should be introduced latter on. That means introducing flexibility in the way one assemble and integrate components, what would bring the point that the components must be multifunctional.

As pointed before, there is an analogy between the environment just depicted to home automation and the one for (flexible) manufacturing systems. With a difference that, because of more generous process time elapsed, home automation make a better and cheap testbed for new approaches.

Therefore a policy change in the way projects are ruled in home automation also brings to the discussion about the nature of such projects. The conventional way is product-oriented even if the final artifact is not really a "product". The proposal here is to make a definitive change to service-oriented [Lush et al. 2008] [Spohrer 2008] what would also determine the way we define components in a home project. Each part provides a service and is an assemble of hardware and software whose final goal is to execute a selected group of processes. Thus, it would be also an process-oriented approach, such is made in information systems [Dumas 2005].

The criteria to divide a home project in parts were already questioned in an early article presented in COBEM'03 and in the ABCM Symposium Series [Silva et al. 2004] where the base of the argument were just to find more significant and integrated components called abstract objects. If applied to control of home automation that architecture predicted a dual object composed of the intelligent control part and an operational part called plant. Again, the analogy with manufacturing systems (on the converse way) is very clear. The discussion by that time was the use of object orientation criteria in the division and the introduction of encapsulation as well as the how it would be important to maintenance and further evolution of the home system. Besides that no rupture were proposed in the conventional approach. Thus, we presented a model-problem built in a mock-up composed by three floors with two rooms in each floor, each one with individual control for HVAC and fire alarm. There was also the elevator system and access control in the entrance.

The basic difference was the mix were rooms were considered component objects, with its internal control, but could be assembled in a fire control system contributing with the state of each room. It would compose the HVAC system in a similar way. Inside the room, all sensors and software system were fully integrated avoiding duplication and making control easier.

A real application were not implemented, but the experiments in the mock-up were enough to conclude that this was a promising approach. To become effective in practice it would depend on an environment that could support the project of a real scale system. As many other cases, we did not pay attention to the user satisfaction and to the difficulties to implement that several times, using the available components in the market.

Now we propose that the object division follow another inspiration, were we do not think about parts, rooms, floors, or even blocks, but in services. Thus, what we really have are specialized processes performed by hardware and software that deliver services, and the result of the server is what is important. The components could be changed or the service could be performed with the help of components that are not local, since the service be provided. The top level integration should be done over a network of service components.

The advantages in flexibility and the encapsulation of the maintenance are evident. Unfortunately the dependence on the network grows fast, even wired or wireless. That could be a problem if home automation is faced on countries with a poor telephone system or in unplugged cities. A good discussion about problems in force or weakness to rely on the communication system is done in [Wacks 2002], and the position of this work is that even in cities as the one in our case study (small cities in Portugal, like Famalicão, Guimarães, Braga, or in big cities as São Paulo, the risk is affordable.

In the following we will resume the proposal of this paper and prepare to show a small example first analyzing the object proposal of 2003 and reusing some features and after that in a new real example.

4. THE HOLONIC INTEGRATION USING PETRI NETS

The word *holon* appeared in the pioneer work of Arhur Koestler, The Ghost in the Machine, in 1989. According the author the etymology of the word point to a concatenation of two Greek words: *holos* that means "whole" and the suffix *on* that means "part". Thus, a holon is something that could play interchangeably the role of the whole or to the part. In a broader sense the *holon* keep important properties of the whole and can be seen as a component by other parts (in a

hierarchical model) or as an integral element.

This denotation is used here to capture exactly this property from the architecture we proposed, that is, the automation of components (such as a living room) is seen as a compositional automated system where thermal comfort, the control of lights, the control of the persians, the sound system, etc. are parts, but it could also be seen as an integral part of the house to which the central control refers as an integral system, exchanging data and asking of offering services. The overall home system could then be classified as a holarchy instead of a simple hierarchy.

Therefore the base of the system is a general integrator of messages and control signals which is scalable, that is, could be adapted to a single room, to a whole section of the house or to the whole house. Thus, parts and the whole system keep similar structure and properties, and are compositional at the same time. Once it is an integrator system, it is expected to be connected to devices that actually perform the actions on the system, and compose what we generically call the "plant" in our analogy with the control of manufacturing systems. The granularity and composition of the holonic elements is a problem of design and should be detached from the requirements, using an object oriented approach, as the one used in itSIMPLE [Vquero et al. 2005].

The mass customization aspect requires that we have a frame capable to fulfill the requirements of a class of stakeholders/users instead of individuals. That means a basic frame that supports all signals and message length in a generically defined house, and that could also be able to treat new situation, characterizing a real flexible system.

