ENHANCED INDUSTRIALIZED CUSTOMIZATION PERFORMANCE BY EMBEDDED MICROSYSTEMS

Thomas Bock
Technische Universität München, Munich
thomas.bock@bri.ar.tum.de

Thomas Linner
Technische Universität München, Munich
thomas.linner@bri.ar.tum.de

Abstract
High-tech buildings lead to new organizational structures multiplying the possibilities of customization and user adaptation. As it will be outlined in the following paper, between industrialized mass customization of buildings and continuous and commercial service value chains built on flexible high-tech buildings a strong relation could be established extending the approach of automation and robotics in construction over the whole life cycle of buildings. Therefore the paper examines and explains synergies between building integrated performance added sub-systems, emerging service based value-creation and new customer integrating industrialization strategies. The paper ends with the conclusion that new market fields for automation and robotics in construction could be entered proactively carrying on existing knowledge into described fields.

KEYWORDS: Industrialized Customization, Building Performance, User Adaptation, Service Science, Microsystems Technology

INTRODUCTION

For a long time the focus of innovation in the area of automation and robotics in construction has been laid on the industrialized and rationalized off-site or on site construction as well as on related processes, building systems, management and/or logistic tools and high-tech construction/prefabrication robotic equipment. Yet, today, the complexity of buildings continues to rise rapidly due to new paradigms as Ubiquitous Computing (Krumm, 2010), the demand for energy efficiency (Lechner, 2009) and emerging assistance technologies (Bock et al., 2002) Buildings become integrated with a multitude of new sub-systems (Elliot, 2009) and extend their performance to areas which have formerly not been accounted as being part of construction and building industry, yet, which now gradually merge with our built environment. With that development the question rises if a solitary focus on construction technologies still helps to improve the advance of automation and robotics in construction or if it could be reasonable to analyze the impact of buildings' developing new performance scope on building systems and industrialized production methods. With the integration of Microsystems Technology into buildings and due to the tendency towards more and more user integration (Piller, 2008), buildings become not only more intelligent but they can be much more personalized to the inhabitants needs and could further serve as platforms for a multitude of continuous and commercial services. These changes could have a tremendous impact on the whole value chain and are likely to transform building structures, construction technologies and business models. In order to maintain the frontier science character of automated and industrialized construction it is necessary to anticipate future developments accompanying buildings' new performance scope and to create relations to building structure and automated/industrialized construction. In this section we first identify emerging building subsystems and further discuss organizational systems that could be extended to integrate those new sub-systems in industrialized building structures. In chapter 2, methods for modularization and industrialization of assistive high-tech buildings are discussed and chapter 3 explains service/performance based value-creation built upon embedded performance added sub-systems. In chapter for multiple types of customization are identified. The paper ends with the conclusion that performance added sub-systems enhance and multiply the possibility to industrially individualize and personalize buildings over the whole life-cycle.

Upgrading of environments with performance added sub-systems

Microsystems Technology gradually permeates all possible application fields within buildings. In the future this application fields will gradually be interconnected to generate synergies until the whole house becomes a distributed and networking system of embedded technologies and cooperating sub-systems able to assist multiple use-cases:
Energy Technology: Today energy management systems enable an intelligent real-time control of energy and consumption related appliances of a house. Various systems generating energy can be interconnected and it is possible to record, control and analyze room temperature, air circulation and excess heat as usual for example in passive houses. More and more all energy relevant components of a house (windows, doors, heating, photovoltaic, aeration) can be equipped with Microsystems Technology, connected to energy management systems and controlled proactively.
Home Automation, Comfort, Security: Home automation provides integrated technologies for comfort and security. Many technologies used in building automation (light and climate control, control of doors and window shutters, security and surveillance systems, etc.) are also used in home automation. Yet functions in home automation mainly include the control of multi-media home entertainment systems, automatic cleaning systems and pre-defined scenes for dinners and parties. Recently the development of user-friendly, intuitive and multimodal interfaces gets into the focus of R&D and industry.
Ambient Assisted Living & Personal Health: AAL (BMBF, 2010) covers ICT-integrated concepts, products and services which aim at raising the life quality of (elderly) people in order to help them to live self-sufficient and independently. AAL technologies, as for example furniture integrated with mechatronics and lifting systems, intelligent mobility devices and wheelchairs, assistive robotic technologies, activity detection by multiple sensor networks, emergency call systems, telemedicine and ICT enabled medical and personalized home care solutions. The demographic change in major industrial societies is likely to push forward mentioned technologies rapidly making an emerging industry.
Maintenance: Gradually not only appliances but also basic components of buildings as structural components, walls, ceilings, roof or any kind of installation will be integrated with sensors and actuators connected to a generic integration platforms via RFID, ZigBee, Bluetooth, Powerline Communication or conventional Bus-Systems. Similar to today's automobiles it will be possible to make an easy (remote) system check and occurring failures within more and more complex buildings will be detected by mobile software agents and reported or fixed automatically.
Future Mobility Concepts: The next generation of cars has plug-in capability and as already proposed by Toyota with the Papi House (Simizu, 2005), a collaborative project of Toyota

