Investigating HCI Challenges for Designing Smart Environments

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Abstract. With the advancement of technologies related to 'Internet of Things', we are moving towards environments characterised by full integration and semantics. Various environments are often summarized with terms such as 'Smart City', 'Smart Home', 'Smart Buildings' or 'Smart Commerce'. In the meantime, technologies and standards for interoperability have been developed. However, to realise the full potential one remaining challenge is the design, integration and interoperability of many elements into a smart environment. In order to address this challenge, researchers have proposed concepts for Information Systems Design and Enterprise Architectures. By inspecting interaction challenges -in particular activities in which Humans are involved- during the design process, we endeavour in this paper to identify key challenges for designing smart environments. In order to address the challenges we propose a conversational approach that supports the main design phases and allows professionals to interact during the design phases for smart environments.

Keywords: Design process · Conversational environment · Smart environments · Enterprise architecture

1 Introduction

With the advent of Internet of Things technologies, we inevitably move towards environments recognized by full integration and semantics. Diverse application areas of such technologies are often summarized with terms such as 'Smart City', 'Smart Home', 'Smart Buildings' and lately Smart Commerce (Pan et al. [21]). Smart environments include smart objects, such as houses, buildings, sustainable urban infrastructure, cars, sensor technology and a lot more. Within these environments, through the application of semantic web technologies and intelligent applications, we are able to offer personalized, responsive, and intuitive systems. One prominent example for a smart environment is smart buildings, which include different smart features, analytics, and sensors used to monitor and control the power supply through renewable energy, smart metering technologies, and smart windows (Baetens et al. [3]). As expressed by Zhou et al. [29], in the case of smart buildings most of these smart technologies exploit information about the building design and its operation specifications at a later stage to estimate energy consumptions for industrial or marketing purposes.

Technologies developed over the last years for smart environments are currently summarised as 'Internet of Things'. However, a significant challenge remains to design

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and maintain the connectivity of smart systems by an integrated information system being able to support business processes and interoperability between the systems. With this paper, we investigate selected design challenges for smart environments and propose an approach to address these. Design processes are typically tacit dominant in which essential knowledge is exchanged between professionals and stakeholders. The knowledge gathered during design is required to be preserved for later design steps, subsequent maintenance, and use.

The paper is structured as follows: After presenting our research approach we review related literature to investigate design problems from an information and knowledge point of view and their impact on design processes. In addition, examining aspects of enterprise architecture, this research summarises the main steps of the Architecture Development Method (ADM) of TOGAF – a common method for enterprise architecture design - to design and implement enterprise architectures (EA). Subsequently, we illustrate design challenges using three examples and discuss the challenges recognised for the design process of smart environments.

2 Research Approach

In order to investigate and attenuate design challenges for smart environments, we argue that applying concepts related to Enterprise Architecture can help. This research is based on conceptual observation and use case descriptions following a qualitative research approach. According to Yin [37], one of the most common methods for data collection in case study is observation. In order to illustrate the design process for smart environments, we will utilise a prominent approach, i.e. TOGAF with its architectural design method (ADM), and a model-driven architecture promulgated by Object Management Group (OMG [38]). ADM defines steps for designing and maintaining enterprise architectures, which initially defines the scope in form of where, what, why, who, and how we design architectures.

The Open Group Architecture Framework (TOGAF) is a framework for enterprise architecture that provides an approach for designing, planning, implementing, and governing enterprise information technology architecture. TOGAF plays an important role in helping to systematise the architecture development process, enabling IT users to build open systems-based solutions to their business needs. According to OMG [38], the ADM is a step-by-step approach to develop enterprise architectures, which caters the business and information technology needs of an organisation. It may be tailored to the organisation's needs and can be then employed to manage the execution of architecture planning activities. TOGAF embraces the concepts and definitions presented in the ANSI/IEEE Standard 1471-2000, specifically the concepts that help guide the development of a view and make the view actionable (Minoli [19]). In order to discuss and investigate the challenges of designing smart environments from an information systems perspective in the following section, we follow the structure of TOGAF and ADM for the purpose of this study.

