About the implantation process of mobile computing in AEC

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Summary

The AEC industry is conscious of the potentials arising from the usage of mobile computer systems to increase productivity by streamlining their business processes. Discussions are no longer on whether or not to use a mobile computer solution, but rather, on how it should be used. However, the implantation process of this new technology in Architecture, Engineering and Construction (AEC) and Facility Management (FM) practise is very slow and should be improved. One way to encourage and ease the usage of mobile computer systems in AEC is a more process-oriented usability and context appropriateness of mobile computer solutions.

Context-sensitivity is defined as a crucial feature to be taken into account for further research in the area of Mobile Computing. Context-sensitive, mobile IT-solutions depend on two features: (1) flexible definitions of (construction) processes describing the context and (2) tools for flexible, multi-dimensional information management representing the context. It is on this premise that the authors propose the n-dimensional data management approach for the implementation of mobile computing solutions. In this paper, we analyse working scenarios in the AEC and FM sector, defining context aspects which are transformed and formalized as dimension hierarchies of the envisaged context model.

1 Introduction

Construction and operation activities require continuous monitoring and documentation on site. So far, advantages of using information systems to support these processes have been limited to office work. Field personnel such as construction managers, foremen and inspectors were not able to connect to information management systems while they were away from the office. The disadvantages are (1) lack of up-to-date information and (2) delayed integration of collected data into company data bases.

Nowadays, new technologies such as mobile devices and wireless networks are available and support nearly unlimited accessibility to digital information. However, the efficient usage of these new technologies requires deep understanding of relevant activities and their inter-relationships. Furthermore, current management and process models need to be analysed and re-engineered in order to be able to fully exploit the potentials of mobile technologies. Finally, mobile technologies need to be complemented by flexible, sophisticated information management systems. The user, working on construction sites should not be overloaded by irrelevant information and not be hampered by inappropriate services and cumbersome in- and output techniques.

Unlike the user's context in an office environment that is rather static the user's context of a mobile application used on site is changing rapidly, such as the user's location and the performed activity. Information systems should take the specific users' context into account and adapt to it in order to best support the human-computer-interaction and provide effective access to the information space. Therefore, context-sensitivity is defined as a crucial system feature to be taken into account for further research in the area of Mobile Computing.

Our approach is to provide context-sensitive information representation by enhancing existing information systems with multidimensional data management features. On the one hand, this technology supports an efficient, pre-calculated, multi-dimensional data representation. On the other hand, it enables monitoring of project progress, user activities as well as modification of data structures corresponding to individual user and project profiles.

In this paper, we start with an analysis of current working situations in Archictecture, Engineering and Construction (AEC) and Facility Management (FM). By defining so-called context aspects the understanding of relevant, on-site activities and their inter-relationships will be improved. Secondly, we use the multi-dimensional data modeling methodology to formalize the context aspects in a context model. Each context aspect corresponds to a dimension hierarchy representing parts of a holistic information space. Thirdly, it is explained how the definition of the dimension hierarchies correspond to the various context aspects. Finally, current field test results are presented, evaluating the appropriateness of the defined dimension hierarchies.

Our research work is carried out within the national research project IuK-System Bau which is funded by the German Ministry of Research, Technology and Higher Education.

2 Analysis of working scenarios in AEC and FM

This section introduces the terms *field worker*, *working scenario* and *context aspects* and their inter-relationships. For each *context aspect* a description and definition is given.

2.1 Definition of terms

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 dangerous to the user, as well as hinder the user in successfully accomplishing a task. Therefore, it is absolutely necessary to understand the major processes of *field workers*.

We define the term *field worker* to describe any individual acting outside her/his office. This can be either personnel acting on construction sites but also inspectors or maintenance crew members working on already existing build artefacts. A *field worker* is acting within a so-called *working scenario*. We relate to the term *working scenario* to point to the entirety of information (including the *field worker* itself) specifying the context in which a field worker is interacting with a mobile information device.

A *working scenario* can be examined from different view points which are called *context aspects*. The term *context aspect* express' a definite abstraction of a working scenario, e. g. in relation to the actors on site. *Context aspects* are transformed and formalized into dimension hierarchies describing the context model.