Motor Corporation and Toyota Home all cars will be able to connect to the house for bidirectional exchange of information and energy. Further the Toyota I-Real concept, providing ubiquitous short distance mobility for young and elderly people, also shows a possible next step in mobility evolution. Connected to the house and a distributed network of sensors and actuators, future mobility concepts will continuously communicate with the home environment and assist daily life or extend elderly peoples´ ability to be mobile.

Adding new sub-systems to conventional building systems

For the controlled integration of mentioned performance oriented sub-systems into the built environment and their synchronization with building structures which are able to be industrialized, new organizational systems are needed. Early approaches for the organization and structuring of building sub-systems and in-house infrastructure are provided by Fritz Haller’s *Armilla Installation System* (Hovestadt, 1984) and John Habraken’s *Matura Infill System* (Habraken, 2000). Both systems organize and modularize classical building service sub-systems as water-sewage system, ventilation, air conditioning, heating and electrical cables. Fritz Haller’s system was originally meant as complementary installation system for his industrialized Mini, Midi and Maxi steel systems. It was designed to systemize and modularize the building’s installation systems, support industrialized prefabrication and give the overall building component system the potential of rearrangement and/or extension. Today, the Armilla Installation System has been developed further towards an advanced computer program supporting the planning process and further being able to generate data for the prefabrication of an installation component kit. Similarly, the Matura Infill system was meant to modularize the building’s service systems and thus to allow its’ industrialized fabrication as well as flexible rearrangements of functional settings according to dynamically changing needs. It decouples the in-house service installation form the base building. The Matura Infill System has the advantage that it also could be applied to the huge market of refurbishment of existing buildings. Yet, neither Armilla Installation system nor Matura Infill System is capable of integrating Microsystems technology and new performance oriented sub-systems becoming inseparable parts of today’s buildings. Further, the *Open Building Approach* (CIB W104, 2010) has to be mentioned. The Open Building Approach aims at making buildings flexible for continuous rearrangements according to dynamically changing needs. Kendall mentions the possibility of dynamically integrating high-tech subsystems through the Open Building Approach as well as the possibility that construction industry could be more related to flexibility and service in the future (Kendall, 2000). All in all, the outlined approaches do not yet give consistent solutions for the flexible and industrialization oriented integration of performance related service sub-systems into the built environment: they have to be extended in order to develop a framework for industrialized high-tech buildings which could moreover serve as platforms for continuous services.

MODULARIZATION, INDUSTRIALIZATION AND LIFE-CYCLE SYNCHRONIZATION

Especially when intelligent high-tech components and performance added sub-systems have to be integrated in our environments, industrialized and modularized systems become of increasing importance. The problem with the development towards more embedded technologies in our built environment is that the economic and technological life span of appliances integrated with electronics or microelectronics differs from all other components of a house or building extremely. Sometimes performance added sub-systems are outdated within one or two years meanwhile basic structures of buildings can have an economic life span of up to 60 years or even more (Pfeiffer, 2006). Additionally, dynamic sampling and individualization in our society combined with fastening innovation cycles lead to the fact that layouts, configurations and functionalities within the house have to be changed or adjusted even faster. In conventional construction and non-modular houses this leads to a fast and irreversible obsolesce of especially performance added sub-systems changes or reconfigurations are costly. On the other hand, industrialized or customized systems based on modular, flexible and exchangeable components and sub-components have the ability to be synchronized with the need for modularity and exchangeability concerning integrated microelectronic systems and services built upon them or generated through them.