3 Design Process Problems with Tacit Knowledge Exchange

The design process requires the exchange of domain knowledge or knowledge about systems and artefacts between many stakeholders. As many researchers (e.g. Ibrahim and Paulson [12], Ibrahim and Fay [10]) have stated the design process is tacit dominant. One challenge with tacit knowledge exchange is the human-human interaction due to the fact that professionals attend project meetings and exchange their tacit knowledge. For design processes professionals' interaction happens in a tacit dominant area. Nissen [35] proposed the concept of a knowledge flow life cycle (KFLC). According to the first step of ADM to create business scenario, key challenges of design process are described utilising KFLC theory. For the next step of ADM, a target business process is required to be planned to address challenges arising from knowledge point of view. Further steps are related to information system and application architecture design and implement.

According to Nissen [35] knowledge is created by people, which is typically in the form of tacit knowledge. The knowledge is shared with other individuals in form of tacit knowledge. Then, through the step of 'formalisation', this knowledge is transformed to explicit knowledge, usually stored and maintained in an information and knowledge system. Therefore, professionals are interacting during the design process with each other to exchange knowledge, a fact being confirmed by many researchers. Poursolfaghar [22] pinpointed that the knowledge created by the professionals tends to reside in their minds as tacit knowledge when not explicitly documented during the design phase. Nonetheless, it is invaluable for later use and this is why it should be persevered. In this relation, Ibrahim and Fay [10] expressed that the design professionals are working in dominantly tacit knowledge areas during the planning and conceptual design phase. Indeed, this kind of human-human interactions which strictly depends on tacit knowledge has a high risk of incompletion. Indeed, the knowledge flow might be interrupted with the possibility of knowledge loss. In this regard, Ibrahim and Nissen [11] accentuated that tacitness of the knowledge can augment the probability of knowledge loss. These parts of knowledge, which had been lost prior to the formalisation, are evidences for the knowledge loss phenomena of design processes.

In addition, Kendall and Kendall [14] declared that the basis of human–computer interaction comprises the knowledge about the interplay among the users, tasks, task contexts, Information Technology (IT), and the environments in which the systems are used. Likewise, Bigham et al. [4] illustrated that human-computer interaction has focused on the user's interaction with many different types of information. During the design process, tacit knowledge is exchanged between the experts aiming to apply it for their own planning. However, this knowledge transfer is characterised with high risk of losing tacit knowledge intrinsic to human-human interactions. In other words, challenges in design processes can be related to knowledge transfers, often observed in a human-computer interaction aiming to prevent knowledge loss.

The design of Enterprise Architectures within Information Systems can be seen as a typical design process to design intergraded information systems. As Nakakawa et al. [31] concluded enterprise architecture is an appropriate approach for organising and dealing with inflexibility in business operations, managing organisational changes, mastering organisational complexity, and effectively aligning all the business aspects. Likewise, it is proposed by Ross et al. [32] and ISACA [33] that enterprise architecture is defined as the planning, design, and integration of business, information, and technology infrastructure in order to better achieve enterprise and IT strategies.

The goal of enterprise architecture is to create a unified IT environment across an enterprise or all of the firm's business units, with tight symbiotic links to the business side of the organisation and its strategy. According to Nakakawa et al. [31], although enterprise architecture offers numerous benefits to organisations, reaping them essentially depends on the successful design of the enterprise architecture process. Moreover, they emphasised that during the design of enterprise architectures, it is vital to ensure effective communication between all stakeholders.

Aiming to investigate the challenges to design a comprehensive and integrated information system for smart environments, this study endeavours to review enterprise architecture related design processes utilising TOGAF, and apply EA concepts to the design of smart environments.

4 Design Processes for Smart Environments

The design process of smart environments consists of steps, in which information about elements of the smart environment (e.g. smart technologies, objects etc.) is exchanged between design experts and other stakeholders. Certainly this information is essential for a detailed design, control and commercial usage. Therefore, according to the first step of TOGAF architectural design method, there is a need to take stakeholders' views and concerns into account. Consequently, a target business model is required to be defined to address recognised challenges in terms of making information accessible. During the subsequent 3rd and 4th steps of ADM, information system and required application to overcome existing challenges will be designed.

