CONTEXT SENSITIVE MOBILE DEVICES IN ARCHITECTURE, ENGINEERING AND CONSTRUCTION

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SUMMARY: *The AEC & FM-sector[1] is aware of the potentials arising from the usage of mobile technology in construction for streamlining their business processes. Discussions are no longer on whether or not to use mobile computer-supported solutions but, rather, on how they should be implanted and used. The following publication describes an integrated, holistic framework for context-sensitive, mobile applications based on the concept of Virtual Organisations, the pattern-based software development paradigm, and multi-dimensional data management developed at the Dresden University of Technology. By applying this approach in early field tests mobile technology became an integrated, complementing part of information systems and newly developed, flexible, adaptable business scenarios instead of remaining just another fashionable toy used as an "add-on" reflecting already existing business practices. The innovations presented in this paper rely on the Concept of the Mobile Worker (CoMoWo) as well as of Mobile, Ambient Intelligent, Networked Environment (MAIN-E). CoMoWo combines pattern definitions and a hierarchically structured layer concept to describe the relationships and interdependencies among the individual patterns. CoMoWo will contribute to the development of innovative methods and adaptive project management models. MAIN-E consists of a set of technology components supporting CoMoWo, such as a multi-dimensional information framework, intelligent agents, and location-based services. This will lead to a supportive IT-infrastructure mobile and fixed to provide information on demand and in the right context to the mobile worker.*

KEYWORDS: *mobile computing, pattern-based design, situation-based information management*

1. INTRODUCTION

Extensive coordination, communication and data exchange processes are performed during the planning, construction, and operation phases of a built artefact among the different actors involved in one specific project. So far, advantages of using information systems have been limited to office work and single tasks. Field personnel (e.g. construction managers, foremen, or inspectors) are not able to connect to information management systems during the time away from the office. Nowadays, new technologies such as mobile devices and wireless networks are available and support nearly unlimited accessibility to digital information. Furthermore, mobile devices not only provide users with the computing support needed but also with newly developed input and output technologies supporting alternative ways of interaction when using the computing device on the construction site. However, the efficient usage of these new technologies requires profound understanding of relevant activities and their inter-relationships. Furthermore, current management and process models need to be analysed and re-engineered to fully exploit the potentials of mobile technologies (Garrett et al. 2000). Mobile technologies need to be complemented by flexible, sophisticated information management systems. The user, working on construction sites, should neither be overloaded with irrelevant information nor be hampered by inappropriate services and cumbersome in- and output techniques (Reinhardt et al. 2000).

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[1] AEC Architecture, Engineering, and Construction – the planning and construction phases
FM Facilities Management – the operation and maintenance phases

1.1 About This Paper

The paper starts with an analysis of current working situations in AEC & FM which define so called ‘context aspects’ to improve the understanding of relevant, ‘*on-site’* activities and their inter-relationships. Secondly, a methodology for flexible process modelling is developed, introducing a three layer concept. This methodology is extended with pattern definitions describing an implantation strategy for mobile computer solutions. The three layer concept and the pattern definitions are the components of the ‘*Concept of the Mobile Worker* (CoMoWo).’

Chapter 5 illustrates how Data Warehouse technology supports the generation of different dimensions representing parts of a “holistic information space.” It explains how the definition of the dimension hierarchies corresponds to the context aspects specified in CoMoWo. The proposed ‘*Data Warehouse Extended Platform*’ (DWEP) supports the required integrated information management approach, equally considering on-site construction activities as well as “in-house” management and supervision processes. Furthermore, it is explained how agent technology might assist the user of mobile devices in the field to support her/his individual requirements in specific working situations. The combination of the DWEP with agent technology creates location-based services, forming the ‘*Mobile, Ambient Intelligent, Networked Environment*’ (MAIN-E).

2. ANALYSIS OF WORKING SITUATIONS IN AEC & FM

Construction sites are dynamically changing, weather-exposed workplaces with many ongoing activities. Dangerous situations can arise quickly and unexpectedly. Using a mobile device in such environments which presents insufficient or inappropriate information and requires cumbersome in- and output activities might be quite dangerous and annoying to the user. Therefore, it is absolutely necessary to understand the major processes of field workers. Field workers can be either personnel acting on construction sites but also inspectors or maintenance crew members working on already existing built artefacts.

DEFINITION: *The term field worker describes any individual acting outside his/her office.*

2.1 Aspects of Context Sensitive Information Management

This chapter focuses on the definition and specification of working situations. In general, there are many working situations in the AEC & FM sector for which the usage of mobile computer systems might be beneficial. However, the efficiency of using mobile computing systems strongly depends on the specific working situation to which they will be employed. Therefore, each system, or part of the system, has to be developed carefully, taking into account the specific requirements.

Therefore, it is necessary to formalize, specify, and categorize the aspects of context sensitive information management in the AEC & FM sector. Relevant aspects characterizing a specific situation while working in the field were defined by Menzel et. al. (2002) or Bürgy (2002). Bürgy, for example, in his work developed a so called ‘*Interaction Constraints Model’*. However, according to the authors’ opinion this model is focused in a very detailed way on the analysis of single tasks. Therefore, the model does only partially reflect the needs for the business-process driven analysis and development of mobile applications. Furthermore, Bürgy’s definition of a work situation only considers locations and activities, whereas the activity analysis is mainly focused on the IT-aspects and considers only partially the domain-specific needs, such as the time aspect reflecting the evolutionary dimension of information management. Based on our analysis as well as the analysis of other research work the following aspects of context sensitivity information management are defined as:

1. the actor aspect
   (person or organisation, its role within the specific project, but also machinery and mechanical aids),
2. the time aspect (including the project status),
3. the activity aspect,
4. the IT-infrastructure aspect,
5. the location aspect (including the building product description)
6. the environmental aspect (specifying the situation in the field, such as weather, light, etc.)

To conclude, the term work situation can be defined as follows:

DEFINITION: Within one specific WORK SITUATION some ACTOR is using a specific IT-INFRASTRUCTURE to obtain, enter, view or modify INFORMATION that he/she requires to successfully accomplish his/her ACTIVITY at a specific LOCATION and TIME under specific ENVIRONMENTAL CONDITIONS.

Within the next sections the various aspects of a work situation are specified. The specifications contribute to the domain specific definition of context-sensitivity and the development of context-sensitive mobile applications.

2.1.1 The Actor Aspect

Closing the gap in the information flow between the office and the construction site requires the involvement of a broader scope of users. Not only engineering and management personnel should be able to use mobile computers but also less qualified field workers. Systems need to be adapted to the individual qualification profiles. One actor's role can be easily determined by using information from existing and integrated organisational schemata. By managing individual workers as groups or organisational units, the internal behaviour and the internal structure of sub-contracted organisations can be 'encapsulated.' However, certain tasks might be completely performed by machines or robots or at least supported by special tools. Therefore, the actor aspect also includes machines and tools. When describing a working situation it is essential to consider the specific requirements to efficiently operate or use the various types of equipment used in AEC & FM.

DEFINITION: The term ACTOR describes a unit that is responsible for performing a specific activity or a set of activities specified by a certain role, whereby a ROLE defines the performance indicators of that unit (e.g. required skills, the qualification profile, or technical indicators). An actor can either be an organisational unit, an individual employee but also a machine, a control unit or a software tool.

2.1.2 The Time Aspect

At first sight the time aspect seems easy to define. This holds true if only the current time (stamp) is required for further processing. The current time stamp is very useful for semi-automatic service functions; e.g. information about further planned activities can be requested from a workflow management system. However, monitoring of the project status needs more sophisticated algorithms mapping current time to project phases in the past or in the future as well as synthesizing and comparing information of different granularity.

DEFINITION: The TIME aspect is used to classify or evaluate information. By using the time aspect the performance of actors can be evaluated. Furthermore, the time aspect determines the sequence of activities.