2.2 Aspects of context

Within the AEC and FM sectors we identified numerous working scenarios that would benefit from the usage of mobile computer applications. The better the application fulfils the requirements of the *working scenario*, the more efficient the interaction with the user will be. Therefore, we analyse specific working scenarios identifying relevant context aspects of mobile information systems within the construction and operation phase of built artefacts.

Relevant aspects characterizing a working scenario were earlier defined in (Menzel et. al. 2002) and (Bürgy 2002). Bürgy for example developed in his work a so called *Interaction Constraints Model*. According to our opinion this model focuses very detailed on the analysis of single tasks. Therefore, it does only partially reflect the needs for a 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 focusing on the IT-aspects and only partially considering the domain specific needs such as the time aspect reflecting the evolutionary dimension of information management.

Driven from a critical analysis of our own work as well as from the analysis of other research work (Chen and Kotz. 2002, Dey and Abowd 1999, Samulowitz 2002), we propose the definition of six *context aspects* that should be considered for context-sensitive information management: (i) actor, (ii) time, (iii) activity, (iv) IT-infrastructure, (v) location and (vi) environment.

Based on the identification of these *context aspects* we conclude with a more precise definition of the term working scenario (as illustrated in Figure 1):

The term *working scenario* describes some *actor* 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 condititions*.

Each *context aspect* is described and specified in one of the following subsections. The specifications are necessary for the domain or sector specific definition of context-sensitivity and the development of context-sensitive applications for mobile devices.

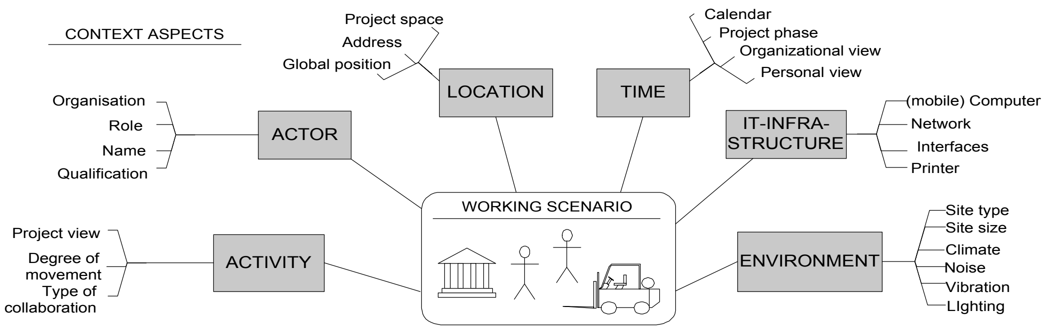

Figure 1: Context aspects to describe a *working scenario.*

2.2.1 The actor aspect

Closing the gap of the information flow between office and construction site requires the involvement of a broader audience. Not only engineering and management personnel, or IT-specialists should be able to use mobile computers but also less qualified field workers. Therefore, systems need to be adaptable according 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.'

Definition: The term *actor* describes a unit that is responsible to perform a specific activity or a set of activities specified by a certain role; whereas a role defines the required skills or the qualification profile. An actor can either be an organisational unit or an individual employee.

2.2.2 The time aspect

On the first view, it seems that the time aspect can easily be defined. This is true, if only the current time (stamp) needs to be acquired. The current time stamp is very useful for semi-automatic service functions; e.g. one can imagine that information about next planned activities can be requested from a workflow management system. Thus, the system is able to control project activities and can support the user managing appointments, meetings, and deadlines. However, monitoring the project status needs sophisticated algorithms to map current time to project phases in the past or in the future as well as to synthesize and compare information of different granularity.

Current time stamps might be retrieved from the hardware system's internal clock.

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

2.2.3 The activity aspect

The accomplishment of a project triggers various activities; whereas each activity requires certain actors, information, and tools. In the context of mobile computing the system must be able to determine the information needed by the user and will present its activities depending on the user. The activity specification might be derived from already existing workflow management systems.

Definition: The *activity* aspect describes and classifies single actions, or whole packages of actions, their sequence and interdependencies among actions. Activities can be hierarchically ordered and grouped.

