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DETERMINING BENEFIT-UNDERSTANDING BUILDINGS AS PRODUCTION SYSTEM ASSETS

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ABSTRACT

Maximizing the client value delivered from construction projects is to large degree a matter of maximizing the benefit in use of the built asset. To do so, we must be able to accurately assess the benefits of a proposed solution at the time of design. While some authors have looked at simulation solutions for examining this issue, we believe that this research is putting the proverbial cart before the horse. A more fundamental understanding of what answers we seek is needed before considering how this technically speaking could be done

In this paper, we first develop an understanding of buildings as production assets from a production theoretical point of view by reviwing relevant production theory in the context of buildings. Therafter, we discuss what questions we must be able to answer to optimize building as production assets in light of the previously developed theoretical foundation. Finally, we discuss how these questions can principally be answered through different evaluation approaches.

Keywords: Fitness for purpose, theory, value

INTRODUCTION

Project Management has in the past decade shifted from focusing on delivering a set scope within a given schedule and budget, towards value delivery (Laursen and Svejvig 2016). Value is the relationship between cost and benefit (Drevland and Lohne 2015; Kelly 2007). Thus, delivering value is a matter of reducing costs or increasing benefits compared to some baseline. While reducing costs in a construction project is not necessarily straightforward, it is at least conceptually well understood. Delivering increased benefits, on the other hand, is more elusive.

What are the benefits of buildings? In prehistoric times, humans went from relying on caves to erecting tents and other simple structures to provide protection from the elements.

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While being shielded from sun, wind and rain are still benefits sought from buildings today, the situation is now more complicated.For instance, buildings also provide access to clean water and sanitation.

Buildings can serve many different purposes.According to Blakstad et al. (2008), buildings are either built to serve as residences for human population, or to serve as production assets. While there are commonalities in how buildings provide benefits for these two purposes, we will in this paper focus on buildings as production assets.

As a production asset, the role of a building is to enable the business processes of the organizations that will occupy it (Mahal 2010). According to Mahal, a business process is "*the combination of a set of activities within an enterprise with a structure describing their logical order and dependence whose objective is to produce a desired result*". The benefits of buildings, that are considered production assets, will therefore be a function of how well the business processes they should support are running. Thus, delivering more benefits, and thereby value, is a matter of ensuring that the business process that the building should support are supported well (Ballard 2008).

In the research literature, when discussing a buildings fitness for purpose, the term usability is often used (Blakstad et al. 2008; Leaman et al. 2010). The term originated in the ICT industry and is defined as the *"extent to which a product can be used by specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO 1998). Furthermore, *effectiveness* is the *"accuracy and completeness which users can achieve specified goals"*, *efficiency* is a measure of the *"resources expended in relation to the accuracy and completeness with which users achieve goals",* and finally, satisfaction is "*freedom from discomfort, and positive attitudes towards the use of the product*". The goals buildings are expected to achieve are related to their functions as productions assets.

There exists a significant body of literature on how building performance can be improved. In the field of facilities management, the most prevalent method described in the literatureis Post-Occupancy Evaluation (POE). The method focuses on evaluating actual building performance and relies heavily on user surveys to map the usability and performance of buildings (Cohen et al. 2001).

Assessing the performance of an existing building can help us to tweak operating parameters such as airflow and lighting, and it can help decide if the building is fit for supporting its current use. Also, the knowledge gained could help inform future projects (Leaman et al. 2010; Rybkowski 2009). However, to have any significant impact on a building's performance, we need to assess the performance of the building before it is built. Buildings are large complex systems that generally have a very long lifespan, and making changes to them are costly. Once a building is built, the processes that will take place within are irrevocably affected for better or for worse for a long period. According to Smith (2009),*"improving the productivity of the people or process that occupy a facility by just 3.8% would pay for the entire facility – design, construction and operations and maintenance".* If we can accuratelyasses the performance of a building that is still on the drawing board, we can fundamentally improve the design for the better.

Some authors have looked into computer-aided approaches for assessing building performance at the design stage. Both Simeone and Fioravant (2012)and Kalay et al.

