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GFBS: A PSS DESIGN MODEL APPLIED TO THE BRIEFING PROCESS OF CONSTRUCTION PROJECTS

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1. Introduction

Models for design theory cover a large spectre of systems and disciplines. Most of them concerns physical artefacts with their origin in architecture. In architecture, the first one to appear is the building model through the Vitruvian model [Morgan 1914], the man-environment paradigm [Hillier and Leaman 1973], or the form-follows-function model [Le Corbusier 1923], [Whitford 2005]. The second model in architecture shifts the focus from the building product to its briefing and project process through the brief/project model , the analysis/synthesis model [Alexander 1971], and the define/solve problem [Simon 1973]. From the Vitruvius approach, design models were developed in engineering disciplines after WWII [Le Masson et al. 2013]. Most of them mainly focus on product and process systems such as Systematic Design [Pahl and Beitz 1995], the Theory of Technical Systems [Hubka et al. 1988], FBS [Gero 1990], Axiomatic Design [Suh 1998], or C-K Theory [Hatchuel and Weil 2003] amongst others.
The concept of service appeared more recently, in the early 1990s [Meyer et al. 2002]. Moritz clarifies the distinction between a product and a service regarding seven qualities [2005]: produced/performed, material/immaterial, tangible/intangible, can/cannot be stored, usually without client or with interaction with client, consumed after/during production, and regarding the origins of defaults either from manufacturing or behaviour. Three of these qualities are considered as basic of most of the services: activity components rather than things, simultaneous production-consumption, and the client involvement in the process [Karni and Kaner 2007]. Even if these qualities can be discussed, it provides certain enlightenment about the gap with existing design theory models. Current industrial problems mainly concern the environment and the impact of mass production/consumption of artefacts [Tomiyama 1997], [Umeda et al. 2000]. One of the identified solution is the concept of Product-Service Systems (PSS): a business model change from product ownership toward utilisation and functionality selling [Mont 2000]. The paradigm shift from product and service systems to product-service systems leads to a novel engineering called service engineering [Arai and Shimomura 2007] and new design models more adapted to such integrated systems. At the moment, there is a lack of PSS methodologies [Müller and Blessing 2007] and a great amount of research is still required [Vasantha et al. 2012].
Design in Architecture, Engineering and Construction (AEC) can benefit from this paradigm shift even if industrial problems are different. Buildings can be considered as PSS in its broadened sense based on their complexity in terms of design and construction project management [[Kubicki et al. 2006], but also based on their composition [Mauger et al. 2013]. Buildings are not standalone physical artefacts (i.e. products); they also integrate a human-intensive activity part (i.e. service) that gives it its essence. As introduced earlier, existing design models in architecture refer to either the building

product alone or its briefing and project process. Both models do not fully integrate this service dimension of buildings whereas PSS models are mainly business-oriented. This paper asks the question of how to support the assignment of functional units to either the product part or the service part of a building system?

Based on a descriptive study of building systems and an extensive literature review on design methods and models, and PSS, Gero's FBS approach was identified as a relevant framework for the development of this proposal through the concept of Behaviour. Behaviour is an encompassing concept. It covers both the product part (i.e. attributes) and the service part (i.e. activities) of building systems. A missing concept was identified in Gero's FBS to support the assignment of functional units although expressed in FBS literature: the concept of Goal also referred as purpose. This paper proposes a design theory based on the original FBS approach for buildings requirements definition using a PSS viewpoint. This design theory is illustrated based on the results of a group work session performed during the briefing process of a real construction project.

Firstly, this paper introduces the PSS conceptual perspective on buildings. Secondly, the GFBS design theory for buildings as PSS based on Gero's FBS is explained. Finally, this design theory is instantiated in a design process applied to a construction project. The construction project in question is a secondary school in Luxembourg, a case study developed upstream of the design theory. As a conclusion, a generalization of the design theory is proposed.

2. Building as PSS: A matter of conceptual perspective and scope

Architectural programming does not just aim to define a building but a whole "operating system" answering clients' needs. This "operating system" is composed of several elements of different natures. From a design perspective, the most interesting one is the building, but from a customer perspective, the most important one is the human activity performed inside it.