Definition of new building levels in relation to performance added subsystems

As mentioned before, buildings gradually extend their performance scope. The usual approach which mainly classified all subsystems as being part of the physical or technical level no longer is applicable to describe the rising performance and complexity of built environment. Also the mentioned industrialization oriented organization systems as Armilla Installation Systems and Matura Infill System as well as classical Open Building Approach mainly focus on physical and technical level. Yet, today systems and concepts driven by ICT technologies merge with the building's structure and new building levels have to be defined:

Level	Phisical	Technical	Software	Services
Systems, Sub - systems	Structure Frame units Facade elements Interior wall	Appliances Infrastructure Sensors / Actors Microsystems	Control Data / Information Patterns Analyzis	Not-digital Digital Health Information
Integration	Modularity, standardized interfaces, platform organization			

Figure 1: Extension of building level classification

Subsystems are cutting cross all building-levels

Moreover, the next generation of houses could be broken down into various categories of performance added subsystems. By the free combination of subsystems according to inhabitants' demands it would be able to customize buildings and to fully integrate the user into the definition of the building's performance. In relation to the defined building levels, performance added subsystems (as described in the introduction) are a highly interdisciplinary matter cutting cross those building levels. So for example a building maintenance system might be rooted in the building's physical and technical structure, equipped with hardware (sensors, actuators) and software (control system, pattern recognition) and finally related to maintenance services. This simple example is showing that for developing and implementing performance added subsystems a cross level-cutting approach is needed. The need for such an approach will in the future even be intensified as developments as Ubiquitous Computing (Krumm, 2010) and Pervasive Health (Varshney, 2009) are just gaining momentum. Due to high complexity, performance oriented building design is likely to become a endeavour which is more multidisciplinary than "Ubicomb" itself.

Towards advanced multilevel component systems

On the one hand, advanced test beds as for example *Place Lab* at MIT (Intille, 2004) already have started with the development of modular infill systems for mass customization of performance oriented buildings. Yet, none of those approaches has yet been carried on to applicable component systems for whole buildings. On the other hand, even advanced and successful component system as Sekisui Heim's *Unit Method* and Toyota Home's *Skelton and Infill System* have not yet found a solution for the integration of new building levels' components or for an afterwards flexibility and adaptability of integrated systems. Although Sekisui Heim's *System Reuse House* (Sekisui Heim, 2010a) method offers rearrangement and deconstruction services, it is not capable of customizing, rearranging or servicing performance added high-tech buildings. All in all, a development of new component systems or a redesign of existing component systems would be needed to handle the rising complexity and further to set up clear standards on behalf of which technology developers and suppliers could build up industrially mass customized and affordable performance oriented subsystems. New multilevel component system must consequently also lead to new production strategies, production methods and business strategies.

Figure 2: Toyota Home, Skelton and Infill System, completion and integration of conventional subsystems through parallelized factory processes

MICRO SYSTEMS AND SERVICE-BASED VALUE CREATION

Embedded micro systems technology in combination with adaptable and multilevel building component systems could transform traditional relations between construction industry and customer/ end user as they could serve as platforms for a multitude of customized service value chains related to building maintenance, building adaptation or the delivery of information, goods or applications to inhabitants on demand. Incentives for advanced service based business models based on certain products or embedded hardware could come from various fields. In the field of facility management for example building automation systems, computer aided facility management systems and enterprises' ERP systems are gradually merging thus generating potential for a multitude of IT-supported services (May, 2006). Also the business model of *Apple* could be mentioned here: the revenue is not only generated by selling millions of portable devices and computers but by services, e.g. downloading form apple store, triggered through this "hardware". Similarly some companies try to generate service related revenue by releasing *open source* software. Further *Shai Agassi's* service concepts for future electrical cars, developed together with Nissan and Renault, show the potential and commercial long-term serviceability of emerging high-tech products (Project better Place, 2010). Further, systems as the "Ambient Medicine Platform" (Friedrich, 2010) have the ability to connect people through wearable and non-wearable sensors to a multitude of medical and/or telemedicine services. The following chapter analyzes the serviceability of modular, flexible and industrially customized high-tech buildings. Further it is outlined that between Mass Customization, which in its basic form aims at continuous customer relation and continuous services, a strong relation could be deployed.