Al-Hader et al. [30] stated that the concept of design accommodates the major system requirements while implementing the first phase of the development. They hypothesise that developers need to concentrate on encompassing smart environments from the initial planning phase. Recent studies realised that there is a need in smart environments to fully consider the knowledge, experience, and technology of all disciplines and stakeholders (Yin et al. [34]). Hence, going through the next three sections, we will inspect the design process for three examples, namely smart buildings, smart energy, and smart ecommerce from a knowledge point of view. We will investigate existing challenges and benefits of knowledge within a design process. This section is concluded by summarising the challenges for utilising the knowledge in a typical design process for smart environments

4.1 Design Process for Smart Buildings

The design process of smart buildings consists of multidisciplinary interactions, which deal with knowledge from various professions, e.g. green technologies, renewable energy, etc. In this relation, Kuo et al. [16] declared that the modern buildings are equipped with a diverse range of service systems, such as mechanical, electrical, and plumbing works. Investigators continuously attempt to add more sensitive regulatory systems in modern buildings to make the living spaces more convenient. As announced by Cohen [7], green technologies and green energy are two key drivers of smart environments, which are two of six key components of any Smart city. On the other hand, Arain [1] argued that organising this knowledge would be indispensable during the early design process. Therefore, researchers concentrated mostly on the knowledge flow during the early phases of design. In this regard, Ibrahim and Nissen [11] considered that the knowledge, which was exchanged during the building design, could affect their performance. Later, Ibrahim and Paulson [12] underlined the importance of knowledge flow to complete a building project successfully. Likewise, Shumate et al. [25] pinpointed that problems in the construction industry are due to the incomplete flow of knowledge arising from tacit knowledge dominated activities in building projects. Kasimu et al. [13] explained that knowledge is created during the construction stage and if not properly captured, stored, and utilised, it will be lost. In this regard, many other researchers realised that tacit knowledge and its acquisition would have a major impact on organisation and projects' performance. Xiaoyong and Wendi [26] reported that construction depends on knowledge sharing, and, crucially, on tacit knowledge. Later, Lin and Lee [17] proposed a new methodology to capture and formalise construction project knowledge to provide tacit knowledge exchange and a management environment to enable the reuse of domain knowledge and experience in future projects. It is paramount to highlight that they focused on the construction phase as an explicit-dominant area, while this research revolves around the tacit-dominant design phase.

4.2 Design Process for Smart Grid and Smart Energy

Regarding the increased efforts for energy saving and energy cost reduction, utility companies attempt to find new ways to promote more effective ways of energy usage. Toward this, they are required to evaluate energy consumption and estimate energy consumption costs at the one hand. On the other hand, they need to have an accurate estimation about customers' demands. In this relation, demand response management (DRM) has been introduced as one of the main features in smart grids. As Chai et al. [6] expressed, the smart grid is regarded as the next generation power system to fulfil these challenges. Mohsenian-Rad and Leon-Garcia [20] and Zugno et al. [28] explained that DRM refers to routines implemented to control the energy consumption at the customer side and aims to improve energy efficiency and reduce cost. Furthermore, Mohsenian-Rad and Leon-Garcia [20] and Samadi et al. [24] illustrated that the main objective of demand response management is to reduce the peak-to-average ratio and balance both the power supply and demand. According to Yu et al. [27], some innovative techniques including machine learning, data mining, and discovery in database have been successfully applied to building energy consumption. In this regard, Korolija et al. [15] developed regression models to predict the annual heating, cooling, and electrical auxiliary energy consumption of five different types of HVAC systems and two chilled ceiling systems for office buildings in the UK. Regarding EIA [8], the majority of energy consumption in commercial buildings is related to space heating, cooling, and lighting. In this context, Mikučionienė et al. [18] evaluated the influence of each variable on energy consumption by analysing some factors such as insulation of external walls, roof insulation, heating substation and so on. In such a condition, Asadi [2] also expressed that predicting building energy consumption depends on multiple variables such as building characteristics, energy systems characteristics, and the like. In line with precedent researches, Capozzoli et al. [5] stated that it is exceedingly important to have the capability to quickly and reliably estimate the buildings' energy consumption, especially for public authorities and institutions that own and manage large building stocks. Apparently, regarding the studied literature, to estimate or predict the building's energy consumption there is an essential need to have sufficient technological information and knowledge about mechanical, electrical, and ICT installed equipment. While regarding this fact that the design process of buildings is a tacit-dominant area, meaning that professionals exchange their knowledge orally, there is no such possibility for different users to have access to the technical knowledge about the buildings. As a matter of fact, this knowledge just preserves as technical reports for buildings, while it could be only accessed by project parties as booklets.