In order to clarify the AEC specificities, the example of a public school is taken. When talking about public building in AEC, three kinds of clients are clearly distinguished: the paying client, the user client, and the customer client. In other engineering domains, as well as with other kinds of buildings, it is quite often that at least two of then are the same person. In the school example, the paying client is the Ministry of National Education who pays for a new school. The user client is the personal (e.g. teachers, director, janitor) required to provide (more or less directly) education to the customer client identified as the pupils. This being said, the studied system in this paper is not limited to the school building but to the whole "operating system" required to provide education to these pupils. As a result, the building as well as the user client (e.g. teachers) and his human-intensive activity (e.g. education) are part of the studied system. The user integration in the studied system is already considered in the design of result-oriented PSS.

Product-Service System (PSS) is mainly presented in literature as a business model. It focuses on functionality or usages to provide to consumers instead of selling products [Meier et al. 2010]. The idea is to sell a marketable mix of products and services that will jointly satisfy the consumers' needs [Goedkoop et al. 1999] and increase at the same time the market proposition [Mont 2000] by integrating services to traditional product functionality [Baines et al. 2007].

2.1 Product part

In this paper, regarding the studied "operating system", any tangible artefact (i.e. resource) required to perform an activity is considered as from the product part. As a result, building, furniture (e.g. tables, chairs), and equipment (e.g. HVAC components, plumbing fixtures) are considered as product parts of the "operating system". User clients are not considered as products even if they are required (human) resources of the "operating system".

2.2 Service part

The concept of Service has several meanings in AEC that differ from PSS. The first one concerns the technical building services that basically give life to the building (e.g. HVAC systems). Technical building services are composed of product parts of the operating system (e.g. heat pump, air vent, conduit). The second one is more related to public services (e.g. education) referring to human-

intensive activities performed by user clients to customer clients inside the building. In this sense, the customer client is assimilated to the consumer of the service.
Three kinds of product-service system are mainly considered in the literature: product-oriented, use-oriented, and result-oriented [Manzini and Vezzoli 2003]. The main difference between each one of them could be synthesized into the degree of ownership sold to the consumer: property of the product, property of its use, and property of its results [Cook et al. 2006].

2.3 Product-Service System

In this paper, PSS is used in a broaden sense, as a model to represent the defined "operating system" composed of interdependent product parts (e.g. building, furniture, equipment) and service parts (i.e. human-intensive activity). Regarding the public school example, the operating system has to provide education to pupils throughout the building, equipment, furniture, and personal.
With result-oriented PSS, products are substituted by services (e.g. laundry services) [Sundin et al. 2009]. In this specific case, two kinds of service content can be distinguished: core services and support services [Yang et al. 2010]. Core services are customer-oriented (e.g. cleaning sheets) whereas support services are product-oriented (e.g. maintenance of the washing machines).
This distinction is adopted for AEC in this paper. Regarding the school building example, any user (e.g. teachers) activity performed to provide value to customers (e.g.pupils) is then considered as a service. The public service (i.e. education) corresponds to the core service of the "operating system". The technical building services (e.g. HVAC systems) can be considered as internal support services whereas cleaning and maintenance services can be considered as external support services. During the architectural programming, all of these services have to be considered, especially in the context of sustainable development. Current literature on sustainability in AEC seems to focus more on the support services and issues regarding energy efficiency and environmental performances [Ding 2008] rather than the core services.
This paper introduces another research trails to contribute to sustainable development through a better alignment between the product part and the service part that compose a building. Both parts can contribute to the customers' needs satisfaction but there is a lack of theory to support the assignement of functions to the product part, the service part, or to a integrated combination of them.

3. A PSS Design Theory based on FBS

PSS methodologies focus efforts early in the design process, on the conceptual design phase [[van Halen et al. 2005]. One of their key issues concerns the function allocation and its decision support [Muller et al. 2007]. AEC meets the same key issue during the conceptual design phase of construction projects. A function can be assigned to either the building (i.e. product) or to a human-intensive activity (i.e. service). The proposed design theory is structured around four main concepts taken and extended from Gero's FBS: Goal, Function, Behaviour, and Structure. To clarify its presentation, the design theory is first introduced using a generic PSS. The next section is more focused on the object of study: building systems. It will present a proof of concept in the frame of the function allocation issue in AEC.