(2014)propose an agent-based approach to simulate the building in use. However, we would argue that this research is putting the proverbial cart before the horse. A fundamental tenet of computer simulation is not to make the simulation model more detailed than what is required to answer the questions at hand (Law 2007). Furthermore, simulation might not even be beneficial. Sometimes analytical approaches are more effective.

Additionally, we have found that this research lacks a proper theoretical underpinning for under standing buildings as production system infrastructure. We would argue that such an understanding should be the starting point for any method aimed at assessing the potential benefits of a building in use. In this paper, rather than look at techniques for building simulation, we look at the question of how to develop an understanding of buildings as production assets from a production theoeretical point of view.Furthermore we discuss what questions must be answered if we are to optimize buildings as production system assets, and investigate potential answers to these questions.

From a business perspective, buildings can have both instrumental and symbolic benefits(Drevland and Klakegg 2017). The former coming from directly supporting business process directly, while the latter from providing image and identity for the organization(s) housed by the building. In this paper, we limit ourselves to consider instrumental benefits.

BUSINESS PROCESSES VERSUS PRODUCTION PROCESSES

Ideally, we should measure the performance of the business processes that a building is meant to support. In a POE context, the actual performance of business processes can be measured and benchmarked with similar processes in similar buildings. However, at the design stage, where designers are deciding layouts, room functions and such, they need to consider issues at a more detailed level. Moreover, certain business processes, such as customer acquisition and quality assurance, do not correlate very well to the physical aspects of a building, i.e.rooms and spaces. However, we can instead consider the corresponding production processes that takes place, such as meetings with customers (customer acquisition) and inspections (quality assurance), and evaluate the performance of these. Thus, we would argue that determining performance and usability of a building entails determining how well the production processes that it houses runs.

PRODUCTION SYSTEMS THEORY

We will in this section provide a brief overview of production systems theory that is relevant for understanding and describing buildings as production system infrastructure.

Koskela's seminal work on production theory (Koskela 2000) shows that through the 20th century three different conceptualizations of production have been used. He argues that all three are necessary and synthesises them to one common theory; the Transformation-Flow-Value (TFV) theory. Historically, the predominant conceptualization of production has been that of a Transformation of inputs to outputs. In this perspective, it is thought that the overall transformations can be decomposed into aset of smaller transformations, which in turn can be optimized to improve the whole.

One shortcoming of the transformation conceptualizations is that it only considers value-adding activities, i.e. where processing takes place. Decomposing a production process into smaller transformation activities will also result in many non-value-adding activities that occur in between, such as transportation, inspection and waiting. This is the focus of the second conceptualization, Flow, which considers production processes as flows of materials and resources. Flow activities – or non-value adding activities - are considered waste and are sought to be minimized or eliminated.

Another flaw of the transformation conceptualization is that it is prone to sub-optimization. Neither the consequences on downstream operations nor the quality of the final product are considered when optimizing the smaller tasks. This is the domain of the third conceptualisation, Value, which is concerned with the realization of the customers (internal and external) needs.

In the context of assessing a buildings ability to support production processes, the value aspect is arguably irrelevant. This aspect is concerned with whether or not the right things are done, something that is the domain of production system design. The question we need to answer is whether or not a building allows the right things to be done well, i.e. to what degree are transformation and flow activities supported by the building.

Thus, instead of considering the usability of the building at a macro level, we need to drill down to a relevant level of detail and consider the usability of the constituent transformation and flow activities that the production system design requires. For example, for a hospital, we must consider the usability of activities such as performing surgeries and transporting patients.

With regard to the level of detail required, any activity could be detailed down to very minute operations. Consider a carpenterwho is nailing a board. The act of him taking a nail out of his pocket and moving it into position can be considered flow. The only true transformation taking place is when the nail is being hit on the head and moves further into the board.

Breaking down activities into this level of detail can make sense in some situations. For example, when developing a tool like a nail gun (eliminating the flow of the nail from the carpenter's pocket to the wall). In the context of buildings, an example of this kind of micro-flowis the movement of doctors and nurses within an operating theatre during an surgery. In this paper we do not propose to examine in detail what might be a suitable level of disaggregation.

Assessing the usability for individual transformation and flow activities has an inherent value with regard to improving these activities in isolation. However, at the system level, i.e. the whole building, doing so in-and-of-itself would only be sufficient in production systems with no variability, something that rarely exist in real life. To truly be able to optimize a building as a whole, we have to consider all the activities at once, taking into account *variability* and *buffer* usages in the production system.