4.3 Design Process for Smart Commerce

From the other side, many businesses promote their products in smart markets. In this regard, Baetens et al. [3] detailed that awareness of smart components is moderately strong about the commercial market. He performed a survey on what types of smart windows are currently available on the market and their properties and potential for daylight and solar energy control in buildings. There is an essential need for smart markets to have a proper access to today's building characteristics to be able to deal with their needs for smart components due to new regulations for energy saving purposes.

At the same time, many other small businesses may benefit from this information and technical knowledge. Yan and Ghose [36] elucidated that both kinds of retailers could always gain profit from having knowledge about customers' needs and willingness to buy. As such, they concurred that market information is vital for a firm's decision making processes. In addition, Yan et al. [36] laid emphasis on the forecast information accuracy effect on the profit of traditional and online retailers. In this context, He et al. [9] expounded that major retailers such as Marks & Spencer's, A&P grocery stores and Von's Supermarket have made substantial investment in developing tracking information systems and engaging in ongoing marketing research to improve information accuracy. In the light of the studied literature on retailers' activities, it is indispensable for these small business owners to inspect their customers' needs and willingness to buy. For this purpose, they are required to have access to the technical information about buildings' instalments.

By taking into account the aforementioned reasons resulting from a deep literature review, this study is supposed to provide such access for the users from different areas and industries (e.g. utility companies and retailers) by means of developing a comprehensive database for buildings' technological information. In such a condition, utility companies will be able to utilise this knowledge (e.g. building characteristics, mechanical, electrical and ICT equipment's technical information) to have an exact prediction about maximum energy usage for any building. Farther, they may compare these predictions with real usage to inspect overhead usage of any building. As regards the retailers' information needs, they can use this database as a useful reference to identify the future needs of probable tenants of the buildings consistent with the information which is supposed to reside in the proposed database by this research.

4.4 Recognised Design Challenges

In the previous sections, we have illustrated and discussed the challenges of designing smart buildings, smart energy grids, and smart commerce systems. We have emphasised the steps to design the systems and its challenges from a knowledge flow point of view, which are summarised in Table 1.

Table 1. Design phase challenges from knowledge point of view (alongside ADM phases)

ADM phase	ADM aims	Design knowledge challenges
A. Architecture vision	Scope, assumptions and methodologies and evaluation criteria are defined Key stakeholders and their concerns/objectives and the key business requirements are identified Business scenarios are created	– Knowledge from different professions and stakeholders – Gather knowledge for later use e.g. Utilising building knowledge for commercial purpose; importance of accessing building info by public authorities and institution, and small businesses at a later stage
B. Business architecture	Baseline and target Business Architectures using UML or IDEF-0 The relevant viewpoints are too identified	– High risk of knowledge loss phenomena due to tacitness of knowledge (human-human interaction)
C. Information system architectures	Data and application architecture and views on those	– Need to formalise and organising knowledge – High risk of incomplete knowledge flow due to tacitness of knowledge (human-computer interaction)
D. Technology architecture	Develop a technology architecture that will form the basis of the following implementation Identify the relevant Technology Architecture building blocks	– Need to formalise and organising the knowledge during design phase – High risk of incomplete knowledge flow due to tacitness of knowledge (human-computer interaction)

(*Continued*)

Table 1. (*Continued*)

ADM phase	ADM aims	Design knowledge challenges
E. Opportunities and solutions	Parameters of change, the major phases along the way and the top-level projects to be undertaken in moving from the current environment to the target	– Importance of complete knowledge flow for project success
F. Migration planning	Prioritisation of the projects within the Technology Architecture and costs are estimated for the migration of the various projects	– Importance of complete knowledge flow for project success
G. Implementation governance	For each of the implementation projects, a corresponding implementation organisation is assigned. At the end of this phase the system is fully developed and implemented, compliant to the architecture	– Knowledge from different professions and stakeholders
H. Architecture Change management	The goal of this phase is to manage changes to the architecture in a cohesive and architected way. During this phase, for each change request, the decision is made whether it is necessary to initiate the ADM cycle again, in order to redesign the architecture	– Knowledge from different professions and stakeholders together with preserved knowledge during earlier design phases – High risk of knowledge misinterpretation