2.2.4 The IT-infrastructure aspect

Today, users wish to access IT-applications by using mobile devices such as wearable computers, PDAs, and web-pads, taking advantage of the mobility these devices offer. Due to their much smaller screen size and different in- and output interfaces these devices should be able to adapt, depending on the specific hardware configuration. For example, the graphical user interface should respond in the following way: (i) resize itself to the display size, (ii) adjust the GUI-items and buttons in an appropriate way for the user, and (iii) hide or rather show specific menus or buttons.

Mobile devices often lack sufficient storage capacity. Furthermore, complex, holistic project information can only be managed and maintained at sophisticated, robust (back-office) information systems. Therefore one needs unrestricted access to this information management services through networks, either wired or wireless. This means the ICT infrastructure available in the field, such as the kind of network coverage, communication and electricity support etc., influences the usability of mobile devices.

The devices themselves can be determined through their MAC-addresses.

Definition: The *IT-infrastructure* aspect describes and classifies the quality of the mobile, end-user device as well as the availability and performance of its network connection. Further, it specifies interfaces and in-/output devices nearby, e. g. printers.

2.2.5 The location aspect

Typically, an organisation is involved in several projects. Therefore, the field workers often work on different sites. By automatically determining the user's location it is easily possible to conclude on which site and, therefore, on which project the actor is working. Consequently, location based services can be made available by only displaying to the user relevant information of the particular construction site. The information about the exact location can be used to derive other relevant information such as objects nearby or environmental conditions. The position of a specific actor can be determined by digital navigation system, e. g. a GPS locator tool.

Definition: A *location* can be identified by using unique global positions. Based on these co-ordinates secondary, project specific descriptions of the location can be calculated.

2.2.6 The environmental aspect

There are several various environmental restrictions that might impact the usage of mobile devices in the field. Restrictions can result from (a) the weather conditions like heavy rains, frost, cold temperatures, sunlight etc., (b) the type and size of construction site which might be a bridge, road, or building construction site, and (c) from other site conditions such as noise level, dust or vibrations.

The environmental restrictions are very often the knock-out criteria when choosing the mobile computing system, especially the device, e. g. a PDA to be used.

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

3 Modelling the context space

This section illustrates the approach we have taken to model the defined context aspects using a multi-dimensional data modelling method. Each context aspect corresponds to a dimension hierarchy representing part of the holistic information space.

3.1 Requirements

In this subsection we identify the design requirements for choosing a modelling method by drawing an introductive example. Therefore, the given definition of a *working scenario* in section 2 is instantiated as follows:

The field worker 'Hans Maier', employed as construction manager in the construction company X, is currently in the basement of the main building at the construction site for the new department taking a note of an omission in the building structure that needs to be fixed. He is using the PDA HP iPAQ 5590 as mobile computer with a GPRS connection. The climate condition is sunny and dry; there is a high noise level on site. Current date is the 14th March, 2004.

The table below (see Table 1) opposes comparatively two possible specifications of the above stated exemplary working scenario.

Context aspect	Description 1	Description 2
Actor	Hans Maier	Construction manager
Time	14.03.2004, 2pm	Phase 2: Shell and core construction
Activity	Standing	Interacting with mobile application to enter a defect
IT-infrastructure	HP iPaq 5590	PDA + GPRS
Location	Main building, basement, room 4	Construction site A, grid axes A.4
Environment	4000 Lux , 95 dB	Sun, noise

Table 1: Comparison between two specifications of the same *working scenario.*

The example indicates the problems that arise when specifying a working scenario and context space respectively. Namely, a problem is the varying granularity and semantics which are used to describe each context aspect as shown in Table 1. The granularity can be expressed by individual attributes. Therefore, the attributes for each context aspect need to be identified.

Further, we can identify functional dependencies between the attributes. For example, the context aspect *location* has the two attributes *room* and *building,* it is obvious that a particular room belongs to a particular building. In this way, the functional dependency between the attribute *room* to the attribute *building* determines a hierarchical order between the attributes. Functional dependencies determine the hierarchical order of the attributes (which corresponds to the dimension hierarchy).

The order of the attributes starts with the attribute of the finest granularity and is followed by attributes of higher granularity. Following the terminology used in the research area of context-awareness, we define the attribute with the finest granularity as primary attribute and the other attributes as secondary attributes. The main difference between the two types is that the values for the secondary attribute are derived from the value of the primary attribute. Commonly, context types are categorized into primary and secondary types, as described in (Dey and Abowd 1999). Primary context types are used as indices to find information about secondary context types.