3.1 FBS

FBS was first introduced by Gero [1990] to model the design as a process and capture the nature of the concepts manipulated during this process through the use of knowledge representation diagram. The basis of this proposition is Gero's FBS ontology applied to structure more precisely the requirements definition of building systems with the following definitions [Kannengiesser and Gero 2011]:

- Function – Teleology of the artefact, what is it for.
- Behaviour – Attributes derivable from the structure, what it does.
- Structure – Components and their relationships of an artefact, what it consist of.

The FBS ontology is not limited to the description of design objects. This framework is also used to model the design process [[Gero and Kannengiesser 2006] as precise as possible. The starting point was originally the concept of Function as the purpose of the system to design (Figure 1.a). Later, it changed to become the concept of Requirement, an input given to the designer by the customer that

indicates the design problem. The last step of the design process remains the same, the documentation (i.e. the description of the design, e.g. CAD drawings and component lists) used for construction or manufacture.
The missing question not answered by this FBS framework is the Why question. Why do we need to change something from the environment from state A to state B? It is somehow related to the concept of purpose as underlined in [Dorst and Vermaas 2005], [Rosenman and Gero 1998]. If this question is not answered in the framework it is most probably because it is not considered to be part of the design process. As mention before, the input of the design process is Requirement that is provided by the customer. Requirement is defined during the requirements definition process of the conceptual phase (Figure 1.a). In this paper, the concept of Requirement as used by Gero is derived from the concept of Goal. This Goal is considered as a driving force of the requirements definition. It provides the necessary rationales to make the designer understand the Requirement and to support the decision making process during the designer-customer interactions.

3.2 Goal vs. Purpose

Purpose is defined as an intentional concept [Dorst and Vermaas 2005] expressing the need of a customer about what he wants to achieve with the system. It is first introduced and distinguished from the concept of Function as the answer to the question Why the system does what it does or what it is for [Rosenman and Gero 1998]. Both concepts answer different questions and the confusion generally comes from the physical disciplines. However, the concept of purpose did not last and was replaced by the concept of Requirement as an input of the design process [Gero and Kannengiesser 2004], proving an uncertainty about the clear distinction between the concept of Purpose and Function in Gero's and his collaborators' mind [Vermaas and Dorst 2007].
The Purpose concept is clearly defined as a state of affairs users of the artefact seek and is supposed to be achieved by performing it [Vermaas and Dorst 2007]. The very same definition is used to defined a Goal in Requirements Engineering: "a state of affairs that the stakeholder wants to achieve" [[Glinz 2011]. In this paper, we decided to move from the uncertainty and confusion between Function and Purpose terminology to using a different concept coming from Requirements Engineering. This general concept of goal was first introduced as a driver for software requirements acquisition.

- Goal – "A goal is a prescriptive statement of intent the system should satisfy through cooperation of its agents". Goals are non-operational objectives. "Non-operational means that the objective is not formulated in terms of objects and actions available to some agent in the system; in other words, a goal as it is formulated cannot be established through appropriate state transitions under control of one of the agents." [Dardenne et al. 1993]

Because of the complexity of targeted software systems, most of the GORE techniques [Lamsweerde 2009], [Yu et al. 2010] organise goals into hierarchical trees or directed acyclic graph models showing how higher-level goals are satisfied by lower-level ones (goal refinement) and, conversely, how lower-level goals contribute to the satisfaction of higher-level ones (goal abstraction) [Lamsweerde 2001]. It provides the rationales behind each requirements of the system. To summarise, GORE models provide adequate foundations for clarifying Gero's FBS ontology.

3.3 GFBS Ontology

The Goal concept is distinct from the concept of Function. As highlighted by Rosenman and Gero [1998], the confusion seems to exist only in physical disciplines. In this paper, the studied system is a Product-Service System, a socio-technical system. In this context, the system is no longer attached only to physical disciplines but get closer to business, management, service-related disciplines [Mauger et al. 2013]. The Goal concept thereafter provides a complementary concept for the ontology related to the requirements definition during the conceptual phase. This new layer of information represents rationales to guide the requirements definition process and support the decision making process.
As a result, we propose to use the following definitions for the new GFBS ontology based on FBS previous definitions and Goal definitions to define and model a Product-Service System:

- Goal – a state of affair or condition defined by the customer that the system must satisfy through cooperation of its components (i.e. sub-systems) and establishing the raison d'être of the system.
- Function – ultimate refinement of a Goal into an ability of action by the system on its environment formulated without context to be triggered by an external event contributing to a higher Goal achievement.
- Behaviour – context dependent (e.g. time, space, preconditions) attribute of the system (or sub-system) associated to or derived from its Structure (i.e. its components).
- Structure – characterized physical and virtual components of the system and their relationships describing what it is composed of.

