KANBAN AS A SUPPORTING TOOL FOR THE SUSTAINABLE DESIGN AND OPERATION OF SMART BUILDINGS

The potential of the Toyota Production System in Architecture

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Abstract. This paper describes the translation of the process management tool 'Kanban' and its adjacent Toyota Production System into an architectural design supporting tool in the context of computer integrated buildings. The triggering question is: 'How can architects handle requirements and services of ubiquitous computing in relation to their cursory knowledge about networked services and its unpredictable future development?'. The paper develops a system called 'Ubicomp-Kanban' based on the characteristics Toyota Production System. It is suitable for both design and operation of binary networked services in built environment in selected architectural scales and selected functions. The application of the system allows more precise planning and resource optimized operation of academic buildings. The paper does not intend to set up a new approach for building information models (BIM).

Keywords. pervasive computing, smart buildings, resource optimization, simulation, sustainability, Toyota Production System, kaizen, kanban.

1. Introduction

A tool is developed that solves the dispute of meeting opposed requirements which various disciplines apply on the design of a building. This general dispute is amplified through services of the novel discipline ubiquitous computing (ubicomp).

Ubicomp services *can* have strong impact on the design of a building, although their services are vaguely known during design process. A future oriented tool is proposed in order to achieve suitable solutions for the building design. This paper shows a successful transformation of major elements of the Toyota Production System (abbr. TPS) (Ohno, 1993), which allows for pre-estimation of ubicomp's physical and/or operational impact on buildings. It is applicable in the design stage and simulation of building operation. It could be used in physical operation as well.

Examples of real world installations show applications such as space optimization (www.performancebuildings.ch: Sep. 2007). But these installations and their promoters are not considering the design phases of buildings (Mallick, 2007).

The paper's thematic focus is the intersection of the four fields 'Toyota Production System/ Kanban", "resource optimization during operation", "academic buildings" and "pervasive computing". This paper does not aim to provide solid novelties for the disciplines of facility management nor business administration, as the authors are not based in those disciplines.

2. State-of-the-art

The four fields are characterized by broadness and impacts on adjacent disciplines. A state-of-the-art is described with focus on process management and the design of academic building.

2.1 THE TOYOTA PRODUCTION SYSTEM (TPS)

Kanban literally means 'visual card'. "Kanban is a signaling system to trigger action" (en.wikipedia.org/wiki/Kanban: Nov 2007) and a central element of the TPS. It can be physical or virtual. The TPS is "a system for the absolute elimination of waste" (Shingo, 1989, p.67). TPS is a combination of 'Just in Time production' and 'automation with human lineament' (Ohno, 1993). Its main aim is to generate a customer driven process (Shingo, 1989, p.3) which causes a so-called *pull-system* that triggers all processes situated ahead. Meanwhile the TPS is applied in other manufacturing processes than car production. Most companies that apply parts of TPS have faster production and higher return of investment. Management concepts such as Kaizen are deeping the broadness of the TPS.

An important characteristic of the TPS is its all-embracing analyze of processes and operations, including space and information management. The itemization of a large process chain into smallest elements is the method for achieving optimized production facilities (see figure 1). These small items are more easily to be understood and to be optimized. Each element and its enclosing group can be seen as control circuits (Geiger, 2003, pp.32).

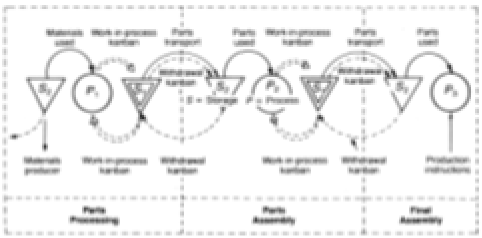

Figure 1: The flow of 'Kanban' within a production process. (source: Shingo, 1989, p. 182).

2.1.1 Multidisciplinary TPS

The TPS can be combined with additional layers such as quality management (QM) systems in order to steadily improve quality. As complex processes are subdivided into many small control circuits, error recognition at early stages will appear. As well, steady improvement and efficient distribution of resources such as staff and material within the overall process is enabled (Shingo, 1989, p.7).