2.1.3 The Activity Aspect

The accomplishment of a project triggers various activities, whereas each activity requires certain actors, information, and tools. A context sensitive mobile computing system must be able to determine the information needed by the user and will present it activity-dependent to the user. The activity specification might be derived from already existing business process modelling tools or workflow management systems. The distinction in activity aspect, actor aspect, IT-infrastructure aspect and product aspect follows the approach taken within the ARIS-methodology (see also Scheer 1998).

DEFINITION: The ACTIVITY aspect describes and classifies tasks, their sequence and interdependencies. Activities can be hierarchically ordered and grouped to activities. Tasks and activities are specified by a location.

2.1.4 The IT-Infrastructure Aspect

Mobile applications should be adaptable to the specific hardware requirements of mobile devices, such as a much smaller screen size or different in- and output interfaces. Besides other aspects, the graphical user interface (GUI) should respond in the following way: (1) reshape content representation to fit the size of the display, (2) adjust GUI-items to exactly meet the process-oriented demands of the specific actors, and (3) hide or rather show GUI-elements supporting on-line or off-line functionality. Mobile devices often lack sufficient storage capacity and processing power. However, the management of complex, holistic project information needs sophisticated, robust information systems. Therefore, one needs unrestricted access to (back-office) information management services through networks, either wired or wireless. Hence, infrastructures available in the field (e.g. network coverage or electricity support) influence the usability of mobile devices. Mobile devices can be identified through their MAC-addresses.

DEFINITION: The IT-INFRASTRUCTURE aspect describes and classifies the quality of the mobile, end-user device as well as the performance of its network connection.

2.1.5 The Location Aspect

Typically, an organisation is involved in several projects. Therefore, field workers often work on different sites. Automatic positioning services allow for the conclusion on which site and, therefore, on which project the actor is working. Furthermore, some activities are directly connected to a certain part of the building e.g. the redressing of errors and omissions. Therefore, it is necessary to describe the location by using a building product model. Location-based services will only deliver relevant information to the user. The position of a specific actor can be determined by a digital navigation system, e. g. a GPS locator tool or an indoor positioning tool, and by interlinking them to local grid systems. Existing standardized product models such as ISO/STEP 10 303/225 or the Industry Foundation Classes (IFC V2.x) can be used for local navigation.

DEFINITION: A LOCATION is identified by a unique global position attached to the user. Based on these co-ordinates, secondary, project-specific descriptions of the location can be calculated.

2.1.6 The Environmental Aspect

There are several environmental restrictions that might impact the usage of mobile devices in the field. Restrictions can result from (a) the natural weather conditions like heavy rains, frosty and cold temperatures, sunlight etc. and (b) the type of construction site such as a bridge, road or building construction site. The environmental restrictions are very often decisive when choosing the mobile computing system, especially the device to be used.

DEFINITION: The ENVIRONMENTAL aspect describes and classifies the conditions under which a mobile device is used. It includes both, the description, classification and evaluation of natural environmental aspects as well as of technological environmental aspects resulting from the type of the technical artefact to be constructed, monitored, or maintained.

2.2 Mapping Context Aspects to Modelling and Implementation Aspects

Context aspects can be used to define parameters specifying and classifying different working situations. FIG. 1 depicts how the context aspects specified in chapter 2 will be used for the specification and verification of the modelling and implementation methods and strategies described within the following chapters. Organizational concepts are described in chapter 3, business process engineering is described in chapter 4, data structures and IT-processes are described in chapter 5, and an example for GUI-design is given in chapter 6.

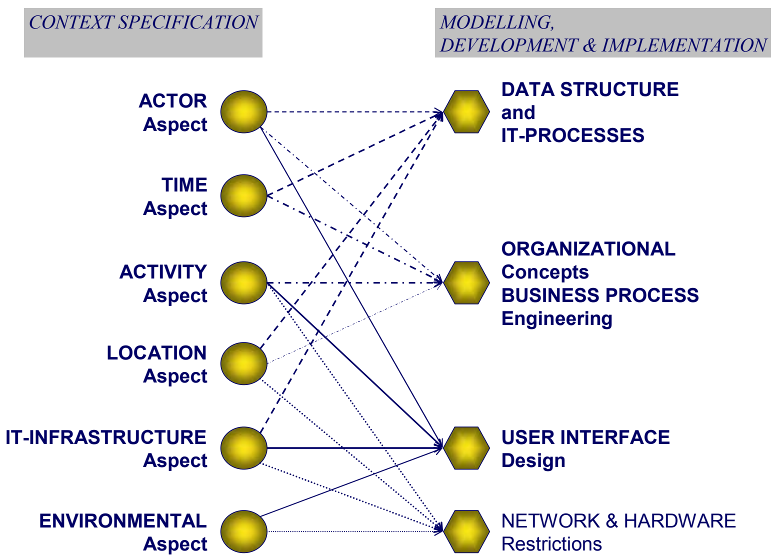


FIG. 1: Mapping context aspects to modelling, development, and implementation aspects

3. VIRTUAL ORGANISATIONS IN THE BUILDING INDUSTRY

Efficiency gains in the AEC & FM sector based on the usage of mobile technologies depend on various aspects. One important aspect is the necessity for synchronization of management paradigms with information management paradigms and methodologies. Therefore, the phases of Virtual Organisations and construction projects are analysed in the next chapter. It needs a better understanding of both domains in order to support integrated management approaches efficiently supported by appropriate IT-tools. A three layer information management concept is introduced with clear and pragmatic definitions. The underlying VO-principles will be compared with popular management philosophies in the AEC & FM sector. The following definition of the term Virtual Organisation is based on statements of sound, well accepted references [VO Net Workshop 1998, Camarinha-Mathos 1999].

DEFINITION: A VIRTUAL ORGANISATION (VO) is an identifiable group of actors that make substantially more use of information and communication technologies than physical presence to interact, conduct business and operate together, in order to achieve common, project-centred business objectives. The aim of the VO is to gather complementing competencies of different actors in order to enhance efficiency and productivity while decreasing overheads.

3.1 Lifecycle Phases and VO-Classification in AEC & FM

The VO life cycle can be divided into the following phases: (1) source network creation, (2) identification of business goals (3) partner search, (4) contract negotiation, (5) operation & evolution, and (6) dissolution. Due to the dynamic nature of construction projects VO-phases will not run in parallel to the building life cycle phases. VO-phases are shorter and can be repeated in each phase of the building life cycle (see FIG. 2).

VOs can be classified according to different criteria like duration, topology, participation, visibility, and coordination. Considering Table 1, a VO for a construction project is most likely a long-term alliance with variable topology due to the dynamic integration and dismissal of partners. Organisations can participate in multiple alliances at one time. Information is visible on multiple layers. It is shared, using a common information space. VOs often have a star-like structure in AEC & FM with a project manager as the driving force.

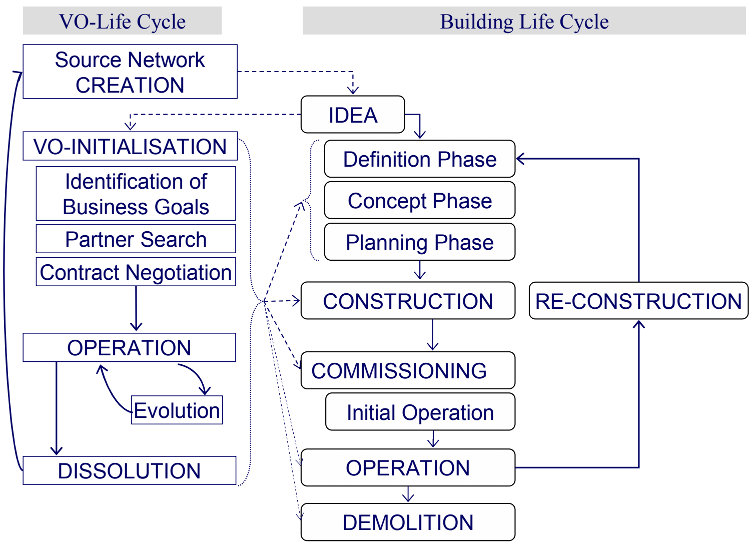


FIG. 2: Lifecycle phases of AEC & FM-specific Virtual Organisation and buildings

Table 1: Classification of VOs in the AEC & FM-sector

Duration:	Participation:	Visibility	Topology:	Co-ordination
☐ Single business	☐ Single alliance	☐ Single level	☑ Variable/dynamic nature	☑ Star-like structure
☑ Long-term alliance	☑ Multiple alliance	☑ Multi-level	☐ Fixed Structure	☐ Democratic Alliance
				☐ Federation

3.2 Components of an IT-infrastructure Supporting VOs in the Building Industry

The star-like structure of a potential VO is shown in FIG. 3 with the project manager and the project information system (PIS) as the leading elements in the centre. VO-partners and VO-candidates can leave or join a VO in the different phases of the building life cycle. Therefore, the PIS manages partners' interaction and controls the project goals. Each VO-partner is represented by two actor-classes, the domain manager and the field worker. Additionally, each VO-partner has its own (company-specific) enterprise information system which must be able to exchange information of different granularity with the PIS, using standardized interfaces. Different granularity of information is required to address the different perspectives of the three actor-classes.