Signal conversion for distinct sensors and actuators are plenty available in the marketing. Thus, the "plant" connection is just a problem of assembling these devices to a micro notebooks without a screen, that would play a role for the central integrator. It would be possible to have a network of these devices composing the system for the whole house. Here we have a dependency of this system with the network and the known problems that TCP/IP can cause in a network. Still, the merging with 485 net was what were used in the experiments described in the next section. However, for convenience those experiments were performed over a 485 net of PLC's and not a 485 net of holons.

We claim that the overall arrangement is not far from the original idea presented here because the integration relies in the software approach and architecture than in the hardware composition. Therefore the experiments are still valid to confirm the possibilities of the proposed architecture.
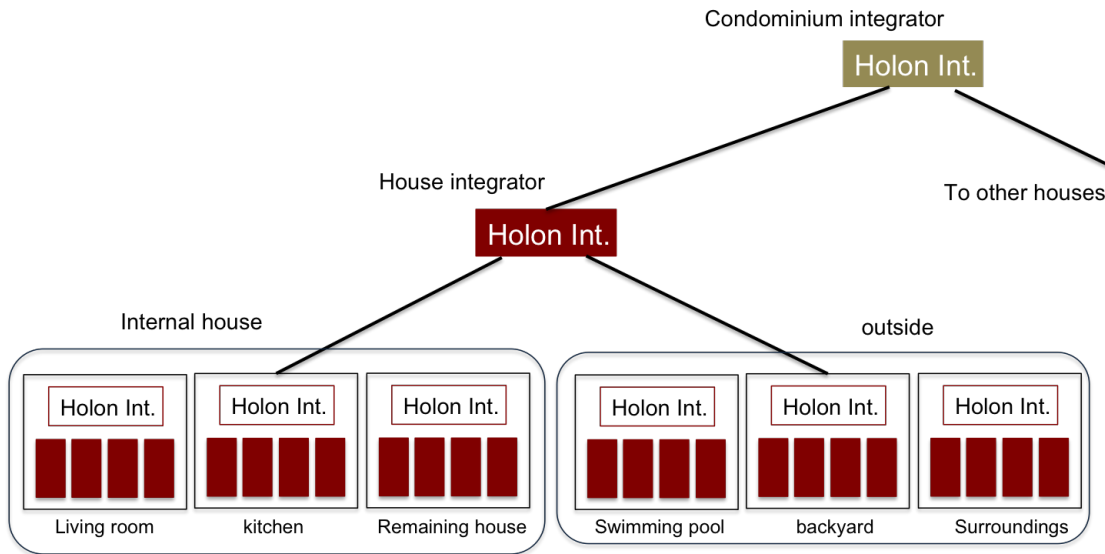
Figure 3. Partial view of a holarchy for a condominium of houses

Figure 3 shows holarchy for a house that is part of a condominium composed of other houses, leisure, sports, access lanes (that do not appear in the picture). It should be stressed that the whole architecture is based on services, that is, all higher level systems see each holon as service providers, rather than sub-elements. Only if the nature of the service become an important information is that these systems would go into the component part.

Finally, it is important to add that the proposed architecture is cooperative in the sense that each holon is intrinsically cooperative (would do whatever it can to provide service), even if local stakeholders/users have priority to receive the service. That would raise the need to add intelligence in the overall architecture. That is something we plan to do in the near future.

5. A SIMPLE EXAMPLE

The examples showed are divided in two parts: the first we just a reference to a work from propose by Silva et al. (2004) where the main concern was to evaluate flexibility with a more generic approach and an architecture based on elements called *integrons*.

In that system, showed in figure 4, the idea was to provide more flexibility in a house or in hotel dependencies were different rooms had to be submitted to the same policy for HVAC, for instance. The first attempt was to give more freedom to the user to adjust parameters and still to have a sound control policy for the whole system. The main conceptual differences to what we will show later is that we did not think in services instead of control procedures, and that therefore the control level were pretty close to what we called it plant.

However, since that first experiment the design model were already implemented, even if not derived from a stable phase of requirement analysis. Petri Nets were used to model the integration of the parts (not a holon yet) - shown in figure 5 - and to model the overall integration of models (figure 6). In both cases, the need for special elements to extend the normal representation of nets were necessary to provide a good modeling in an affordable time. For instance, an special element to represent observable event but not controllable were introduce, and called pseudobox. To represent the entrance of an individual in a room for instance, or the occurrence of a firing condition these elements were very important.