Variability in the context of production systems could refer to product variability, either good - e.g. model variants, or bad - e.g. defects (Hopp and Spearman 2011). However, in the context of measuring a buildings ability to support a production system, our primary concern is the variability in time spent performing transformation and flow activities.

The Buffer law tells us that any production system will always be buffered by a combination of capacity, inventory and time(Hopp and Spearman 2011). Hopp and Spearman also refer to this law as the pay-me-now-or-pay-me-later law. If you do not pro-actively place buffers in the production system, you will suffer the consequence of doing so later. Take for example restrooms. There can be a considerable variability in the demandto use them depending on the time of day and the activity in the building. The activity “going to the restroom” must be buffered. Ideally by capacity (more stalls and urinals), but an inventory buffer (people waiting in line) is also possible. If this kind of buffering is not purposely considered at the design phase, buffers could haphazardly form whenever the building is in use to the detriment of overall system performance, e.g. the case of people waiting in line to got to the restroom blocking corridors and slowing transport through the building.

PRODUCTION SYSTEM MODEL

To be able to determine if a proposed building design will properly support the production system that will be housed in the building, we would argue that some model of the production system is needed. We would furthermore argue that the kind of model required here is something vastly different from the outcome of traditional architectural space programming, which is a list of rooms with specific requirements. The problem with that approach is that it entails an early locking of the design space. The production system(s) that are to be housed in the building might be better served by a different configuration of rooms. This, however, is not something that can be considered without taking into consideration the physical layout and characteristics of the building. A good example is the layout of a nursing unit in a hospital. *“The strategic placement of support functions on nursing unit floor plans affects caregivers' movement, as reflected in walking distances, timeliness, fatigue, and exposure to interruptions”*(Zadeh et al. 2012). Thus, a bad layout of a nursing unit could lead to either more nurses being required to do the same job or suboptimal care being provided.

In this paper we conceptually refer to a model containing information about the production activities that will take place in the building as a Building Activity Model (BAM). Furthermore, we refer to any activity directed towards determining how well the BAM is supported by a proposed design as a BAM evaluation. Since nowadays building designs almost inevitably will be expressed in some form of Building Information Model (BIM), a BAM evaluation can also be thought of ‘clashing’ the BIM and the BAM

The purpose of doing such a BAM-evaluation is to not only do an absolute evaluation of fitness for purpose of a specific desing, but also to provide sufficient information to evaluate design trade-offs to improve the design. At an aggregate level, there are basically two questions that need to be answered: Can the system work? Does it work well? If we are benchmarking two or more designs against each other, having key performance indicators at the system level might be sufficient. However, in order to be able to improve the design, we are not primarily interested in any absolute performance measurements, but rather if and where there is room for improvement. That is, where in the system can ineffectiveness, inefficiency and dissatisfaction be found, and what are the reasons for them. This requires that we acquire information at the activity level. Thus, going back to the usability term, we need to understand to what degree these activities described in the BAM can be performed from the perspectives of *effectiveness, efficiency and satisfaction.*

EVALUATION METHODS

Before considering the specifics of a BAM evaluation, we need to have a notion of the different evaluation approaches that can be used. There are fundamentally two approaches that can be used to examine a system; analysis and simulation (Law 2007). Analytical solutions can be used if the model are simple enough. In this paper, we will separate analytical solutions into verification into two types, verification and calculation

In the Project Management Body of Knowledge, verification is defined as “the evaluation of whether or not a product, service, or system complies with a regulation, requirement, specification, or imposed condition”(PMI 2013). In this paper, we define verification somewhat more narrowly. Our definition aligns with what can be found in the systems literature, where the purpose of verification is “showing that all system trajectories satisfy the desired property” (Girard and Pappas 2006). In other words, the answer to a verification question will always be a binary true or false. Further more. “all systems trajectories” entails that uncertainty or variability can be reduced to worst case scenarios.

Some of the answers we want from a BAM evaluation will be numeric. In many cases, this will require the use of computer simulations. However, that is not always the case. Thus, we will define calculation to include any method that yields numericalanswers but does not rely on computer simulation.