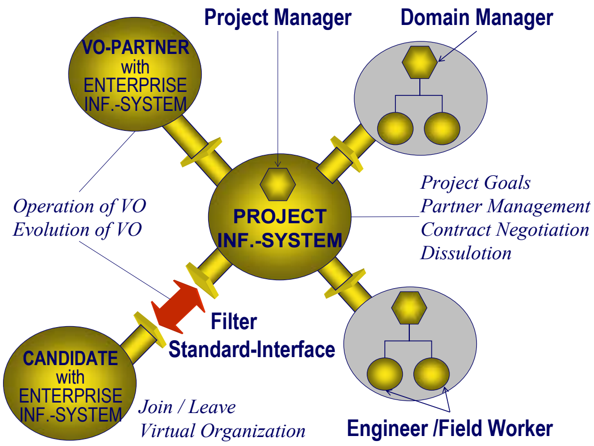


FIG. 3: Structure of a VO information system

3.3 The Layer Concept: Integrating Actor – Time – Activity

To reduce the complexity of a project its information management should be decomposed into different levels of granularity – so called layers. Furthermore, the proposed layered architecture must reflect the requirements of the VO-concept. Therefore, each layer should have its own modelling paradigm representing the desired information (Jablonski, Böhm, et al. 1997). This means, the information scope corresponds to a specific actor's role in the project and addresses his individual demands on precision. However, the models must be integrated into a homogeneous domain description. Consequentially, we suggest introducing a three layer concept consisting of: (A) the strategic layer, (B) the tactical layer, and (C) the operative layer (see Table 2).

Table 2: Layer concept for a construction project

Layer	Content	Model
Strategic	goals, milestones	goal function
Tactical	formal sequences (business processes)	workflow-management (planning & controlling)
Operative	times & resources	scheduling

3.3.1 Strategic Layer

The strategic layer defines the boundary conditions of the project by outlining the project aims in a goal function. Goals and their relationships should be described in a formal and definite manner with performance indicators like time, costs, resources, etc. By dividing the goals into sub-goals in accordance with the project progress, milestones can be determined. The project manager manages the strategic layer.

DEFINITION: *The STRATEGIC LAYER is the basis of all planning and management activities. It provides general project information designated to the project management. The strategic layer supports progress monitoring and early detection and prevention of conflicts on the project level.*

3.3.2 Tactical Layer

By introducing the tactical layer a complex AEC & FM project can be planned and controlled, using workflow management models. It is divided into homogeneous, closed phases combining a certain number of business processes to activities. Each activity contributes to the fulfilment of the goals of the strategic layer. The domain manager, together with the engineering staff, manages the tactical layer.

DEFINTION: *The TACTICAL LAYER is introduced to specify domain specific activities. The required input and the generated output as well as the responsible actor for each activity are defined. Furthermore, the sequence of activities is defined by specifying the successor and predecessor. Technological restrictions are taken into consideration.*

3.3.3 Operative Layer

While the activities defined in the tactical layer specify the output needed to achieve the goal of a milestone, the operative layer defines the way of how to achieve the goal by considering the given restrictions of the strategic layer (e.g. time, cost, quality). The engineering personnel, together with the field workers, manage or use the operational layer.

DEFINITION: *The OPERATIVE LAYER defines and schedules sub-activities, so called TASKS, needed to fulfil the goals of each activity in accordance with the boundary conditions defined in the tactical layer (e.g. time, cost, quality). Tasks and activities are planned on the actor-level. The critical path is calculated. Interdependencies among different actors are considered.*

3.4 Architecture of the System-Model

Technical data as well as information about activities, sequences, and roles accumulates over time from the first schematic model to very detailed work schedules reflecting the evolutionary and iterative nature of AEC & FM projects. In order to be able to work on the overall project at any time, it is inevitable to use different process model representations depicting the various processes in an adequate form and at an appropriate level of granularity. While the objectives of later processes are modelled and specified more abstractly, the characteristics of the processes in the near future must be specified precisely. This means, the process information of AEC & FM projects can be graphically represented in the shape of a wave as depicted in FIG. 4.

The integrated usage of the VO-concept, the layer concept, and the pattern-based activity modelling approach will lead to an architecture supporting the implantation process of mobile technologies as well as to newly developed activity definitions and re-engineered business-processes. FIG. 4 depicts the integration methodology:

- Activity pattern library: The creation and operation of a VO can be managed by selecting, combining, and instantiating activity patterns from a library. Furthermore, it is ensured that the 'handling & operation' of mobile applications remains comparable and independent of specific project requirements.
- Layer concept: By separating the project into three layers different dimensions of information can be represented. The strategic layer defines activity sequences and i./o.-specifications, the tactical layer defines functions, events, as well as actors, and the operative layer defines precise schedules and controls the interdependencies among actors from different professions.

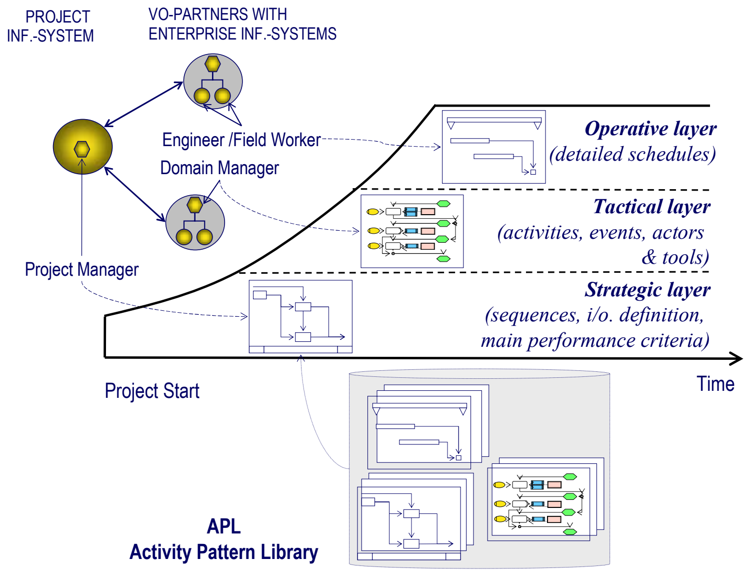


FIG. 4: Integration of processes, organisation and layers

4. INTRODUCING MOBILE TECHNOLOGIES TO THE AEC & FM SECTOR

Inspired by the pattern-based design in Architecture and Software Engineering a pattern-based approach is proposed to facilitate the implantation process of mobile computing in the AEC & FM sector. Using the pattern-based approach, analysis and design solutions to recurring problems can be developed more easily and faster. The following paragraphs briefly explain the similarities and differences of the existing pattern-based design approaches.

Christopher Alexander, an architect, developed the pattern-based design approach in the areas of urban development, architecture and building engineering (Alexander 1977). Together with his research group he developed a pattern language consisting of more than 250 design patterns. Alexander's patterns are based on observing existing systems and discovering general structural or behavioural patterns in them. Templates are used to describe these patterns in a comparable, unified way. However, the pattern description relies on natural language rather than a formal, specific language. Examples are added to illustrate the structure and behaviour of selected patterns.