These needs bring us to develop a new unified net called GHENeSys that incorporates all this elements in a sound formalism that could still have a state equation and well defined properties to support analysis.
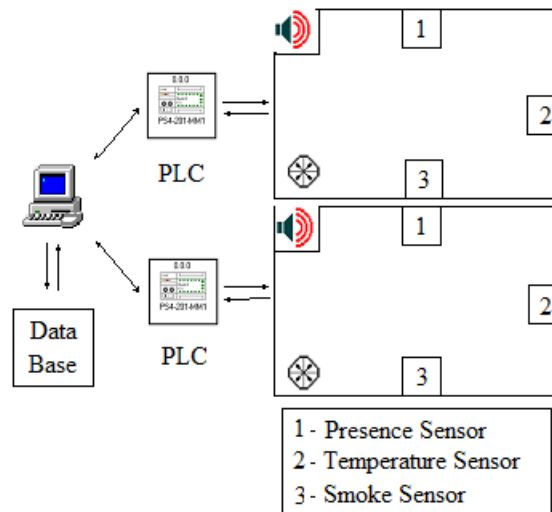

Figure 4. A modular component composed of two rooms

More recently we revisited the first experiment, now with all the features of the architecture defined above, and with the additional objective to test all these ideas in a scalable and real system. The target system was the project of a house (today a real one) in a region of Famalicão, Portugal.

In our revisited example a big house should have some independent environments such as bedrooms, television or living rooms. Kitchens also have a special integration system focused on the comfort and elimination of fumes. These remaining compartments will be controlled in a similar way then the objects of the previous system but with the holonic approach in mind. All the remaining systems would compose a same holonic integron just as the architecture showed in the figure 3.

Also, the outside of the house composed another block which components were the swimming pool, the garden (with an automatic system to water plants), and the security and surveillance system for the gates, fences, garage, etc. Figure 7 shows a general view of the interior of the house with the location of sensors and actuators. These elements that compose what we call *plant* should be grouped together to compose the holonic integrons. Again, the granularity, that is, how many elements in from what locations would be grouped is a question pertinent to the design goals and to the requirements elicited from the stakeholder/user.

Figure 8 shows a mockup of the target house what brings the idea on how big that is. The empty region between the construction in a "L" is what we location of the swimming pool and the garden that should be controlled for the home automation system.

A final test were not done with a whole condominium, but the maturity of the project and the parallel development
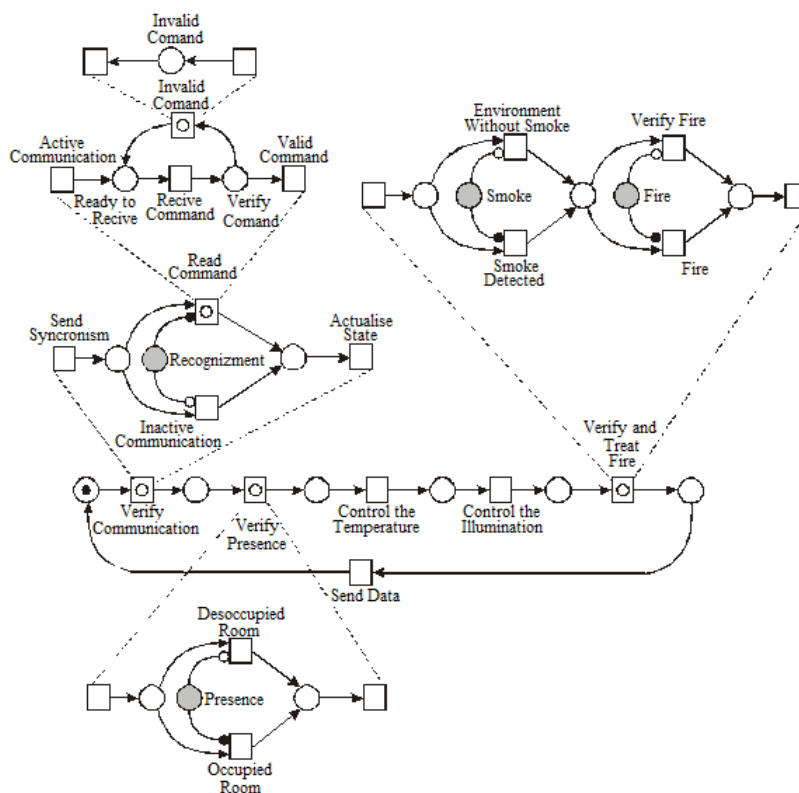
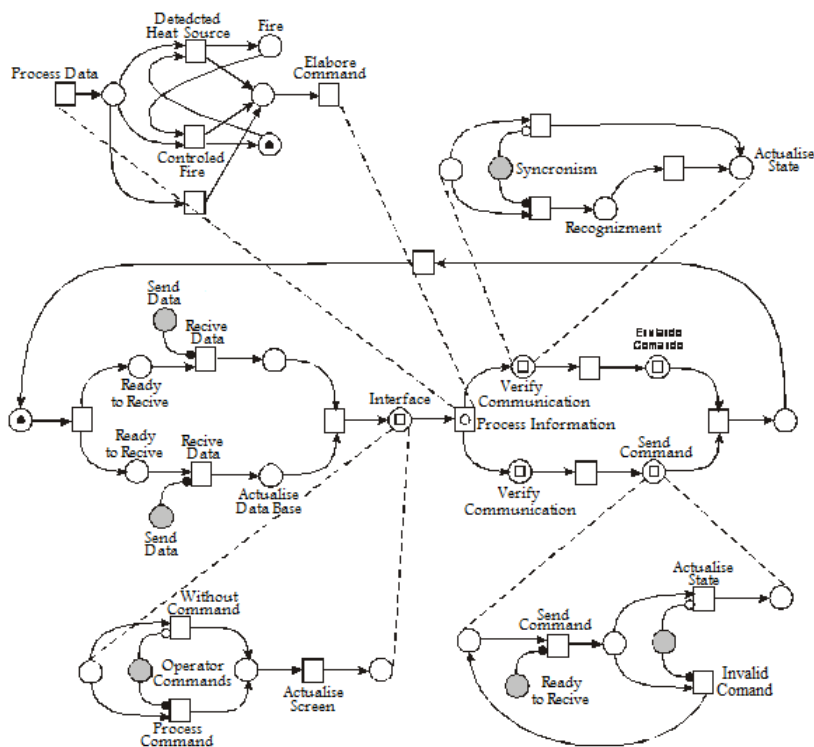Figure 5. Representation in GHENeSys of a modular component.