Besides the attributes with a classifying character (as just described), there are attributes with a more descriptive character. For example, the technical parameters of a mobile computer are rather a description of the device than a classification into a hierarchical structure.

In summary, we need a modelling method capable of modelling varying granularities and functional dependencies. Each context aspect corresponds to a dimension within the information space leading to an information space that spans over multiple dimensions.

3.2 Modelling approach

We propose a multi-dimensional data modelling approach to transform the defined context aspects into a context model.

Multi-dimensional data modelling approaches are used for the design of powerful data schemas that are able to represent a complex vocabulary of concepts. In opposite to relational data modelling approaches, the multi-dimensional approach differentiates between qualifying and quantifying information. The qualifying information is used as navigation raster defining possible analysis structures. The quantifying information is the subject analysed. Concluding, a multi-dimensional schema consists of a set of dimension hierarchies (the qualifying information) and a set of fact data (the quantifying information), which are spanning a multi-dimensional space (in Lehner 2003).

The *context aspects* we defined previously correspond to the qualifying information. Each *context aspect* corresponds to a dimension hierarchy representing part of the information space. Each dimension hierarchy contains the attributes of the corresponding *context aspect* defining the complex vocabulary of concepts. The hierarchy is given by the functional dependencies between the attributes. According to (Lehner 2003) the hierarchy of the dimension can be refined by assigning roles to the attribute e. g. classifying attribute, dimensional attribute and primary attribute. The role classifying attribute is used to refer to an attribute that categorizes the hierarchical structure, and the role dimensional attribute is used for an attribute that describes a classifying attribute. The role primary attribute is given to the classifying attribute with the finest granularity.

Therefore, according to the defined *context aspects* we define six dimensions, which can be extended if other aspects need to be considered, e. g. the product. In the first step we define the following dimensions: (i) actor, (ii) time, (iii) activity/process, (iv) IT-infrastructure, (v) location, and (iv) environment. In the next step exemplarily the dimensions *location* and *actor* are described.

3.2.1 Dimension location

The *location* within a *working scenario* describes a particular, exact point in the world. The exact global position of a location is given by the attribute values longitude, latitude and elevation. The global position is most likely the attribute with the finest granularity for the dimension location, and is therefore the primary attribute. The three attributes longitude, latitude and elevation are dimensional attributes to the position because of their descriptive character.

Opposed to the global position of a location, we are often interested in which room, level and building of a particular project the location refers to. Therefore, we identify other attributes which classify the location according to the spatial structure of a particular project, e. g. room, level, building, section, site and grid. Using these attributes, we classify the location along the hierarchy due to the functional dependencies between the attributes rather than describe them. A functional dependency between two attributes A and B exists, when an element of attribute A defines one element from attribute B.

Classifying attributes can exist in parallel hierarchies; e. g. the location can be classified by a room and a building, but also by grid axes and a building.

Classifying attributes		Dimensional attributes
Primary	Secondary	
Global position		Longitude, latitude, elevation
	Room	Type, description
	Level	Description
	Grid	x-Axes, y-axes, z-axes
	Building	Adress
	Section	
	Site	Type of site, area size
	Project	

Table 2: Attributes of the dimension *location.*

Table 2 summarizes the attributes of the dimension *location*. Figure 2 illustrates the dimension hierarchy showing the attributes and their functional dependencies.