Alexander's pattern language also contains the description of relations among patterns. Furthermore, there exists a hierarchical order in which the patterns should be used. Although it is claimed one can design an artefact to be built simply by applying Alexander's patterns, Alexander does not deny the need for creativity and a high level of expertise. According to Alexander (1977) a pattern can be defined as follows:

***DEFINITION**: 'Each pattern is a three-part rule, which expresses a relation between certain context, a problem, and a solution. … As an element in the world, each pattern is a relationship between a certain context, a certain system of forces which occurs repeatedly in that context, and a certain (spatial) configuration which allows these forces to resolve themselves.'*

With the 'revival' of the object-oriented programming languages, Erich Gamma et al. (Gamma1994) developed one of the first general pattern catalogues to the field of software engineering. This effort was inspired by Alexander's work as well as earlier and more specific contributions in the field of software engineering, such as '*The Art of Computer Programming'* by Donald Knuth, '*Advanced C++: Programming Styles and Idioms'* by James Coplien or Kent Beck's development of Smalltalk Patterns.

In contrast to Alexander's pattern language Gamma's design patterns are intended to describe pragmatic solutions for software engineering problems. There is no specific order or hierarchy that defines how Gamma's patterns are to be applied. Gamma et al. do not claim that the application of their patterns will lead to complete software systems. Last but not least; one should notice that there exists much less experience in designing software systems than in designing infrastructure systems. Thus, it will take more iteration to check software engineering patterns against real life examples (see also Fowler 1997).

4.1 Developing Mobile Computer Applications Using the Pattern-Based Design

Establishing the organisational as well as the process structure of a new project requires a lot of effort and experience of the project manager. However, it is impossible to predetermine each single task needed to complete the project. Predefined process descriptions might be of invaluable help to better describe prospective activities. However, predefined process descriptions shall not cover each single task that has to be performed; instead, so called process patterns generally specify domain-specific activities. Furthermore, by using a '*Activity Pattern Library'* (APL) homogeneous process management guidelines are made available for the set-up of new (virtual) project organisations. Finally, an existing process model can be modified in an evolutionary way by integrating further patterns on the fly using a database of process reference models.

An APL specifying AEC & FM activities can be easily extended with patterns describing necessary IT-related implantation activities. By integrating the IT-implantation patterns into an existing AEC & FM-specific APL one ensures that these patterns are developed in a synchronized way with the domain-specific patterns. Thus, by applying these patterns, the implantation of mobile technologies in the AEC & FM sector will be performed in correspondence to the domain-specific process models, allowing optimal usage of the potential of mobile technology in AEC & FM.

The following sections show some examples of patterns which might be used to support the implantation process of mobile technologies in the AEC & FM sector, especially in Small and Medium-Sized Enterprises (SME).

4.1.1 The Origins of the Approach

Within the EU-cluster project VOSTER the results of appr. 30 EU-research projects in the area of VOs were consolidated and synthesised. A VO core concept and a general modelling framework were developed (VOSTER 2004). These results were used as the basis for the development of the framework depicted in FIG. 5. Within the next sections the authors specify selected patterns of that framework, describing in a more detailed way how to implant mobile technologies in the AEC & FM sector in correspondence to the VO-paradigm. As shown in FIG. 5 the following patterns will be explained: (1) transparency and self-organisation, (2) lateral VO-structures, (3) continuous VO-structures, (4) distributed software architectures, and (5) integrated systems.

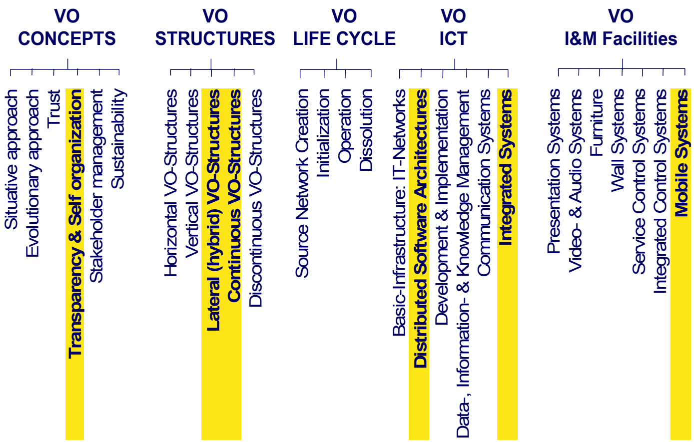


FIG. 5: Framework for VO-Patterns in the AEC & FM sector

4.1.2 Transparency and Self-Organisation - Pattern

CONTEXT/PROBLEM: To support the VO-approach it is necessary that all partners of a construction project have transparent access to integrated information about construction activities, such as information about delays or missing resources. Furthermore, warnings on detrimental impacts can be generated automatically by the system and immediately forwarded to the actors concerned.

SUGGESTED SOLUTION: A process-analysis is needed to obtain a detailed overview of the current status and to develop improved, homogeneous activity and information flow-descriptions. The result of this pattern is an optimized, integrated ACTIVITY specification interlinked with an ACTOR-specification and an IT-resource specification. FIG. 6 depicts the process description of the "as-is" status and FIG. 7 depicts the optimized process description showing 'errors and omissions registration' activities by using the ARIS-methodology (Scheer 1998). By additionally applying the 'Integrated System'-pattern 'stand-alone' applications (e.g. workflow management systems) will be synchronized with each other. Thus, IT-applications remain no longer a singular tool but will support the self-organisation process of (virtual) project organisations.

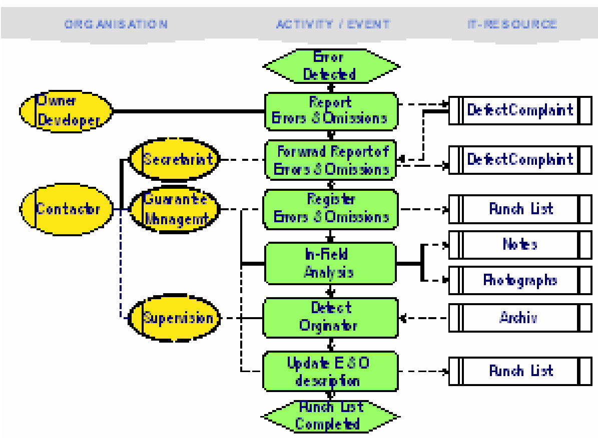


FIG. 6: 'As-Is' Actor-Activity information flow

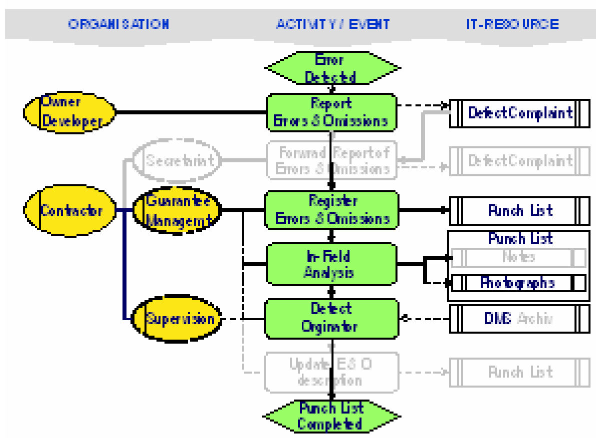


FIG. 7: Optimized Actor-Activity information flow

4.1.3 Lateral VO-Structures - Pattern

CONTEXT: AEC & FM organisations are mostly operated project based. Therefore, it is essential to support continuous, up-to-date information access as well as information acquisition. Mobile technologies complemented by holistic information systems are used to bridge the gap in the information flow in two ways: (1) across 'organisational' levels and (2) across sectorial boarders.

PROBLEM: A common basis of business process descriptions is necessary to support the interdisciplinary knowledge transfer between the different AEC & FM-actors as well as between AEC&FM actors and those representing the software engineering sector. Currently, major business processes and information models are described using different notifications and modelling languages.