Figure 6. Integration of the modules with the remaining system.

of other tools such as itSIMPLE and GHENeSys (the object oriented Unified Petri Nets environment) would make us confident on the scalability of the approach since the proper software environment is provided. Even with the simple arrangement of tools we have so far it is possible already to go far um the integration and flexility process and have good
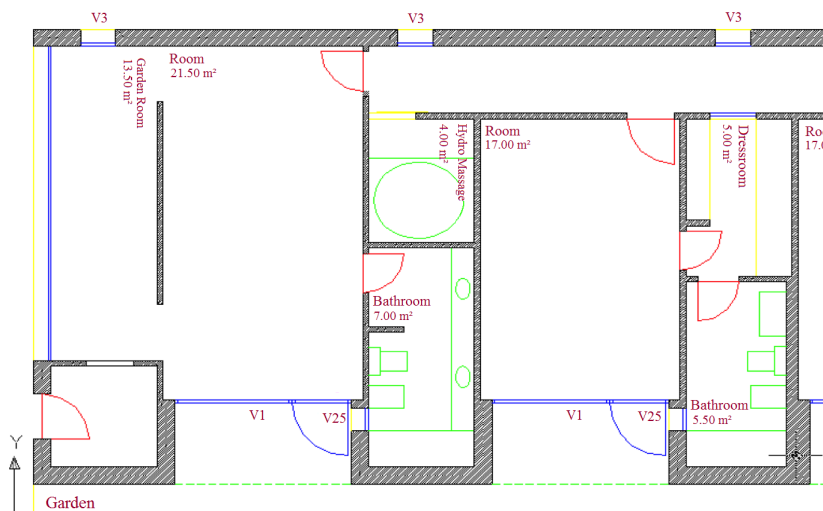
Figure 7. Similar representation revisited for a house automation.

Figure 8. A mockup for the target house in Famalicão, Portugal.

feedback for further developments, what we discuss in the next section.

6. CONCLUDING REMARKS

In conclusion we reinforce the position that to bridge the gap in the bell curve of Moore (1991) home automation should adopt a more competitive posture, changing its design process to pay more attention to the early phase of requirements analysis. Petri Nets are recommended to this analysis as in OMG specification for UNL 2.0. That would be the base for the modeling that could also be made in Petri Nets, as shown in the examples. However, the granularity of the division in holons would be very dependent of the requirements elicited.

The superposed position of the final client as stakeholder and user at the same time would require special attention to the early phase. Object orientation is also recommended since the early phase and going through to the modeling and design. However the proposed approach would be suitable and scalable if the conceptual guide would be service or a service-dominant architecture instead of a product-dominant one. That is just the difference between our first attempt and the current one.