Simulation is a ratherbroad term. Law (2007) describes it as ”techniques for using computers to imitate […] the operations of various kinds of real-world facilities or processes”. While we agree with Simeone and Fioravant (2012)and Kalay et al.(2014) that agent-based simulation is likely most beneficial when it comes to simulating building use, we do not here assume any specific simulation method when discussing simulation.

In addition to the types of evaluation that can be used, we must also distinguish between deterministic and stochastic models. A deterministic model is one where all the input variables are known, while a stochastic model is a model where one or more of the input variables are uncertain (Law 2007). Some people mistakenly equate stochastic with simulation and deterministic with analytical solution. However, stochastic models can be solved analytically. E.g. the PERT is a stochastic scheduling method that initially employed analytical methods for evaluation (Clark 1962). Conversely, some deterministic models are simply too complex to be evaluated using analytical solutions and require the use of simulation (Law 2007).

BAM EVALUATION

In the introduction, we referred to Law (2007) who states that modelling should not be done beyond what is necessary to answer the questions one wants to be answered. What are then the questions we want to answer? In the previous discussions we have argued that we need information at the activity level of the production system(s) that will be housed in the building. Therefore, we would argue that there are two main questions that need to be answered. Firstly, can the activities in the BAM can be done. Secondly, how well can these activities be done. Below we discuss how these questions can be answered through a BAM evaluation. Furthermore, while getting information at the activity level is necessary to optimize the buildings design, designers and decisions makers will better be served with aggregate level indicators as an initial result of a BAM evaluation to give them an overall feedback of the quality of the design. Therefore, we also discuss what performance indicators could be usseful at the aggregate level.

Can the activities be done?

The most fundamental type of BAM evaluation is to check if an activity can be carried out in the spaces that should support them, i.e. is the required infrastructure in place, can the required resources, and can materials be transported into the area? This evaluation can be done by relatively simple verification and is already being done today, it then has to be verified against a space program rather than a BAM (Kim et al. 2013).

If we consider the question of whether the required activities can be performed or not more broadly, we are then looking at a far more complicated situation. This entails evaluating whether the building has sufficient capacity to support the needs of the production system, rather than just considering if production activities can be done in the allocated spaces.

Determining if the building will have enough capacity for a specific activity can in some cases be determined by verification. For example, if we have a design for a university building where each of the faculty is supposed to have their own office, then verifying that research activities are sufficiently supported is easily done by comparing the number of offices to the number of faculty resources specified in the BAM. The same with small meetings, if the faculty offices are designed to accommodate this. Determining if there is sufficient space for large meetings, on the other hand, cannot be determined by simple verification. At least not unless the building has been designed with one meeting room per faculty. Verification only yields a yes or no answer. In a situation where the supply of spaces with the required infrastructure might outstrip the demand from activities needing them, we need to move on up to calculation or simulation.

Calculation could be used for simpler scenarios. We can calculate the maximum activity capacity, for example simultaneous meetings, from the BIM, and the total expected meeting room requirements from the BAM. Since there is usually some flexibility as to when meetings are scheduled, this might be sufficient. If, however, we are dealing with activities that cannot be scheduled in advance, the analysis becomes more difficult. Take for example people going to the restroom. This is not something that one would schedule days in advance. Determining sufficient capacity here can be done through calculation, relying on rules of thumbs and averages. However, if some characteristics of the system cause batching to occur, for example people arriving on an airplane at an airport, such average numbers will lack reliability. Thus, in a highly variable setting, we need to simulate circumstancesto get sufficiently relaibleanswers.

How well can the activities be done?

Determining if the activities can be done well, i.e. with high efficiency, effectiveness and satisfaction, is not a trivial matter to determine. The reason for this is the high degree of interdependencies between activities and resources in most productions systems and the inherent variability within these systems.