This new ontology forms the basis of the proposed design theory for Product-Service Systems.

3.4 GFBS Design Theory for PSS

Based on the defined ontology, GFBS and PSS concepts are merged in a design theory. GFBS structures the framework of the theory whereas PSS structures the studied system. The Goal and Function concepts are associated to the global system (i.e. PSS) at a macro level. Behaviour is firstly associated to the gloabal system (Sys) then refined between its product part (Pro) and service part (Ser). To limit the complexity, the Structure concept is maintained on the full system. The GFBS design theory proposed in this paper is structured around six steps (Figure 1.b) and focus on the system's design (not its components). These steps do not present back and forth. The back and forth loops have to be introduced in its instantiation in a design process. Axiomatic Design principle of zigzagging [Suh 1998] should be kept in mind. Several design process can be deduced from the proposed theory.

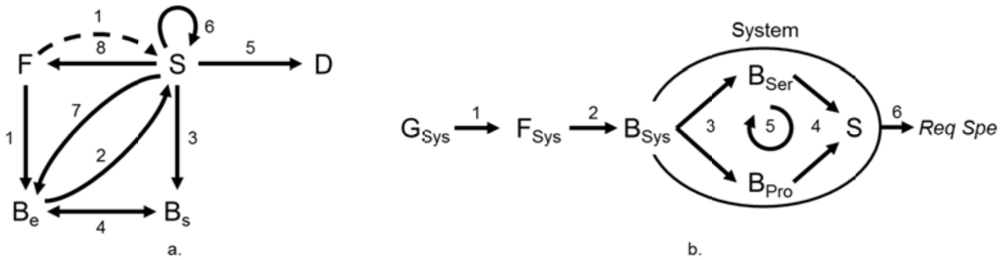

Figure 1. (a) Gero's original FBS, based on [Gero 1990]; (b) GFBS Design Theory for PSS

In this paper, design aims at finding a solution to a current problem. The current problem is represented by the context of the system. This context is defined by unsatisfying facts about elements of the environment. Therefore, goals represent the desired state of affair or condition to achieve through the system's creation. Goals of the System (G_{Sys}) are the input of the design process; they are defined and refined with the client. Goals drive the decisions along the framework.

1. G_{Sys} ➔ F_{Sys} – Function generation: functions are abilities of action that, when properly triggered, contribute to the achievement of one or several goals, singularly or in combination with other functions. During this step, the designer transforms states of affairs or conditions of the environment to achieve or maintain into abilities of action by the system, independently from the technical solutions.
2. F_{Sys} ➔ B_{Sys} – Function allocation: at this step, the designer sketches how the system as a whole will behave to provide the required functions. It results in a description of basic solution principles without details about the components (i.e. behavioural description of the system rather than structural description).
3. B_{Sys} ➔ $B_{Pro/Ser}$ – Behavioural refinement: based on the basic solution principles, the designer refines how the system will perform the functions in terms of product attributes (B_{Pro}) or service attribute (B_{Ser}). Product attributes (B_{Pro}) refer to expected behaviours of the product part of the system under specific conditions (i.e. passive behaviour) whereas service attributes (B_{Ser}) describe expected behaviours of the service part of the system (i.e. active behaviour).

Decision to refine a system's behaviour (B_{Sys}) to either an active behaviour (B_{Ser}) or a passive behaviour (B_{Pro}) of its components is led by the defined system's goals (G_{Sys}).

4. $B_{Pro/Ser} \rightarrow S_{Sys}$ – Structure synthesis: expected behaviours are associated to elementary or combination of components of the system more or less independently. It is a nomenclature or a product breakdown structure listing all the required component of the system (i.e. structural description of the system).
5. Requirements processing or Behaviour-Structure balance: at this step, dependencies between behaviours and structure elements is checked for requirements consistency with the clients (e.g. limited number of structure elements can only ensure limited number of behaviours). A balance between them is performed to modify, reduce or delete requirements on the system according to the defined goals [Mauger and Kubicki 2013].
6. Requirements specification: this step consists in synthesizing resulting requirements about the system (i.e. globally) and its components (i.e. locally). It corresponds to the design description of the system as presented in Gero's model [Gero 1990].