Structural Changes and the power of the "digital economy"

A look on the Gross Domestic Product (GDP) and the Gross Value Added (GVA) in Germany (as an example for a worldwide development) split into the different fields of activity shows that the economic meaning of construction is gradually shrinking. Meanwhile sectors like Health, Information and Communication and Services in general extend their relative economic importance. Accoring to the "Digital Competitiveness" report published in August 2008 Europe was world leader in broadband internet and ICT use. Moreover ior reported that Europe had more mobile subscribers than citizens. According to the report Europe will advance even further as a "digital" generation of young Europeans becomes a strong market driver for growth and innovation. Building up on those potentials the digital economy is supposed to become essential for Europe's recovery from the economic crisis and for further economic development (Bock et al., 2009). All in all, the development of infrastructures for digital systems and applications could be seen as one of the main enablers for services and building related service value chains as described later in the section "Service Science".

Towards customer integration and life-cycle based value creation

What are the basic characteristics of strategy focusing on customization and advanced user-integration? Firstly, with the deployment of customization the value-chain-model shifts from a *transaction-based model* to an *interaction-based model*, which is the basis for long-term customer relations (Lindemann et al. 2006). The integration of the customer into the value chain is mainly realized by deploying a configuration system and a customer relation. The customer relation is quite important as it allows realizing gains through further sales of products or services- whereas establishing the configuration process is more related to additional costs (Linner et al, 2009). The customer relation established by providing a customized or personalized home could easily be used to deploy further to continuous service value chains.

Continuous Rearrangement Services

Buildings of the Japanese Prefab Maker “Sekisui Heim” can be accepted as trade-ins for a new Sekisui Heim building (Sekisui Heim, 2010a). Therefore the deconstruction process is a modified and reversed version of the construction process which was based on unit factory completion and rapid on site assembly of prefabricated units. For deconstruction the once prefabricated units are transported to a special dismantling factory unit by unit. There the outdated finishes are disassembled and fed into reuse cycles established around factories. The steel frame units are refurbished further and then equipped with new finishes and fit-outs desired by a customer who has chosen to buy a reused house. On a Web-Platform for “Reuse System Houses” Sekisui has started t organize a matching of people who want to sell their modular house for reuse and people willing to buy reused house modules for further customization. Renewed units are re-organized and re-customized in the factory, transported to other customer's building sites and then assembled on a new foundation in a new site. Accordingly, a Sekisui Heim spin-off company called *Fami S* (Sekisui Heim, 2010b) has set its focus on life-cycle and rearrangement services. Both approaches do not yet cover the rearrangement, exchange or adaptation of integrated, performance added sub-systems and assistive technologies. Yet, they provide a basis and show in which direction the servicing of high-tech buildings could develop.

Service Science

Demographic change and a growing amount of elderly people living at home are putting pressure on the development of assistance technologies and household-related services. Enhanced working pressure and the need for more and more comfort and connectivity also requires new services related to our homes for younger or middle-aged generations. Service providers in Germany are already creating standards for the thriving market of household related services (STADIWAMI, 2009) considering especially the potential of Microsystems Technology for implementing these services. Therefore standardization throughout the whole value-chain of services integrated in living environments is brought forward. The new aspect concerning services today is not only their content but also the possibility to create modular and multiple service packages from the collectivity of services.

- Classical household related services (cleaning, shopping, laundry washing…)
- Security and safety related services (thievery prevention, fire prevention...)
- Care services
- Leisure time related services (organization of events, wellness…)
- Other services (babysitting, housekeeping, carpenters…)

Costs and coordination complexity for providing services can be reduced significantly through the use of house integrated micro system technology. Micro system technology facilitates the initiation of household related services enormously. The initiation by Microsystems can be done in 3 ways:

- Manual initiation (TV, Control Station, Touch Panel...)
- Initiation by sensors (activity detection, vital sensors…)
- Initiation by processing/analyzing of information and patterns

Microsystems Technology and performance added sub-systems have the ability to facilitate household related services and moreover they are more and more integrated in the building’s infrastructure. Therefore the hypothesis could be stated that in near future housing companies will not only deliver living space but also continuous living services. (Linner et al., 2009)

MULTILEVEL INDUSTRIALIZED CUSTOMIZATION

Although high-tech buildings lead to enhanced complexity and new organizational structures, they multiply the possibilities of industrialized customization and user adaptation. Customization can not only take place on the mere physical level for a single static use case but on several levels dynamically over time. The following section defines types of customization that can be deployed to industrialized building systems through the integration of Microsystems Technology and performance added sub-systems. The classification has been derived from issues discussed in the former sections.