Hopp and Spearman (2011) distinguish between process variability and flow variability in production systems. Process, or transformation (to use the term of Koskela (2000)) variability originates whollywhit in the process itself. Flow variability is caused by upstream variability. Similarly, we can separate between activities underperforming due to flow issues and due to process issues. Flow issues are those that cause an activity to be starved of some material or input. In this case the activity is not performed at all while waiting for materials or resources to arrive or be released. This could be due to characteristics of the building. For example, staff spending a disproportionate time waiting in line or hunting for bathrooms if the capacity is too low. Process issues, on the other hand, do not cause non-performance but rather degrade performance. Some issues could be purely related to the characteristics of the building, like having suboptimal lighting, while others will be caused by other activities in the system, such as noise in an office landscape.

Some of these aspects could be partially analysed using calculation. For example, consider a case where the HVAC system of an office building is designed to handle outside temperatures of up to 28 degrees Celsius. If the outside temperature rises above this, the inside temperature of the building will fall outside the thermal comfort envelope of its occupants, causing productivity loss to occur (Tham and Ullah 1993). Based on weather statistics and the specifications of the HVAC, designers could determine the mean number of work hours per year where work conditions will be outside of the thermal comfort envelop. Then, with this as a basis, calculate the number of man-hours of productivity impaired or lost each year.

However, such a calculation cannot adequately consider mitigation efforts undertaken by the inhabitants, such as opening doors and windows, and the secondary effects these have on the production activities, like noise. The interdependencies in production systems entails that simulation is required to fully determine how well an activity can be done in a building.

Aggregate performance indicators

At the aggregate level, there are several indicators that could be relevant. The nature of the production system will dictate which indicators are more interesting. Some systems are very flow oriented, and some are more resource oriented. For example, airport terminals are focused on the flow of passengers to and from entrances and gates while office buildings are focused on the production of the people resources working in the building.

In production systems where there is a clear linear flow, such as assembly plants, the parameters that make up Little’s law are of interest. Little’s states that Cycle Time = Work in Progress / Throughput (Hopp and Spearman 2011). For systems with low variability, these parameters could conceivably be determined by employing analytical approaches. However, we would argue most scenarios are more complex and require simulation.

Productions systems that are not flow oriented will typically be knowledge work based and be oriented around immaterial products. For example, academics producing research or architects producing designs. In these cases, the building does not have to provide for the flow of a physical object. Thus, while we could potentially model and simulate the process of the creation of an academic paper, this would be a prime example of taking modelling too far in relation to the questions we want to have answered. Doing high concentration knowledge work is dependent on favourable environmental conditions, such as proper lighting and little ambient noise. So here, a suitable metric would be some measurment of*activity quality*, based on a performance formula with the environmental conditions, at the time of doing the activity,as input variabels.

Whether we are dealing with flow or resource dominant system, having metrics for resource usage is of interest. The most relevant metrics here are the percentage of time spent doing value adding activities and non-value adding activities (waste), and a further drill-down of these categories. The latter is essential to be able to identify inefficiencies in how the building supports the production system. For example, if we see that some resource spends a disproportionate amount of time on transportation, this could mean that the layout of the building is suboptimal. However, it is also important to be aware that in some cases a resource will have a low utilization rate by design to act as a buffer for variability in the system. It is therefore crucial, for example, to be able to distinguish between waiting that is required by an activity or activity sequence or waiting in line for an elevator.

Going back to the situation of the knowledge worker, just tracking the participation of resources in value and non-value adding activities is insufficient in this case. In some scenarios, value-adding could take place in a suboptimal way. Environmental conditions, such as thermal comfort and noise level, being sub-optimal will slow down the work, thus becoming *less* value-adding, however *not* non-value adding. Thus, a productivity index would be a relevant metric for these kinds of resources. The data for which could easily be gathered if some measurement of activity quality, as described above, is undertaken.

CONCLUSION

We have argued that evaluating the benefits of a building at design time should entail an analysis of their ability to support the production system that it will house. To do so there are two fundamental questions that we must be able to answer: Can the activities of the production system be performed? And how well can they be performed?

Answering these questions will require some Building Activity Model (BAM) describing said production systems and its activities. Furthermore, we conclude that while the simpler evaluation methods of verification and calculation can partially answer the questions, to fully determine to which extent a proposed design will support a given BAM, computer simulation will be required.

While previous authors have argued some of the ideas presented in this paper in general terms, we are not aware of anyone who has put them into the same kind of fundamental production theoretical context as we have provided here. We would argue doing so is a prerequisite to properly developing simulation models and other tools.

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