So far the approach has been very promising but a a real test with the last level, which is the condominium level was not done because it would be dependent of an integrated software environment. All the experiments shown here were done using different tools, developed in different projects. That would make documentation very difficult for a big project.

For the future we plan to construct and encapsulate the basic integrator already tested in lab and in a real project into a tool that could be transported to the local application. That means solving small problems of hardware integration. A new software would be developed prepared to advance in the processing of intelligent tasks. On the other hand, a software environment is also being developed and assembled (reusing components already developed) to allow a test on the higher level of a horizontal condominium.

We believe that that would be a good contribution since home automation is in fact a good testbed for automation systems techniques and theory. Besides, it seems to be already a fact that more and mores people prefer to live in closed horizontal condominiums and that a parsimonious automation system would provide comfort, economy, and rationality in the use of energy and water while controlling security and the disposal of garbage.

7. REFERENCES

D. M. Anderson. *Build-to-Order & Mass Customization: the ultimate supply chain management and lean manufacturing strategy for low-cost on-demand production without forecasts or inventory*. CIM Press, 3rd edition edition, 2004.

E. J. Barkmeyer, Allison Barnard Feeney, P. Denno, D. Flater, D. Libes, Michelle Potts Steves, and Evan Wallace. Concepts for automation systems integration. Technical report, National Institute of Standards and Technology, Manufacturing Systems Integration Division, February 2003.

Jeffrey S. Conant, Michael P. Mokwa, and P. Rajan Varadarajan. Strategic types, distinctive marketing competencies and organizational performance: A multiple mesures-based-sudy. *Strategic Management Journal*, 11:365–383, 1990.

M. Dumas, W. van der Alst, and A. H.M. ter Hofstede, editors. *Process-Aware Information Systems*. John Wiley & Sons, 2005.

Wernher R. Friedrich and John A. van der Poll. Towards a methodology to elicit tacit domain knowledge from users. *Interdisciplinary Journal of Information, Knowledge, and Management*, 2:179–193, 2007.

D. Greaves. Control software for home automation, design aspects and position paper. In *Procc. of the 22nd. Int. Conf. on Distributed Computing Systems Workshops*. IEEE Computer Society, 2002.

Ann M. Hickey and Alan M. Davis. Elicitation technique selection: How do experts do it? In *11th IEEE International Requirements Engineering Conference*, 2003.

Ann M. Hickey, Alan M. Davis, and Denali Kaiser. Requirements elicitation technics: Analyzing the gap between technology availability and technology use. *Comparative Technology Transfer and Society*, 1:279ñ304, 2003.

Gerald Kotonya and Ian Sommerville. Requirements engineering with viewpoints. *Software Engineering Journal*, 11:5–18, 1996.

Don Libes, Edward J. Barkmeyer, Peter Denno, David Flater, Michelle Potts Steves, Evan Wallace, and Allison Barnard Feeney. The amis approach to systems integration: An overview. Technical report, National Institute of Standards and Techology, Manufacturing Systems Integration Division, May 2004.

Geoffrey A. Moore. *Crossing the Chasm - Marketing and Selling High-Tech Products to Mainstream Costumers*. HarperBusiness, 1991.

B. Joseph Pine II. *Mass Customization: A new Frontier in Business Competition*. McGraw-Hill Ltda., 1993.

R.F. Lush, S.L. Vargo, C. Wessels Toward a conceptual foundation for service science: Contributions from service-dominant logic. *IBM Systems Journal*, 47(1):5–14, 2008.

J. R. Silva, E. A. Santos, and T. S. Vaquero. Specification and analysis for automated flexible manufacturing. In *Procc. of COBEM 2005*, 2005.

J.R. Silva, M. A. Poli, and P. A. Restrepo. Towards a modeling discipline for building and residence automation. *ABCM Symposium Series in Mechatronics*, 1:560–569, 2004.

Jim Spohrer, Laura C. Anderson, Norman J. Pass, Tryg Ager, and Daniel Gruhl. Service science. *Journal of Grid Computing*, 6:313–324, 2008.

Nam P. Suh. *The Principles of Design*. Oxfort University Press, 1990.

T. S. Vaquero, F. Tonidandel, and J.R. Silva. The itsimple tool for modeling planning domais. In *Procc. of the Int. Conf. Automated Planning and Scheduling*. AAAI, 2005.

K. Wacks. Home system standards: Achievements and challenges. *IEEE Comunication Magazine*, 40(4):152–159, April 2002.

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