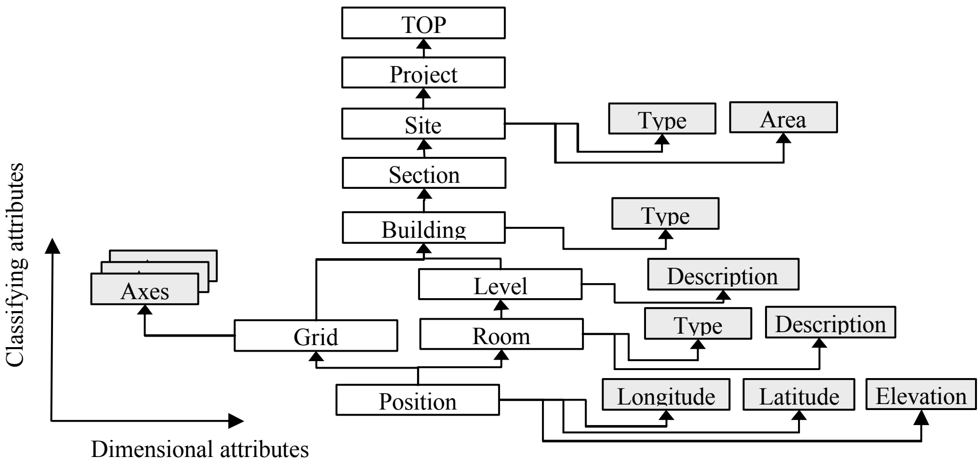

Figure 2: Dimension *location.*

3.2.2 Dimension actor

The *actor* within a *working scenario* describes a particular (field) worker or alternatively a particular role. The primary attribute is the identity of the actor. Each actor can be described by a role (that is assigned to the entity e. g. by an organisation), by the qualification profile, the name, address etc.

The actor belongs to a company, where s/he has a position in a department and/or branch. Furthermore, the company can be part of a group of companies (corporation).

Classifying attributes		Dimensional attributes
Primary	Secondary	
Identity		Role, qualification, address
	Position	Description
	Department	
	Branch	
	Company	Type, services
	Corporation	Type

Table 3: Attributes for the dimension *actor.*

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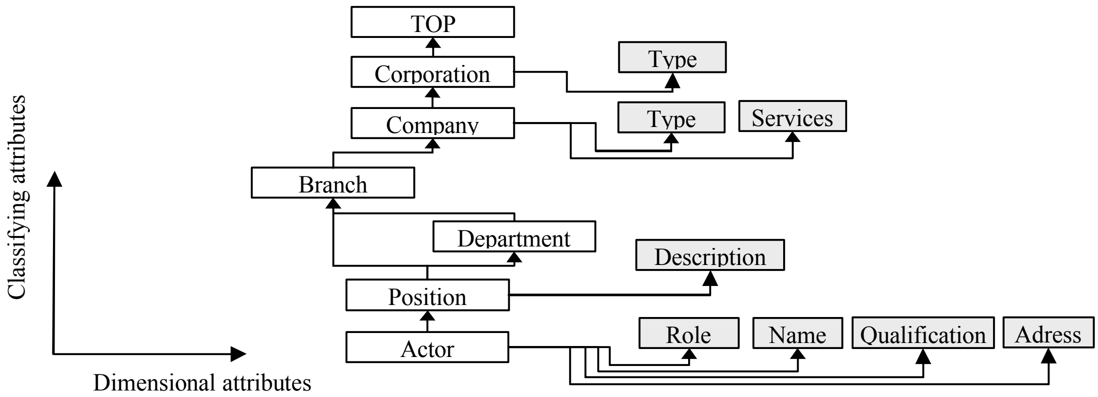

Figure 3: Dimension *actor.*

4 Case Study

This section illustrates possible instantiations of the model described above using working scenarios identified in the current conducted field tests.

4.1 Background about the field test

Currently, we are testing the first prototypes that have been developed within the project 'IuK-System Bau' at a construction site of the Dresden University of Technology, operated by one of the project's industry partners. The project is the construction of a new building for the Department of Informatics at the Dresden University of Technology.

The construction site is situated in the southern part of the main campus of TUD. It is a three-storey building with an underground floor. The building is composed of three main wings (west, middle and east wing) which are connected by so-called connectors. The wings are enclosing a glass-covered atrium and a u-shape glass-covered foyer. The construction site covers an area of 100 m x 170 m. The area is fully covered by network connectivity: (1) GSM/GPRS, (2) W-LAN and (3) UMTS. The foundation, as well as the shell and core are being constructed by the company 'Müller-Altvatter Bauunternehmung GmbH & Co. KG' since November 2003 and are expected to be finished in July 2004. Field tests are carried out from March 2004 to June 2004.

During the field tests we evaluate the software prototype developed within the project 'IuK-System Bau' and the networks used for data transmission. The software prototype consists of two modules: (1) a module for the management of defects, errors and omissions and (2) a construction diary module.