Mass Customization

The term Mass Customization was firstly defined by Davis (Davis, 1987) outlining a strategy of reaching a large number of customers while meeting individual needs. Further, the introduction of Mass customization became more and more related to the spread of modern Information and Communication Technologies (Piller, 2006). Today Mass Customization strategies translate customer demands into products and services as directly as possible by using a dynamic and adaptive knowledge structures. Moreover, aircraft construction is customized for each airline and the final assembly of airbus 380 is done stationary resembling a construction site or shipyard using high-tech and high performance components. Ford Automobile developed from offering one version in 1914 to about 24.000 alternatives without colour choice. However, Mass Customization in building industry today mainly is related to automatically prefabricating the physical building structure (physical level, chapter 2.1) and 3-dimensional building components (Bock, 2008). Mass Customization mainly refers to the initial product delivery and not yet to continuous customization. Examples for advanced production strategies can especially be found in the Japanese prefabrication sector (Linner, 2009). Moreover, performance added sub-systems will in the future become an integrated part of component systems and production strategies aiming at individualization.

Personalization through assistive modular Microsystems Technology

Personalization can take place without the exchange/rearrangement of modules but through the configuration of the integrated Microsystems Technology itself. An enhanced technology rate in our homes could be used for both strengthening customer relations and for easy system configuration according to customer preferences and needs. Microelectronics as own and separate discipline more and more disappears as it gradually merges with other segments. In car industry drive and gear are already highly integrated with electronics and distributed and interconnected cooperating performance added sub-systems. Driving experiences and motor sounds of different models are often not any more generated by placing different drive and gear components but by changing the settings of electronics and software (Borgeest, 2008). Similar user-defined, intelligent houses will recognize its´ inhabitants moving through the living environment and room configuration, multimedia human- machine interfaces, climate, energy, lightning, height of tables or furniture and displayed services could be configured on demand or automatically to dynamically changing use cases.

Continuous Customization

Continuous customization refers to flexible and open buildings that could be adapted dynamically over time. Controlled rearrangement, extension or deconstruction could be combined with reverse logistics, component reuse systems and service or leasing models.

Various components and structural elements have various lifecycles. This problem intensifies with the integration of performance added sub-systems. Therefore a service system and reverse logistics systems could be implemented and the deconstruction process should further be a reversed and adapted version of the construction process. Based on industrialized fabrication and reverse logistics, parts could directly be fed into industrialized networks again once a house is rearranged or deconstructed. For deconstruction, modules and components could be transported to special dismantling factories just-in-time and just-in-sequence.

Service Customization supported by integrated Microsystems Technology

Integrated Microsystems and performance added-subsystems moreover foster any kind of targeted services weather they could be performed digitally or not. Thy simplify the initiation of not-digital services manually, by sensors or by the analysis of data and information. So for example intelligent appliances and distributed software applications could help to identify demanded services. Critical health conditions, for example, could be recognized by sensor networks automatically triggering services. Real-time analyzes of actions and preferences could help to suggest suitable services of any kind location based and on demand. Additionally, the modern e-Business is built up on the ongoing digitalization of services creating more and more so called “eServices”. In eService business the core item of the service product is provided digitally. This means that service providers and service customers can be distributed locally and any kind of embedded system, appliance or intelligent network able to access the internet could act as transfer station for services offered from around the world. Emerging ICT infrastructures in combination with environmentally embedded performance added sub-systems are enablers for a multitude of new and continuous service value chains.