2.1.2 Limitations of the TPS

The principles of TPS don't work efficiently in situations such as:

- disruption in the Kanban-chained processes.
- employees that are paid on piecework-basis, as they would receive less salary if they would return the Kanban.
- TPS expects economic success through products with excellent quality because that causes highest customer satisfaction. But economic success is not necessarily bound to excellent quality.

2.2 UBICOMP SERVICES

Ubicomp services are diffusing information technology "into everyday objects and settings" (www.disappearing-computer.net: Nov. 2007). The impacts of these services can affect the built environment on various scales. Contemporary examples of academic building projects and master plans partly show the need of integrating ubicomp services for optimized operation, safety, comfort and communication as well as resource management (www.sciencecity.ethz.ch: Aug. 2007). This paper aims for an open definition of ubicomp services rather than focusing on a given list of devices and services. Ubicomp works can be seen as pull- and push-system. Ubicomp can create hybrid data in context which allows information retrieval of higher quality (Schoch, 2007).

2.2.1 Impact of ubicomp of structure and typologies

In most cases there is little or no *direct* impact of ubicomp services on the typology of a building. Typological changes mainly occur through secondary and tertiary effects, as technology e.g. triggers different habits of users (Schoch, 2005). Ubicomp's impact on the user and the way of usage of the building can be vast and therefore the design of a building is changing (Schoch, 2006), e.g. the need for waiting areas when applying smart people guidance services. In addition, it is known that the computing devices are about to visually disappear in physical environment (Weiser, 1991).

Nevertheless, devices for ubicomp services might need at least physical connectivity such as power supply and data cabling. This demand can be crucial. It has to be considered during planning and operation of buildings.

2.2.2 Ubicomp and Resource Demands

It is known, that services based on pervasive computing technology allow a more resource efficient operation of buildings than buildings without computer integrated services (Schoch, 2006). Other known qualities of ubicomp services are the ability to be updated virtually every second and with little or no changes to the built structure.

2.3 DESIGN OF ACADEMIC BUILDINGS

This paper considers architectural design from niches up to near surroundings of campuses represented by scales 1:10 to 1:500. This paper defines 'design' to include all phases from concept drawings to construction management.

As by 2007, there is a global tendency of holistic planning of campuses (H ger et. al, 2007). These projects' vary in scales from flexible rooms to globally networked campuses. Built examples are already proving the successful feasibility (Nerdinger, 2007, p. 152).

Academic buildings are of different typology such as buildings for housing, office, lecture, etc. Their use is mainly clocked by the lecture periods which results in phases of high and low resource demands.

2.4 RESOURCES

Resources are considered to be all kind of physical or virtual entity of limited availability. They are countable and therefore able to be evaluated in terms of availability, costs, quality, etc. In this paper, resources are as different as space, time, equipment, primary energy sources, illumination, energy, oxygen, people, transportation, money, services, etc. Sustainable buildings as seen as properties of reduced demand of resources, but with increased comfort and safety.

3. Method

The method to elaborate the 'Ubicomp-Kanban' is as follows:

1. key attributes of the three fields ubicomp services, architectural design and resource optimization are detected. These key attributes are named 'potential connectors'.
2. the TPS is analyzed in relation to it's ability to connect with the requirements of ubicomp services, architectural design and resource optimization.

3. the ‘potentials connectors’ are checked against connectivity among each other.
4. exemplary tasks are analyzed in detail in regards to the requirements and parameters of the three fields ‘ubicomp services’, ‘building design’ and ‘resource optimization’.
5. ‘ubicomp-Kanban’ is elaborated by merging the suitable connectors. This is accomplished by following the principles of TPS. TPS is therefore the systems foundation.
6. a critical discussion about missing attributes is performed by checking the loose connectors

4. Elaboration of ‘ubicomp-Kanban’

Due to limited space, both broadness and depths of the analyses are partly simplified in this paper.

4.1 DETECTING KEY ATTRIBUTES

The listing of key attributes from each field enables the detection of similarities within the fours fields. The attributes are illustrated in figure 2.

4.2 KEY ATTRIBUTES OF THE TPS

Shingo (Shingo, 1989) states that “production is a network of processes and operations”. His definition of process is the transformation of material. ‘Operations’ (Shingo, 1989, p.3) are the interaction and flow of equipment and operators in time and space in order to fulfill the transformation.