Then a new design phase starts: the design of the components. Based on these requirements, each component of the system (S_{Sys}) can be designed individually by the right designer (e.g. an architect for a building, a cabinetmaker for furniture).

In this design theory, the question of the actual behaviour is not considered (i.e. how the structure really behaves in its context). Nevertheless, goals, when properly defined, provide indicators of achievement regarding the requirements that can be used to assess the system's performance.

4. Instantiation on a Briefing Process

In this section, the proposed GFBS design theory is illustrated on a briefing process of construction project. The taken example is the result of a real discussion in a group work session with teachers and psychological personal regarding the architectural programming of a secondary school in Luxembourg. The discussed problem was about bully zones in the current building and how to avoid "lawless" areas. It illustrates how GFBS theory would support or structure the briefing process. In reality, the discussions were unstructured and confused. In order to explicit the flows of information along the process, the modified briefing process is modelled using IDEF-0 (Figure 2 and 3).

In this paper, the focus is on the internal analysis which produces programmatic concepts. This activity is considered as a design activity.

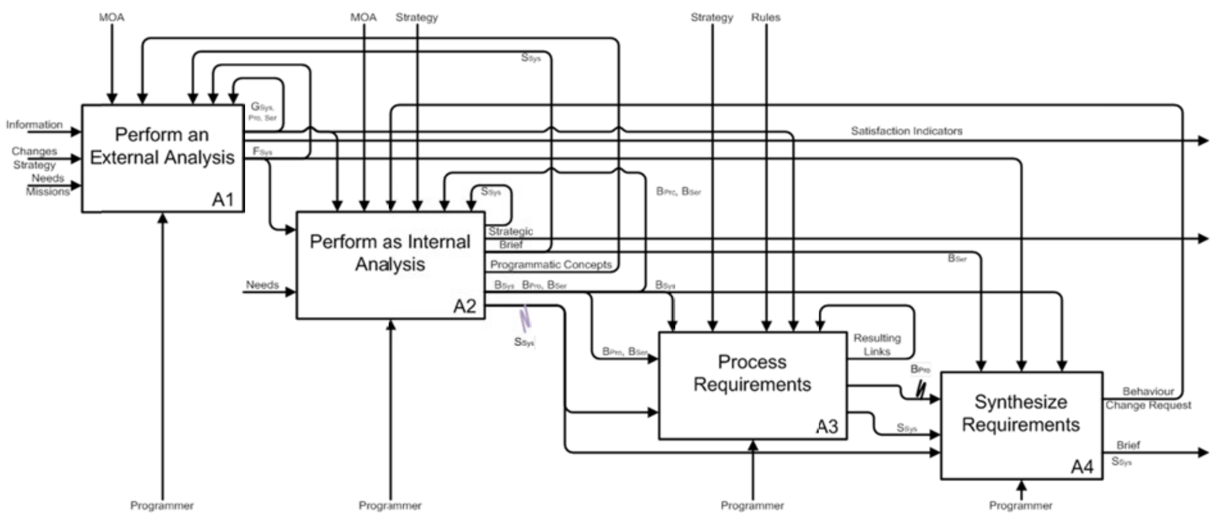

Figure 2. A0 diagram of the GFBS briefing process

Perform an Internal Analysis – This activity refers to the internal functional analysis of the building system. The main purpose is to define how the building system will perform its functions (F_{Sys}). The inputs of this activity are the system's functions (F_{Sys}) and the clients' needs. The controls of this activity are the goals of the building system defined in the previous activity (A1), the contracting

owner (noted MOA), behaviour change requests, the strategy defined by the paying client (i.e. MOA), the components of the building system and the defined behaviours. The outputs are activities (B_{Ser}) and attributes (B_{Pro}) of the system assigned to its components (S_{Sys}), the programmatic concepts, the strategic brief based on these concepts and some requirements about the building system.
The internal analysis activity is divided into four activities: create programmatic concepts, describe behaviours, refine behaviours, and refine structure (Figure 3). The first activity (A21) consists in creating programmatic concepts that will realize the functions of the system (F_{Sys}). Several concepts can ensure the same function. For example, a function of a school building concerns the security of pupils. This security can be realized through different concepts such as [Mauger et al. 2013]:

- *Architecture, relations and positioning*
- *Materials*
- *People*
- *CCTV system.*

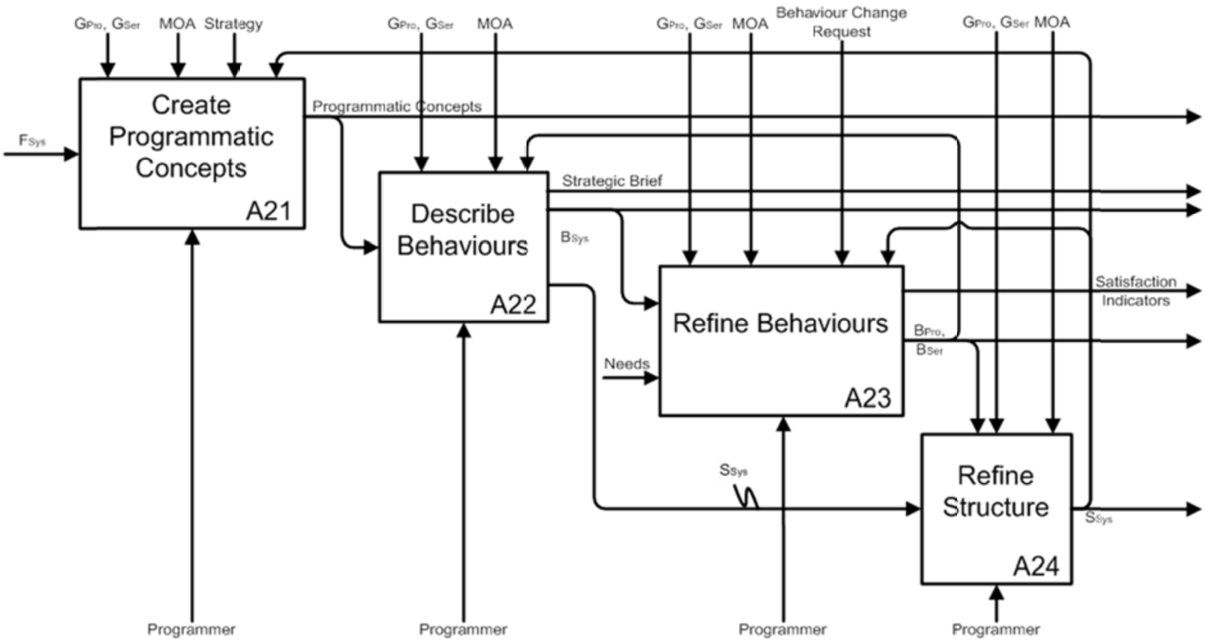

Figure 3. Details of the A2 activity "Perform an Internal Analysis"

The selection of relevant concepts to be applied is guided by the controls of this activity such as the defined and refined goals (G_{Sys}), the paying client (MOA), and his business strategy. A CCTV system and guards would better fit with a goal such as “pupils are under surveillance all the time for their own safety”. On the other hand, if there is a goal about “pupils feel safe and protected during school breaks”, the surveillance does not need to be all the time, then teachers and rounds would be sufficient. This is related to the paying client’s strategy, i.e. the degree of teachers’ commitment he wants.
The second activity (A22) refers to the description of the system’s behaviours (B_{Sys}) related to the programmatic concepts choose on a macro scale. In order to give more examples, each programmatic concept defined earlier is explained [Mauger et al. 2013]:

- *Architecture, relations and positioning.* The layout and design shape of the building system (S_{Sys}) improve the watching of pupils (B_{Sys}) (like in prisons).
- *Materials.* The use of see-through materials for walls and windows (S_{Sys}) prevents bullying by lack of spaces privacy (B_{Sys}).
- *People.* School’s personnel (S_{Sys}) do some rounds scheduled by pair during the breaks (B_{Sys}).
- *CCTV system.* A CCTV system (S_{Sys}) is deployed in the school to watch over pupils (B_{Sys}).