The purposes of the field tests are to evaluate the functionality and usability of the software prototypes and network types, especially for usage on site.

Therefore, several test *working scenarios* were developed and realized with the intention to evaluate the appropriateness of the software prototypes in different contexts. The scenarios are varying in their location, actor, time and IT-infrastructure, whereas the actor and IT-infrastructure play the major role. In each scenario the same activity is performed: user interaction with the mobile application in order to collect defect management data. Changes in the environment are documented, especially regarding the project progress and weather conditions. Possible instantiations for the *working scenario* are summarized in Table 4.

Context aspect	Attribute	Instantiation
Actor	Role	Construction manager, foreman and sales personnel
	Person	Two per role
Time	Date	Any date during the time period
IT-infrastructure	Mobile device	T-Mobile MDA II, Panasonic Toughbook CF-P1, Fujitsi-Siemens TabletPC Stylistic ST4110
	Network	GPRS/GSM, UMTS and WLAN
Location	Site	Department of Informatics
	Level	Basement, ground floor, first floor, second floor, third floor
	Room	All possible (ca. 500 rooms)
	Grid	All possible (ca. 35)

Table 4: *Working scenarios* during the field test.

4.2 Instantiated context model

In this subsection we illustrate how to formalize a *working scenario* using the defined dimension hierarchies. Therefore, a particular working scenario from the field test (see Table 4) is chosen and analyzed regarding the two dimensions *location* and *actor* aiming on: (1) the formalization of *working scenarios* using the defined context model and (2) the discussion of the appropriateness of the model to map the 'real world' context.

One of the *working scenarios* is given as follows: While being in room number 15 in the basement of the main building at the construction site "Department of Informatics" the field worker 'Thater' is interacting with the Panasonic Toughbook CF-P1 in order to enter data about a defect in the building structure. The sun is shining, there are normal site conditions (no noise, no vibrations, sunny). Current date is the 14th of March, 2004.

4.2.1 Dimension location

The dimension *location* is specified with the room number, the level, the building, and the site. In this case the attribute room has the finest granularity that determines the location. Due to the functional dependencies between the attributes it is possible to fully derive the values of the other attributes from the value of the attribute *room.* However, in some cases the values of several attributes are needed in order to exactly determine the context. Such cases appear when (1) no exact position of the location is given, e. g. by GPS data, (2) the location is given with a relative position, e. g. the room number specifies the location in relation to the project, and (3) attribute values are not uniquely defined world wide.

For example, assuming the location is specified by a room number, which is unique on each floor, but not unique for the level of the building, we need to know the specification of all higher attributes in the hierarchy in order to find out to which project or site the working scenario can be assigned to. Alternatively, other context aspects need to be considered to derive the required context information from there specifications, e. g. from the functional dependency between the attributes actor, company and site from the dimension actor. In each case, it is best to get the specification of the primary attribute, e. g. the GPS coordination of a location.

Alternatively, the location can be specified using the grid coordinates of the site layouts.

Figure 4 illustrates the instantiation of the *working scenario* for the dimension *location*.

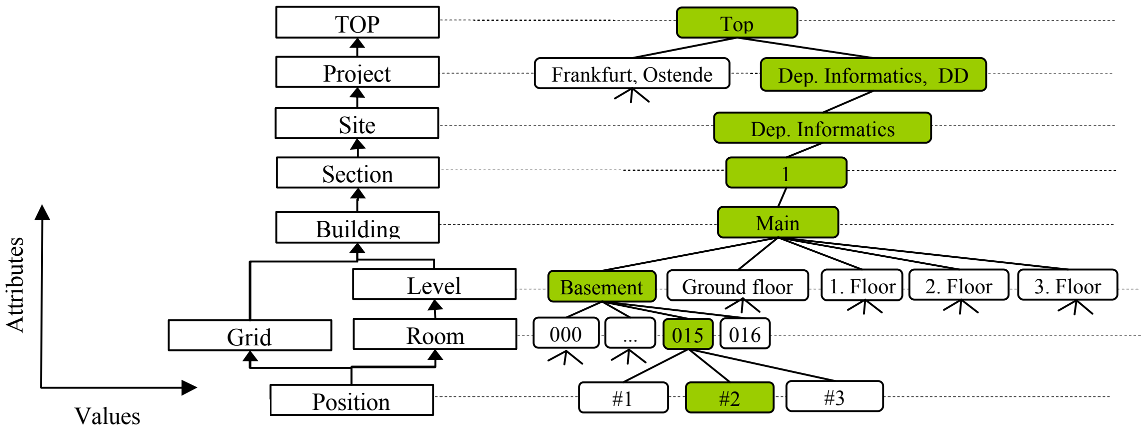

Figure 4: Instantiation of the dimension *location*.