Apparently, many researchers have maintained that dominating tacit knowledge during the design phase is the most crucial barrier to make this knowledge accessible by different parties. According to the ADM of TOGAF, the development of architecture views from business to technology is necessary to properly identify the concerns and requirements of the stakeholders (Minoli [19]). Indeed, the recognised challenges for the design process are highlighting different stakeholders' concerns which inhibit their future access to a valuable information resource. To overcome such challenges, we propose a digital environment that can help capture valuable knowledge during the design processes. In this way, one of the recognised challenges for the design process (business process) will be addressed by capturing and formalising tacit knowledge of the experts. Accordingly, some other challenges like knowledge loss and incomplete knowledge flow will be covered. Through the next step of ADM, information system architecture to preserve the captured knowledge is developed. The preserved information would be accessible by authorities, institutions, and small businesses via provided applications and technologies, which are supposed to be designed and developed during the technology architecture step.

4.5 A Digital Conversation Environment

In this section, we will discuss an initial proposal for digital environment that helps to address the listed challenges. Provided solutions to address these challenges could be utilised as a template for designing various information systems for smart environments. Recently, some researchers highlighted the importance of considering knowledge, experience, and technology of all disciplines and stakeholders in smart environments. Therefore, defined patterns for the proposed digital conversation environment can be used for other smart systems.

As a solution, challenges arising from human-human interactions and highly dependent on tacit knowledge of the experts have been converted to a human-computer interaction by means of utilising a pre-defined knowledge exchange environment. Within TOGAF the concept of the Enterprise Continuum has been proposed [38], which provides methods for classifying architecture and solution artefacts within an Architecture Repository. The Enterprise Continuum enables the architect to design enterprise architectures and articulate the broad perspective of what, why, and how the enterprise architecture has been designed. From a Knowledge perspective, Pourzolfaghar et al. [23] have developed a knowledge-based framework for the design phase, which entails the entity of the required architectural, mechanical and electrical knowledge. This allows to transform and to formalise tacit knowledge of the experts to an explicit type. Indeed, this environment will act as an interface between professionals to conform the existing challenges to the design phase.

Developing this framework, the knowledge flow has been combined with design processes. The knowledge aspect of this framework considers architectural, mechanical, electrical and ICT knowledge, which needs to be combined and reviewed. This framework included the entity of the required mechanical and electrical knowledge that has to be considered during the design phase.

The proposed environment helps to provide a condition to make this information accessible by different stakeholders for the control, maintenance, or commercial purposes. As discussed, utility companies use building information to predict or estimate the customers' consumptions to promote effective ways of energy usage, as well as reducing the price. Moreover, small business owners like retailers may benefit from this environment. In this way, they will be able to obtain useful information about all the buildings and their capacities to have an accurate prediction about their energy consumption or future needs for technical equipment. Like so, they will be able to fulfil their estimation, predictions, and demand management. This environment as a comprehensive database for a potential market surrounding the areas around the buildings is supposed to be fed through a conversational environment for the design phase of the smart building project. Additionally, various users (e.g. Utility companies and retailers) can benefit from detailed information and knowledge about technological equipment.

5 Conclusion and Summary

The design process of smart environments is highly tacit dominant in which very essential knowledge is exchanged between the professionals. This valuable knowledge is required to be preserved for later maintenance and use. However, a problem associated with this phase arises from tacitness of knowledge. In this paper we have reviewed design processes and related challenges from an information systems point of view. We have followed the architectural development method proposed within TOGAF to investigate and describe challenges knowledge transfer and formalisation, in particular in regard to human-human and human-computer interaction.

As environments become increasingly connected into smart environments, these challenges hamper increasingly the design of smart environments. Therefore, in order to realise the full potential one remaining challenge is the design, integration and interoperability of many elements into a smart environment. We have proposed a conversational approach that supports the main design phases and allows professionals to interact during the design phases for smart environments. This environment is supposed to be established on an existing knowledge-based framework for the design phase. To develop such an environment, this study makes use of the TOGAF enterprise architecture development method. Accordingly, the recognised challenges are considered as stakeholders' views and target business process is planned to address them. The digital environment helps to address recognised challenges for design process of smart environments in terms of preserving tacit knowledge and making it accessible for various stakeholders. Further research will investigate and confirm the identified challenges in various case studies, such as smart commerce. In addition we aim to refine and evaluate the proposed conversational environment.

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