SUGGESTED SOLUTION: Major business processes are described using the ARIS-model and the Unified Modelling Language (UML). By representing complex process specifications in synchronized models but multiple perspectives, it becomes possible to consider the various aspects of context-sensitive information management in detail. Furthermore, the need for synchronized terminologies of the different sectors and process modelling layers can be addressed. The availability of activity patterns will allow for quick and easy customisation of the '*mobile framework'* to match the project-specific needs. The usage of patterns ensures that existing and well proven specifications of activities will be used as the basis for the organisation of a new project. Patterns can also be combined in different ways, using well defined and described interfaces. Thus, the VO project coordinator has still enough flexibility when combining the existing patterns.

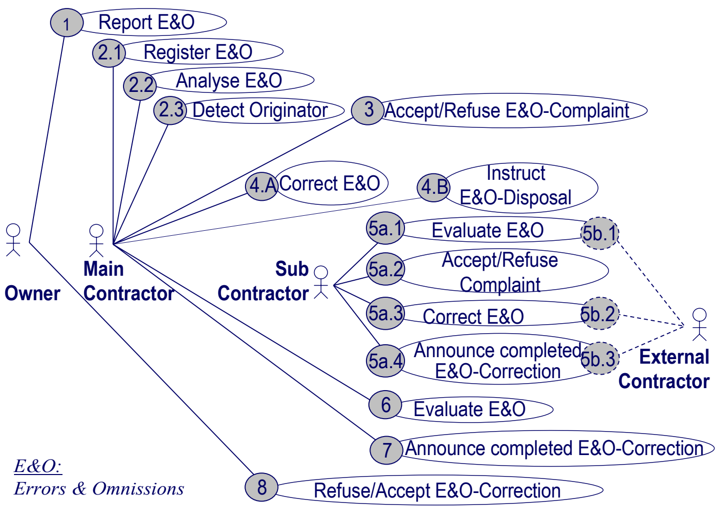


FIG. 8: Use case diagram – Cross-Organisational perspective

One example describing selected 'Error and Omission Management' activities is depicted in ***FIG. 8***. The Use Case Diagram illustrates that up to 4 'Actor Roles' are involved in the E&O-Management activities. However, the owner must only interact with the 'Main Contractor'. The 'Main Contractor' represents the VO and manages the internal processes. Internal process management includes the decision whether the 'Main Contractor' is responsible for the error correction (see 4.A) or if a 'Sub Contractor' is responsible for it (path 5a.x). In case the 'Sub Contractor' refuses the responsibility or the 'Sub-Contractor' is no longer a member of the VO an 'External Contractor' must receive an order to fix the mistake (see path 5b.x).

4.1.4 Continuous VO-Structures – Pattern

CONTEXT: The structure of a VO to manage a construction project must be set up in way that, on the one hand, the client has only to contact the VO-representative, and on the other hand, VO-partners can easily join or leave the VO. However, the project management information and all technical data must be available at any time to all VO-members and the client.

PROBLEM: In order to bridge the cross-sectorial gap in VOs, relevant information from the various partners' information systems and data collected in the field must be integrated, consolidated, and made available for long-term usage.

SUGGESTED SOLUTION: Project-related, VO-specific information can be compiled in a separate information space by using data warehouse technology. This consolidated information can be extended in a more detailed way by domain engineers during the life-cycle of the project. The presentation of this complex information to the field personnel can be simplified through the usage of decomposed partial models. FIG. 9 shows the information management activities during the life-cycle of a VO in the proposed three layer architecture (see chapter 3).

Furthermore, mobile technology enables workers and engineering personnel in the field to monitor construction processes or to report errors and omissions. Data collected in the field needs to be stored and managed in the finest granularity possible. However, field data needs to be integrated into a '*project information space'*, consolidated, and finally aggregated. The sequential combination of in-field data acquisition, data integration, and data aggregation bridges the gap in the information flow between the different organisational levels and ensures the availability and accessibility of information over a long period.

In one of our ongoing research projects we implemented a "Construction Diary" prototype as well as an "Error and Omission Management" prototype to be used in SMEs working in the construction sector (see chapter 6). The prototypes focus on the support of the operation phase of a VO. The moderate complexity of the cross-sectorial integration does not require the implementation of an ontology-based information management framework. However, definitions for dimension hierarchies defining aggregation and decomposition of data were developed in our project (Eisenblätter, Menzel et al. 2004).

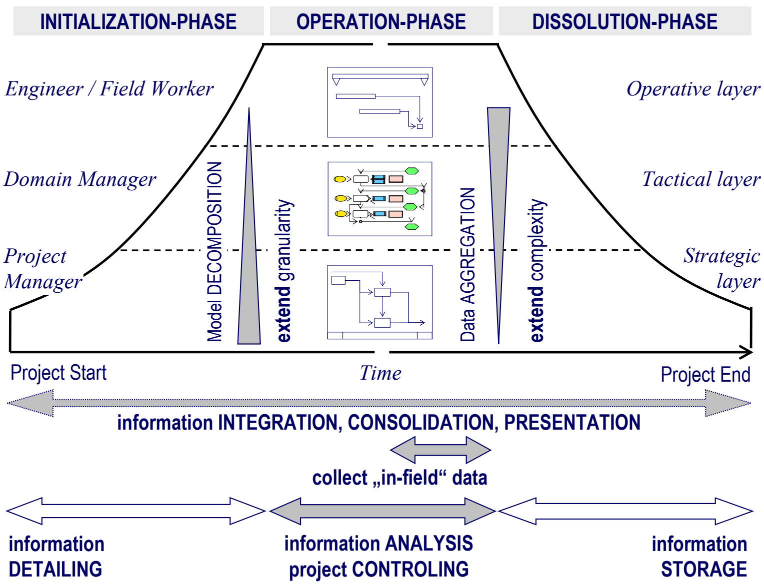


FIG. 9: The "information wave" and related information management operations

4.1.5 Distributed software architecture - Pattern

CONTEXT: The fragmented organisational structure of the AEC & FM sector requires a distributed data management architecture.

PROBLEM: Each organisation stores and manages relevant data in its own IT-systems. However, this information must be interlinked with data from other VO-partners.

SUGGESTED SOLUTION: Project-based information spaces can be implemented by introducing a web-portal. This means, the primary organisation-centred information management infrastructure is extended by an (over-lapping), secondary project-centred information management infrastructure. The proposed architecture supports a clear but flexible distinction between the two necessary organisational structures: the 'internal', organisation-oriented structure, and the external project or VO-oriented structure. FIG. 10 shows the proposed architecture.

Such a distributed software architecture easily supports the integration of (project-centred) mobile applications. This means, personnel working in the field is able to access all relevant information through the web-portal. Furthermore, information collected in the field can be distributed multiple times to the different VO-partners through the Web-portal.

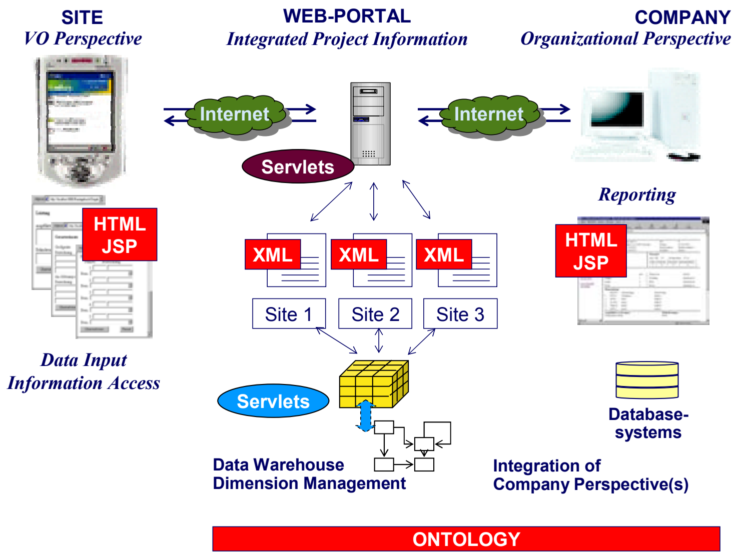


FIG. 10: Proposed and partially implemented software architecture

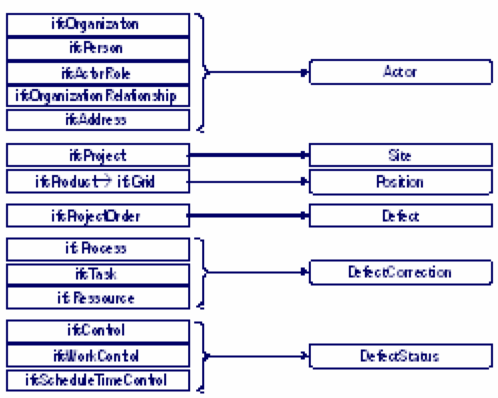
4.1.6 Integrated systems - Pattern

CONTEXT: Within one VO it is absolutely necessary that all partners use the same terminology, comparable standards and technical specifications in order to avoid misunderstandings and ensure the utmost quality.