Amazingly, some of the aspects TPS are daily routine of architects. Building design is customer driven (pull system). Design is an interaction and evaluation of individual elements. Architects mainly aim for efficiency and long-term customer satisfaction.

4.3 INTERCONNECTABILITY OF ATTRIBUTES

The ranking of similar attributes allows the approximation of the four distant fields in order to achieve one tool that combines most aspects. Guiding field is the TPS.

4.3.1 Common attributes

Area A in figure 2 shows the attributes that appear to be part of all fields. These attributes are the basis of Ubicomp-Kanban as it is proving that TPS is suitable in building design. Attribute ‘push system’ is outstanding, as it is by definition not an attribute of the TPS. The diagram shows as well, that the understanding of architectural design seems to be broad. This field offers most connecting attributes.

4.3.2 Loose Attributes

Attributes that have no link to the TPS (area D) do exist. They describe the specifics field’s unique characteristics. They are not crucial for avoiding a Ubicomp-Kanban as they are considered in the fields detail planning.

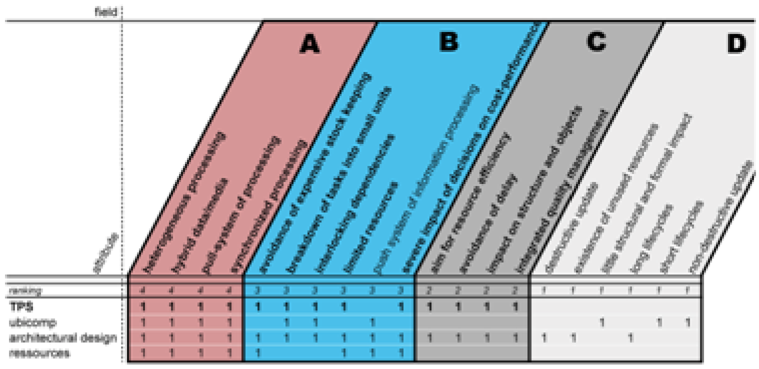

Figure 2: Ranking of the attributes of each field.

4.4 ANALYSING TASKS WITHIN ACADEMIC BUILDINGS

A common task within academic buildings is used to obtain an in depth view on possible ubicomp resource management. The task is: 'Make a reservation of a suitable room for a lecture' (figure 3). The building is expected to have a people guidance system based on public screens.

It seems to be a simple task, but a large number of cascading sub-procedures occur. Their classification towards dependencies on space, time and resources are relevant for the process of building design. By breaking down processes into sub-elements, the great diversity of demands from different tasks appears.

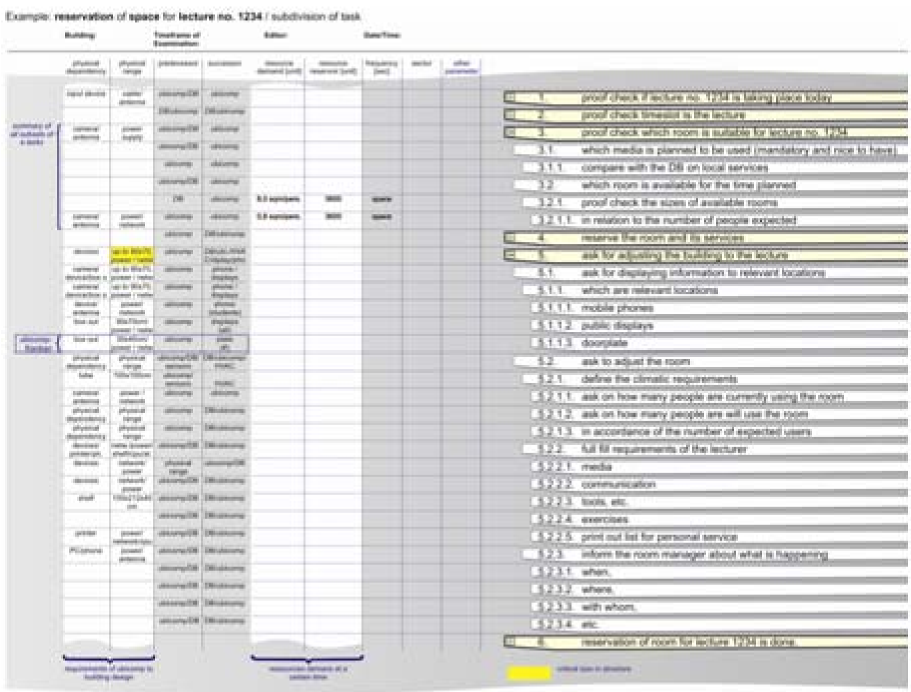

Figure 3. Example of analyse and applied 'Ubicomp-Kanban'.