The description of the main behaviour is enough to produce the strategic brief. It gives the main orientation of the briefing process. This document has to be approved by the paying client before continuing the process.

The third activity (A23) consists in refine the main behaviours (B_{Sys}) based on the refined goals of the system (G_{Sys}). Change behaviour requests influence the process on this activity. Based on the required changes, the refinement has to be adapted. The refinement of behaviour can also influence the description of the main behaviour as from time to time a main behaviour might not be possible.

- *Architecture and positioning.* Requirements to provide are about proximity and visibility between particular spaces, i.e. attributes of the building spaces (B_{Pro}). For example, teacher's offices are spread around the school building and the schoolyard is in the middle of them.
- *Transparent materials.* Requirements to provide are about kind of materials to be used and visibility to and from particular spaces, i.e. attributes on walls and windows of the building (B_{Pro}). For example, all the rooms have at least two glass walls.
- *People.* Teachers have an obligation to perform a 15 minutes surveillance round each week during a break (B_{Ser}). The schedule of their rounds is managed by the superintendent.
- *CCTV system.* Requirements would concern attributes of the equipment, the network, and the janitor's office (B_{Pro}), and a new activity for the janitor (B_{Ser}). For example, all the circulation and public areas should have enough cameras to avoid blind spot. The janitor has to watch over the screen during his daily activities.

The last activity (A24) concerns the refinement of the system's structure (S_{Sys}). The refinement of the system's structure is controlled by the refined goals and the paying client. The resulting structure influence the programmatic concepts defined in A21 and the refined behaviours in A23 which make the process co-evolutive.

- *Architecture, relations and positioning.* The system structure refinement refers to the listing of all the spaces and their typology (e.g. public/private spaces and circulations, courtyard, classroom).
- *Materials.* All the components of the building are concerned in this case.
- *People.* Teachers are concerned but also all the personnel of the school can be mobilized for the rounds.
- *CCTV system.* Cameras are not enough, there is a need for secured internal network and a watch room all connected to each other as well as a person in charge of watching the screen.

In the case study, the choice of the superintendent fell on a combination of the suggested programming concepts, a passive surveillance by the adults (B_{Ser}) facilitated by the use of see-through materials (B_{Pro}) and a clever repartition (B_{Pro}) of teachers' and staff members' offices (S_{Sys}) around the school. This decision was led by the main goals (G_{Sys}) refering to the well-being of pupils and the impact on teachers' and staff members' daily work as well as expenses regarding each programmatic concept.

5. Discussion and Conclusion

The proposed GFBS briefing process (Figure 2 and 3) presents one possibility of instantiation amongst others. The focus is on functional requirements, meaning that the whole briefing process is not considered. It could be considered as an ideal process given that in practice, it is often difficult if not impossible to make the stakeholder commit a predefined process. Each construction project has its own specificities and the programmer should adapt the briefing process accordingly to reflect them. It has to be noticed that all the presented activities are performed by the programmer. This is a viewpoint chosen to explain the briefing process. The contracting owner and other stakeholders are parts of the briefing process but they are considered as input providers and controllers rather than performers.

The inputs of this briefing process come from preliminary studies (not included in this briefing process). The preliminary studies are essential so that the contracting owner acquire a certain level of maturity and perception of the reality on his project.

This paper presents a design theory to support the conceptual design of such PSS. The proposed theory was developed based on Gero's FBS and an analysis of building systems as PSS. The results of these analyses led to the use of the Behaviour concept as a support for product or service distinction and assignment of functions and the extension of Gero's approach with the concept of Goal as a key element of decision support for the assignment. The proposed design theory was then applied post-ex facto on the briefing process of a construction case study. The resulting process illustrates the flows of information between activities and the control loops of the process. This limited application provides an illustration of the GFBS design theory on a real case study. The GFBS design theory is PSS-oriented. It was applied on a building system in this paper but might be applied on other kinds of PSS. Perspectives on this research include other viewpoints on buildings. Indeed, a building can be represented as a Socio-Technical System to integrate a social dimension in addition to the hardware (e.g. building, equipment, furniture) and software part (e.g. processes) of a building system. This viewpoint can be used to introduce some analogies with Human-Computer Interaction to develop Human-Building Interaction. This perspective would close the loop with knowledge-based architectural programming through social and behavioural sciences.

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