PROBLEM: IT-solutions are to support complete activities or business processes instead of single tasks. Therefore, mobile applications must be an integrated part of existing software environments instead of single solutions. Furthermore, data collected in the field must be transferred into existing standardized data or information models.

SUGGESTED SOLUTION: Integrated systems and distributed data and information management do not exclude each other. In addition to the development of the above explained patterns, it is also necessary to integrate technical specifications. This can be achieved by using standardized data exchange formats and their underlying product and process models. **Napaka! Vira sklicevanja ni bilo mogoče najti.** illustrates the general mapping schema from IFC-Classes to elements of the data model we have developed.

Last but not least, the integration of IT-applications will also be achieved by using common design styles and libraries for the development of common GUIs. ***Fig.*** depicts a sequence diagram of our E&O Management prototype describing the access of different GUI-objects. Independent of the location, all GUI's follow one unified development style (see also chapter 6).



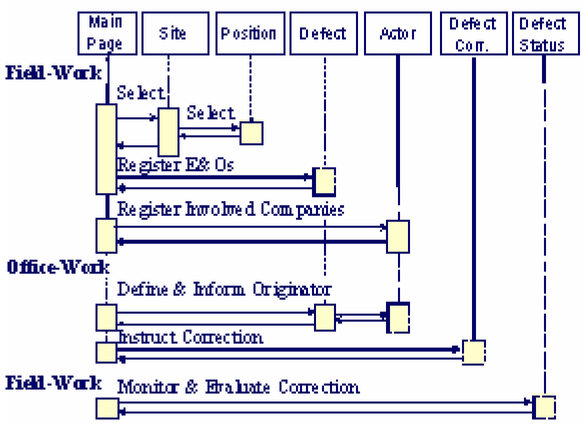


Fig. 11: Mapping IFC-classes to 'Mobile Objects' *Fig. 12: Integrated web-application*

5. MULTI-DIMENSIONAL DATA MANGAGEMENT APPROACH

This section explains the potentials of n-dimensional data management in combination with agent technology for context-sensitive process and data management. High performance back-end services are the basis for efficient usage of mobile technologies. The aim is to provide a homogeneous, synchronized data management platform which can be easily and flexibly be accessed by mobile devices. Before analysing the potential of multi-dimensional data management and data warehouse technology, we will briefly explain both terms.

5.1 Data Warehouse Technology

Data Warehouse Technology provides methods and tools to systematically organize, understand, and use complex data. Data warehouses integrate input data from already existing information systems and data collected by (mobile) applications. They consolidate and store data for fast access and retrieval and deliver requested data in an appropriate presentation format. Data Warehouses are designed to support three main functions:
(1) data pre-processing, (2) on-line analytical processing, and (3) presentation and output generation.

Data pre-processing is necessary to consolidate existing and collected data. Inconsistencies and errors need to be eliminated. On-line analytical processing (OLAP) provides a user-friendly environment for interactive data analysis. OLAP is based on data structures generated by concept hierarchies and extended with data cube operations defined in the meta-data of the data warehouse. Presentation and output generation modules represent the analysis' results in a context-sensitive way to a specific actor appropriately configured to his/her specific needs.

Data Warehouses are based on a multidimensional data model. This model represents data by using the metaphor of a data cube. It is defined by dimensions and facts. A data cube allows data to be modelled and represented in multiple dimensions. Dimensions are defined in Dimension Hierarchies. Dimensions are the perspective with respect to which a user wants to have the data presented or analysed (Kurz 1999 and Ian, Witten, Eibe 2001).
A formalised description of dimensions according to Lehner (Lehner 2003) is presented in formulas [1] to [6].

Facts are (numerical) values representing quantities by which relationships between dimensions are analysed.
A formal fact definition is given in formula [7].

DEFINITION: One schema 'DS' of a dimension hierarchy 'DH' consists of a partially ordered set of category attributes, whereas" →"is the functional dependency.

$$(\{ D_1, \ldots , D_n, Top_D\}; \rightarrow) \qquad [1]$$

TopD is one specific generic, maximum element which is functionally definable from all other attributes.

$$\forall i \ (1 \leq i \leq n): Di \rightarrow Top_D \qquad [2]$$

Furthermore, there exists exactly one 'Di' which determines all other category attributes and thus defines the finest granularity.

$$\exists i \ (1 \leq i \leq n) \ \ \forall j \ (1 \leq j \leq n, i \neq j): \ Di \rightarrow Dj \qquad [3]$$

DEFINITION: The granularity 'G' is a subset of the category attributes of all existing dimensions of all dimension schemata $DS_1, \ldots , DS_n$

$$G=\{G_1, \ldots , G_n\} \qquad [4]$$

$$\forall i \ (1 \leq i \leq k) \ \ \exists j \ (1 \leq j \leq n): \quad Gi \in DSj \qquad [5]$$

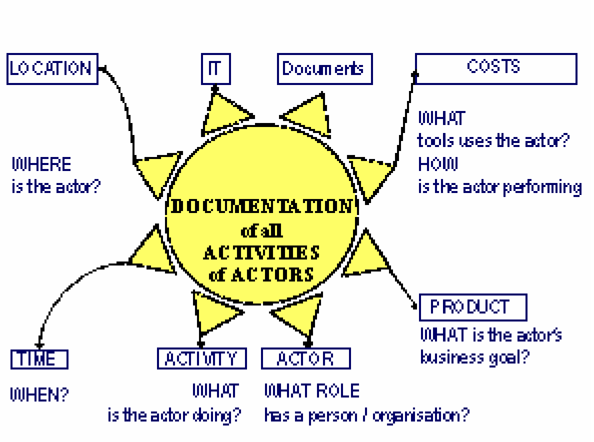
$$\forall i \ (1 \leq i \leq k) \ \ \forall j \ (1 \leq j \leq k) \ \ i \neq j: \ Gi \rightarrow Gj \qquad [6]$$

DEFINITION: Facts 'F' consist of a certain granularity 'G' and one specific 'summation type'.

$$F=(G, SumTyp) \qquad [7]$$

5.1.1 Schemata and Navigation

A multi-dimensional data model can exist in the form of a star schema, a snowflake schema or a starflake schema. The star schema is the simplest schema, consisting of one fact data table and a set of (smaller) attendant dimension tables. The snowflake schema normalizes some dimension tables and thereby splits the dimension data into additional tables. Starflake schemas additionally allow for multiple fact data tables. FIG.. illustrates how the context aspects defined in chapter 2 are used to define the basic structure of a star schema. It clearly illustrates how different perspectives on the consolidated central pool of fact data can be defined in order to reflect the various context aspects. FIG.. depicts a detailed description of the different dimension hierarchies used to describe the context aspects (see also Menzel, Scherer et al. 2002).