4.5 FORMALIZATION OF 'UBICOMP-KANBAN'

The principles of the TPS can be applied when merging those attributes that are connecting all fields (figure 2, area A). In order to set up an 'ubicomp-Kanban', methods of the TPS are applied in order to lay out problems. The methods are such as 'push-system', 'itemization of tasks', etc. The table reminds of original Kanban-cards. Requirements of ubicomp services that are essential for an adaptation within a building design will be identified in that list. Demands can simply be added vertically, so that reading is eased. The system is represented by a table whereas other forms could include software, web service, BIM-plug-ins or dynamic simulations.

4.7 DISCUSSION OF 'UBICOMP-KANBAN'

'Ubicomp-Kanban' tool has two main outputs.

4.7.1 Detecting physical requirements

Ubicomp Kanban allows the identification of simultaneous or permanent requirements. It shows when and where physical capacities might exceed. This is an important issue of the overall design. Values that are critical to structure or design can be detected by the educated architect or specialist.

The system is both supporting the direct needs of a service or a device as well as the summarized demand of all services or the summarized demand within a certain area. Simultaneity of demands is readable when marking the table and the elements with time-tags. This is both equivalent to mechanisms of TPS and time-stamps in data bases such as MySQL.

4.7.2 Enabling resource optimization through 'Ubicomp-Kanban'

Ubicomp-Kanban is time oriented. This allows scheduling of resource demands during operation. Based on the pull-system in combination with the findings of Russell (2003) the building will permanently operate optimized according to the TPS. The flow of information and resources is based on the current physical situation as well as on prospective situations. In physical operation, it is expected that for each task the simulated virtual space is step by step taking over the control of the real space (Russell, 2003). The simulation can learn from past real events, eventually based on the recognition of similar pattern that are critically analyzed in order to achieve a optimization of the near future event compared to old events (Theodoridis, et. al., 2006).

New services might need to be integrated into the building's software in order to allow higher grade of optimization. Because of the characteristics of itemization, Ubicomp-Kanban eases the integration of additional software or devices as all available data, information or devices are listed.

4.7.3 Evaluation

The evaluation of the Ubicomp-Kanban is made by qualifying the simultaneous compliance of the following requirements in virtual or real tests:

1. does the building make its users more happy?
2. is the owner of the building more happy?

The owner is happy if the value of the building is retained as good as possible. This includes the life-cycles of the elements of a building and the resource demand for operation. Resources are energy demands, spaces, etc. The users are happy if their demands are fulfilled. The pull system allows the avoidance of over consumption same as in the TPS. A resource efficient operation is possible. Within operation, one critical element is the false prediction of future events. Here as well, the fine grained sub-processes allow an instant correction of the operation once the failure is detected.

The users are happy, if their needs for space, thermal conditioning, safety, etc. are fulfilled. This is sometimes in conflict with the concerns of the owner. In order to find solution for these decision processes, the building operation software could use self-organizing algorithms or agent systems.

Simulations using Ubicomp-Kanban show an average of 10% resource optimization in space-distribution. When applied on the design of a building, up to 30% of cabling can be eliminated with the same time 100% additional services based on a given set of ubicomp devices (Schoch, 2006).

5. Result

Ubicomp-Kanban shows significant qualities as a handy device to point out requirements of ubicomp services in relation to

1. physical demands within a building
2. optimization of resource demands during operation

The tool allows the support of the design of academic buildings and campuses in the information age. A critical application of the tool is necessary as it might ignore cultural, legal or aesthetic parameters.

6. Outlook

Future work will include the integration of purely software based services (such as e-learning systems), adjacent building typologies such as student housing as well as larger scale planning (interior space to global).

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