CONCLUSION

Today buildings become integrated with a multitude of new sub-systems and extend their performance to areas which have formerly not been accounted as being part of construction industry and which now gradually merge with our built environment. Additionally the meaning of construction industry in most highly industrialized countries is diminishing meanwhile ICT and service oriented industry sections become stronger. Especially Microsystems technology is continuously rising in its’ meaning as a so called cross-sectional technology. This provides a huge potential for automation and robotics in construction to proactively enter into the area of building integrated performance added sub-systems. Classical industrialization and automation methods, processes, automated logistics and production technologies could be developed further to meet the demand of multilevel industrialized and customized production. Although high-tech buildings lead to enhanced complexity and new organizational structures, they multiply the possibilities of customization, personalization and service based and continuous user adaptation. As outlined in the paper between Mass Customization and continuous service value chains a strong relation could be established extending the approach of automation and robotics in construction over the whole life cycle of buildings.

REFERENCES

1. Krumm, J (2010) Ubiquitos Computing - Fundamentals. Washington: CRC Press

2. Lechner, N. (2009) Heating, Cooling, Lighting: Sustainable Design Methods for Architects. New Jersey: John Wiley & Sons Inc.
3. Bock, T., Linner, T. (2008) Service Oriented Design. Proceedings of 2nd German Congress on Ambient Assisted Living, Berlin
4. Piller, F.T. (2008) Interactive value creation with users and customers. Anne S. Huff (ed.): Leading Open Innovation, Munich: Peter-Pribilla-Foundation, 16-24.
5. Shimizu, N (2005) A House of Sustainability: PAPI - Intelligent House in the Age of Ubiquitous Computing. Architecture and Urbanism (AU), Special Issue Dec.05
6. Hovestadt V., Hovestadt L. (1998) The ARMILLA project. 1998 Elsevier Science.
7. Habraken, N.J. (2000) The Structure of the Ordinary – Form and Control in the Built Environment. The MIT Press
8. CIB W104 Open Building Implementation. www.open-building.org
9. Kendall, S., Teicher, J. (2000) Residential Open Buidling. International Council for Building Research Studies, CIB
10. Pfeiffer, M. (2006) Variables and Indicators for life-cycle cost according to building types, Fraunhofer IRB Verlag, Germany
11. BMBF (2010) Ambient Assisted Living. www.aal-europe.eu
12. Varshney, U (2009) Pervasive Healthcare Computing. Berlin: Springer
13. Intille, S., Larson, K., Beaudin, J. S., Nawyn J., Munguia Tapia, E., Kaushik, P. (2004) A living laboratory for the design and evaluation of ubiquitous computing technologies. Conference on Human Factors in Computing Systems. NY: ACM Press
14. Sekisui Heim (2010a) Japan, System Reuse House, available at: www.sekisuichemical.com/about/division/housing/reuse.html
15. May, M. (2006) Computer Aided Facility Management – Handbook. Berlin: Springer
16. Project Better Place (2010) available at: www.betterplace.com
17. P. Friedrich, J. Clauss, A. Scholz, B. (2009) Wolf Ambient Medicine® - Telematic Medical Systems for Individualized and Personalized Assistance ITU-Report und Journal eHealth, Japan, Journal for eHealth Technology and Application
18. Bock, T. & Linner, T. (2009) Structural Changes and Technology Utilization in German Construction. JCMA, Japan Construction Mechanization Association, Japan
19. Lindemann, U. Reichwald, R., Piller, F.T. (2006) Individualized Product. Berlin: Springer
20. Linner, T., Bock, T. (2009) Industrialized Customization in Architecture. World Conference on Mass Customization, Personalization and Co-Creation (MCPC), Helsinki
21. Sekisui Heim (2010b) Fami S Co., Ltd, Life Style Consulting
22. STADIWAMI (2009) Standards for Housing related and digitally supported Services, Collaborative Project, DLR, DIN, TU Berlin
23. Davis, S. (1987) Future Perfect, Reading 1987
24. Piller, F.T. (2006) Mass Customization. Wiesbaden: Deutscher Universitätsverlag
25. Bock, T. (2008) Digital Design and Robotic Production of three dimensionally shaped precast concrete elements, 25th ISARC, Vilnius, Lithuania
26. Elliot, C. (2009) Intelligent Buildings- Systems Engineering for the Built Environment. Intelligent Buildings International, Journal Volume 1, Earth Scan Journals
27. Borgeest, K. (2008) Microelectronic Systems in Automotive Engineering. Aschaffenburg: Vierweg Verlag
28. Figure 2: Copyright T. Bock