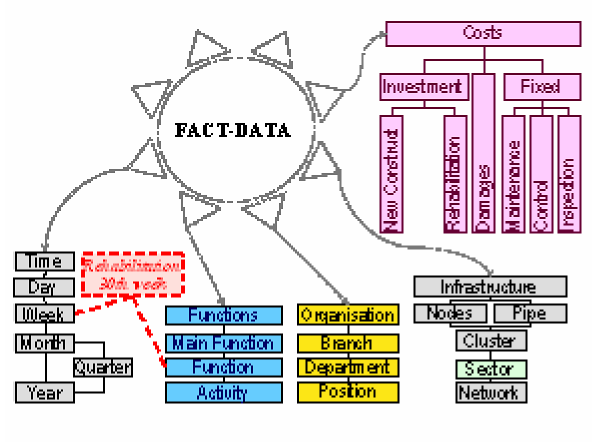


FIG.. 13: Context aspects ordered in a star schema

FIG.. 14: Hierarchies specifying context aspects

Navigation through the different levels of the data cube is called '*drill down*' (showing more detailed data) or '*roll up*' (showing data on the next aggregation level). The different dimensions generated by the system will be available as pre-processed aggregated dimensions of the fact data (cuboids). Finally, the operations "*slicing*" and '*dicing'* enable the presentation (or analysis) of selected parts of the whole data cube.

5.2 Data Warehouse Extended Platform

The multi-dimensional data management approach and the usage of data warehouse technology can compensate the various restrictions of mobile technology, such as: smaller screen size, lower data processing and storage capacity, or smaller bandwidth of wireless networks. Therefore, the authors suggest the introduction of a Data Warehouse Extended Platform (DWEP). The proposed DWEP-architecture is depicted in

and consists of the following parts: (1) user interface component with small computing demands running on mobile clients, and (2) data management and consolidation components with extensive computational demands running on servers.

The data warehouse is the main data source containing all project information of the VO. When data is requested by the mobile user the complex data structure and the huge amount of data would slow down processing time dramatically in case one were to use a traditional database. Fast data processing is ensured through the prearrangement of data in appropriate dimensions reflecting the different aspects of context sensitivity. Furthermore, it will be possible to store and analyse user access records. As a result, the dimension hierarchies can be re-arranged. Finally, other external context data, such as delivery information or weather data can be collected and integrated semi-automatically. This means, activities are documented in a holistic way. Consequentially, actors working in the filed become an integrated part of the digital information cycle by getting instant access to project information and being able to acquire information documenting the project status.

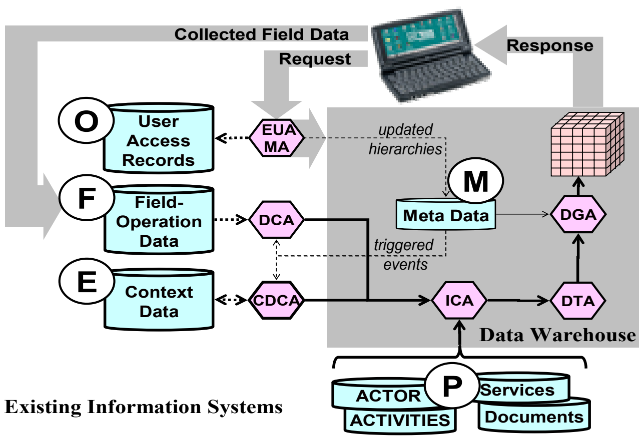


FIG. 15: Proposed system architecture, software components, data classification and flow.

5.3 Data classification

This section classifies and analyses the content of the DWEP with respect to the previously defined context aspects.

depicts the following data categories: Planning and Design Data (P), Field Data (F), Externally Collected Data (E), User Access Record (O), and Data Warehouse Meta-Data (M). Within this section we describe each data category and define the relationship between each data category and the context-aspects (see also **FIG. 1**).

5.3.1 Planning and design data (P)

Planning and design data consists of user data (actor aspect), process definition data (activity aspect), and information about available software tools (IT-infrastructure aspect). Most of this data is already part of the individual, organisation-specific information systems of the VO-partners. Therefore, this information can be collected, consolidated and integrated into the DWEP by semi-automatic mechanisms. Planning and design data can be managed and presented efficiently by developing appropriate data structures and defining improved data management processes reflecting the requirements of the different business processes.

The management of technical data is not in the scope of this paper. Therefore, the necessary information management activities are not explained herein.

5.3.2 Field data (F)

Field data is collected on the construction site while monitoring all construction activities, including service processes (e.g. material delivery). It contains information about the status of a specific construction site (time and location aspect), which includes the employees on the site (actor and location aspect), the accomplished and the ongoing construction processes (activity and location aspect), the resources, such as equipment or material used and available (actor and location aspect), and other spontaneous notes (environmental and location aspect).

The acquisition of field data can be improved by designing appropriate user interfaces reflecting the designed activity sequences.

5.3.3 User Access Records (O)

User Access Records contain information about the access profile of each actor, the requested service and the mobile device that (s)he is using (IT-infrastructure aspect), the construction site described by GPS-co-ordinates (location aspect), the time of the request, and the activity (s)he is working on.
This data specifies the users' access records. Users' access records are analysed and used to decide which aggregated information needs to be stored in the system. In case of dramatically changed user profiles dimension hierarchies need to be re-arranged by the system administrator.

5.3.4 Externally collected data (E)

External data further specify the actor, activity, and environmental aspect. The automatic collection of external data supports the user due to reduced necessary input activities. There exist different mechanisms to trigger the semi-automatic data collection mechanisms, such as a time event or the availability of a certain volume of new data.

Data collection processes are pre-determined by the specific business process model. It is necessary to design and implement an appropriate data structure and IT-processes which support semi-automatic data acquisition.

5.3.5 Data warehouse meta data (M)

Data warehouse meta-data describe the data warehouse architecture which is characterized by dimensions. Meta-data define how to generate, request, modify, store, restore, and delete the various dimensions. Furthermore, meta data contain rules for interpreting the results of the user request profiles.

The term 'meta data' is used in different ways. On the one hand, the term 'meta data' generally describes the content of specific documents to facilitate content management activities. On the other hand, in data warehouse technology the term 'meta data' specifies the architecture (or schema) that controls the behaviour of a data warehouse system. In this paper we are following the second interpretation.

5.4 Functionalities

The following section describes the software components of the proposed DWEP. The functionality of each component depicted in is briefly discussed. Currently, the agent paradigm is discussed intensively in the literature and used in many software prototypes. Most of our system specifications require software components which must be able to act independently on behalf of the user. Therefore, we have named all of the described components 'agents.' However, the authors are aware of current discussions about limitations and negative aspects of the agent paradigm, such as security features.

5.4.1 Data collection agent (DCA)

The DCA is an external, reactive agent and carries out part of the data pre-processing activities of the DWEP. Pre-processing activities cover all of the data input and consolidation activities. Two modes of activating the agent exist: first, when the amount of modified data has exceeded a certain limit, or second, when time has exceeded a certain period.

5.4.2 Information consolidation agent (ICA)

The ICA belongs to the core of the DWEP. Its behaviour is controlled by using the meta-data of the DWEP. Since real world data tends to be incomplete and inconsistent, information consolidation routines that will attempt to fill in missing values and correct inconsistencies are necessary. ICA-functions will be specified based on a data analysis process which must be performed in co-operation with domain experts.

5.4.3 Data transformation agent (DTA)

The DTA is also part of the core of the DWEP. Its tasks are: (1) aggregation, (2) generalization, (3) normalization, and (4) feature construction.

Aggregation and generalization reduce the amount of data. Both functions are described in more detail in the section about the dimension generation agent (see below). Normalisation will be used to calculate meaningful status descriptions for progress reports instead of presenting total numbers to the user (e.g. work is 'due,' 'overdue,' with 'lower budget,' 'in budget,' 'heavily over budget'). Generally, there are two basic normalization methods: Min-Max-Normalization and Zero-Mean Normalization.

5.4.4 Dimension generation agent (DGA)

The DGA is part of the representation layer of the DWEP. To ensure fast data presentation and on-line analytical processing the DGA will pre-compute the cuboids as subparts of the data cube. Depending on the basic technology used, one distinguishes between the relational and the multidimensional approach. Cube aggregation within relational environments uses sorting, hashing, and grouping operations to re-order and cluster dimension attributes. Partial grouping steps are introduced to decrease the computation time of sub-aggregates.