4.2.2 Dimension actor

The dimension actor is specified by the attribute actor with the name 'Thater'. Unfortunately, the name of an actor is not as unique as the coordinates describing a location. Each actor would be unique if we introduce a global ID.

Figure 5 illustrated the instantiation of the *working scenario* for the dimension *location*.

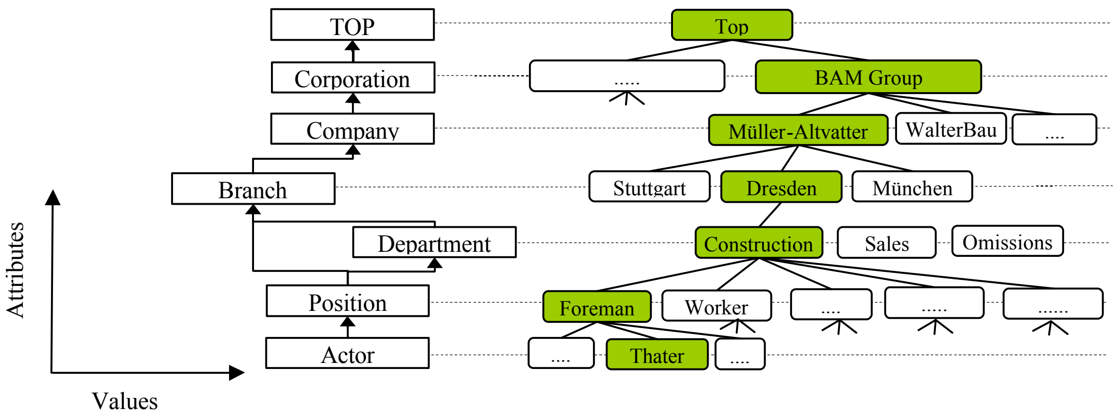

Figure 5: Instantiation of the dimension *actor*.

5 Summary

Mobile computers are a new technology for the AEC and FM sector and will therefore require major changes in our industry. Even in the basic sciences such as e.g. computer science or human computer interaction exist still many uncertainties on how to apply this modern technology appropriately and efficiently. This means there exist neither any formalized implantation strategy nor detailed proven "rules of thumb."

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

6 Acknowledgement

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7 References

Bürgy, C. (2002). An Interaction Constraint Model for Mobile and Wearable Computer-Aided Engineering Systems in Industrial Applications, PhD Thesis, Carnegie Mellon University.

Chen, Guanling, Kotz, David. (2000). A Survey of Context-Aware Mobile Computing Research, a Technical Report TR2000-381, Dartmouth College, Department of Computer Science, 2000.

Dey, Anind K., Abowd, Gregory D. (1999). Towards a Better Understanding of Context and Context-Awareness, a Technical Report GIT-GVU-99-22, Georgia Institute of Technology, College of Computing, June 1999.

Menzel, K., Eisenblätter, K., Keller, M. and Scherer, R.J. (2002). Context Sensitive Representation of Personalized Processes and Data Management on Mobile Devices, in Proceedings of the 5th European Conference on Product and Process Modelling, page 549 – 554, Portoroz, Slovenia, September 2002: Swets & Zeitlinger Publishers, Lisse, The Netherlands (ISBN 90 5809 507 X), September 2002.

Lehner, Wolfgang. (2003). Datenbanktechnologie für Data-Warehouse-Systeme – Konzepte und Methoden, 1.Auflage: dpunkt.verlag GmbH, Heidelberg, 2003.

Samulowitz, Michael. (2002). Kontextadaptive Dienstnutzung in Ubiquitous Computing Umgebungen, PhD Thesis, Ludwig-Maximiliams-Universität München, Fakultät für Mathematik, Informatik und Statistik, 2002.