The array-based multidimensional approach divides the array into chunks. A chunk is a sub-cube small enough to fit into the memory. In a second step, chunks are compressed in order to remove wasted space from empty cells. Furthermore, the order in which cells are visited can be optimised in a way that the number of times each cell must be (re)visited is minimised.

5.4.5 End-user-access monitoring agent (EUA-MA)

The end-user-access monitoring agent (EUA-MA) is the only cognitive agent within the described scenario. It can either be implemented as an external agent or as a part of the DWEP. The authors suggest implementing the EUA-MA as an external agent.

The EUA-MA monitors all user requests sent towards the DWEP which is only a reactive feature. However, the EUA-MA is able to collaborate with the CDCA (see below). The CDCA might interpret the core of the output-request context data. Using this extended context description, the EUA-MA decides whether a new dimension should be generated or not.

5.4.6 Context data collection agent (CDCA)

The context data collection agent (CDCA) is a reactive agent. It is an external agent and has its own knowledge base. Supported by its knowledge base, the agent is able to interpret core context data and extend it with additional information.

6. CASE STUDY

Within the framework of the nationally founded research project '*IuK System Bau'* two applications are under development: a construction diary application and a mobile application supporting errors and omissions management in the field. The following section presents some early prototypes of mobile applications which were developed and used by the authors for observation and analysis of mobile-supported 'field activities' Additionally, interviews with field workers and engineering personnel were performed aiming at determining exactly what the field personnel currently does or, even more important, how current activities might be streamlined through the usage of mobile technologies. The results were used to optimise the proposed system architecture and the existing *graphical user interfaces* (GUIs).

However, mobile computers are a new technology for the AEC & FM practitioners. Rapid technological improvements are still expected. Under these dynamic conditions, the potential of new technologies and the appropriateness of our existing system have to be continuously monitored and evaluated in the future.

6.1 The Construction Diary

A construction diary is used to document construction activities, resources used (including drawings), weather conditions, and irregular situations (including delays by other partners) for the client. Depending on the project and the size of the company, the documentation is usually performed either by the construction manager or by the foreman at the end of each working day. One can distinguish between two different user scenarios. The foreman uses the mobile device on-site for collecting and acquiring the required information specified above while the construction manager or the client analyzes the available information for a specific time period and construction site while working on a desktop PC in the office.

6.1.1 The Mobile Client

The PDA client (GUI examples are shown in FIG. 11 to FIG. 13) allows for the presentation and acquisition of data on-site, using a mobile device. The GUIs are specifically designed for the small screen size of mobile devices.

FIG. 11: GUI actor & location

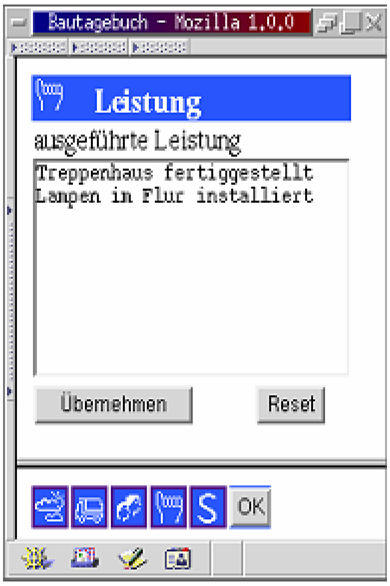


FIG.. 12: GUI activity

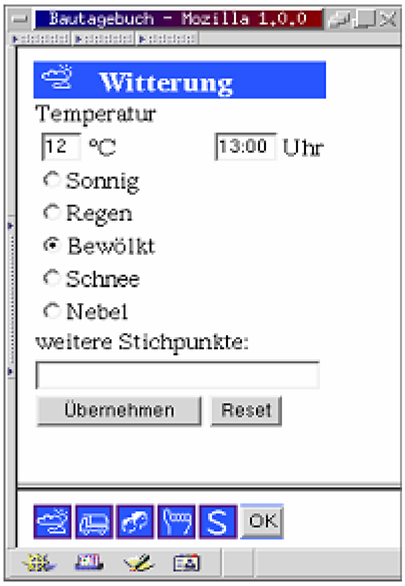


FIG. 13: GUI environm. context

FIG. 11 represents the GUI for the documentation of the activities of the field personnel. The foreman only receives information about field workers on the specific construction site. Thus, this GUI represents the location and actor context. FIG.. 12 depicts the early prototype of the GUI for activity documentation. One can easily imagine that this GUI is completely insufficient and unacceptable for the usage of mobile devices because it requires the 'hand-written' input of activity descriptions. Instead, existing activity templates, describing the work package (e.g. taken from the work flow management system) can be presented as a function of location and time. In a second step, the user selects the appropriate template and adds the degree of completion.

FIG. 13 depicts the GUI for environmental data acquisition. As mentioned before, this data can be acquired by the system using e.g. agent technology. Thus, the GUI can be either eliminated or replaced by a GUI just confirming the correct, automatic weather data collection.

6.1.2 The Desktop Client

The desktop client application, as shown in FIG. 14, allows for analyzing and printing data collected on-site. Whereas the PDA client only displays information relevant to site activities, the desktop client provides all information of the construction diary such as company name, construction site address etc.

In this way the PC-client represents the integrated view on the information, instead of having to browse through all the individual perspectives. The data warehouse technology allows the generation of either individual, customized data representations or for the generation of such general, integrated representation and analysis perspectives.

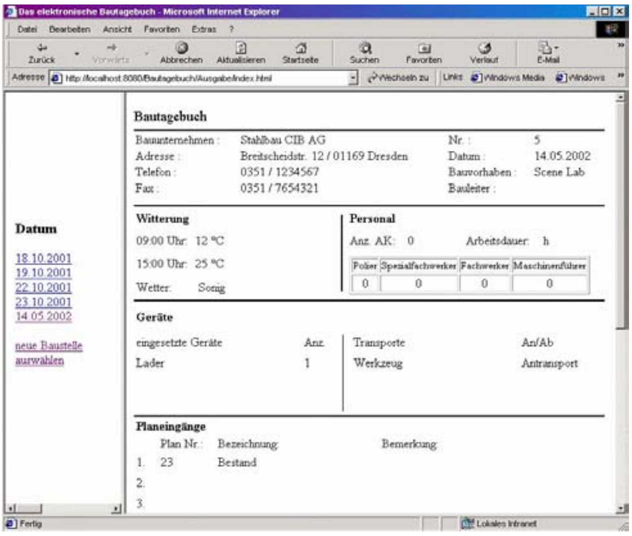


FIG. 14: GUI Integrated project wide perspective considering the time aspect (hierarchy level 'day')

7. CONCLUSION

Mobile computers are a relatively new technology that has not yet been adopted by the AEC & FM industry. The implantation process will require changes in the AEC & FM-industry. Even in the basic sciences, such as e.g. computer science or human computer interaction, many uncertainties still exist on how to apply this technology appropriately and efficiently. This means, there neither exist any formalized implantation strategy nor any detailed proven "rules of thumb."

The development of context-sensitive mobile applications complemented by multi-dimensional data management technology might be one possible approach to solving some problems related to the use of mobile devices on construction sites. However, the lack of general design and development criteria leads to the consequence that only by systematic, intensive field-testing of prototypical solutions the advantages, disadvantages, and limitations of mobile computing technology can be revealed.

The analysis of these results will lead to the development of new business processes, considering the availability and potentials of mobile, wireless technologies. Finally, it will lead to an integration of wireless and mobile technologies into the core businesses of the AEC & FM sector. To achieve this goal it is absolutely necessary to develop and define guidelines, standards, and specifications for, both, software development and business process re-engineering.

Therefore, the future work of our research group will focus on the integrated work in the areas of business process modelling and software engineering for mobile computer environments, focusing on interface design and multi dimensional information management.

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