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Estimating occupancy- and space utilization rates in non-residential buildings using planned-activity data

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Abstract

Occupancy- and space utilization rates in non-residential buildings are often used as a metric for building efficiency. However, these rates are typically measured only for buildings already in use, at a stage where optimizing the size or layout of a building to improve efficiency becomes increasingly challenging and expensive.

The aim of this exploratory study is to describe a method for estimating the occupancy- and space utilization rates in non-residential buildings using planned-activity -based data. Such a method enables the client to obtain estimates of the occupancy- and space utilization rates already during the design phase of a building, when size- and layout -related changes are more easily and affordably executable. The method is best applicable to buildings with a high degree of usage predictability, such as educational establishments.

The research design of the study is based on a descriptive embedded single case study. In effect, the activity-based occupancy- and utilization rate estimation method is applied in the context of evaluating a building layout during the design phase of a school building project in Southern Finland. The main finding of the study is that an ex-ante estimation of occupancy and space utilization rates facilitates in optimizing the building layout during the design phase to improve its efficiency during the usage phase. Moreover, the results suggest that the developed method helps clients to improve project scope management and building value in use.

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Keywords: building efficiency; building value; occupancy rate; project scope management; space utilization rate

1. Introduction

Two of the key metrics in measuring the efficiency of a non-residential building are its occupancy- and space utilization (O&SU) -rates. Occupancy rates measure the ratio between the total time of a space being in use, and its total availability, while space utilization rates refer to the average capacity use of a space, while occupied. Both of these rates have an impact on several stakeholders of the building: O&SU -rates above optimal levels can lead to dissatisfaction of tenants as well as increased maintenance costs for the building owner On the other hand, if O&SU -rates fall below their target levels, the return on investment for the owner can fall short of expectations. It should thus be of mutual interest for all stakeholder groups of, that the occupancy and space utilization rates of commercial buildings are given appropriate emphasis already during the design phase of a building.

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However, in practice, it is usually only after the completion of a building that O&SU -rates are evaluated. While the scope of a building project, along with its layout are naturally designed with the intention of ensuring optimal O&SU -rates, no actual estimates are usually calculated ex-ante. In effect, it is exceptional that building investment feasibility studies and project briefs contain quantitative analysis or measurable targets for building efficiency [1]. Based on the authors' experience, this can lead to unrealistic expectations of building efficiency, as well as bottleneck spaces, and imbalanced occupancy rates between spaces of a building. In the case of a school building, neglecting ex ante O&SU -rate estimation while designing the layout can lead to the following issues among others:

- The number of teaching areas needed is calculated directly based on the number of student groups, leading to vacant classrooms, low occupancy-rates and poor building value
- Extracurricular, and possible after-school rental usage of spaces is overestimated, lowering both the occupancy as well as the space utilization rates and decreasing the net present value of the building
- The special spatial needs of external users of the building are not taken into consideration

The aim of this paper is to describe a procedure that allows for an ex-ante estimation of the O&SU-rates of a building, by a method of using planned activity -data. We describe applying this method to a real case, a school building project in the city of Järvenpää, Finland, with a population of nearly 40 000 inhabitants. The case was selected because it aims to create a new school building project model for the public sector. In fact, the project is a national benchmark project for new practices in school building construction.

The empirical contribution of the paper is in the application of activity-based O&SU -rate estimation method in the context of evaluating a building layout during the design phase of a school building. By describing a new method for activity-based O&SU -rate estimation, this study increases understanding of how the occupancy- and space utilization rates can be estimated and utilized in non-residential buildings using planned-activity -based data.
The remainder of this paper is structured as follows. After a brief clarification of the terminology, we will review earlier academic literature on the subject. Next, we present and discuss the benefits of the planned activity -based method, followed by an introduction to the case project, a school building in Järvenpää, Finland. We describe the implementation of the planned activity -based method in our case example in detail. Finally, the results and findings from the implementation are then presented and summarized, along with their implications to the stakeholders of the case project.

2. Defining occupancy and space utilization -rates

The terms "occupancy" and "space utilization" in the context of non-residential real estate are widely used in both academic literature, as well as within practitioners within the industry. However, their definitions seem to vary depending on the context, and the terms are in effect mostly used in commercial settings. For example, Statistics Finland (Tilastokeskus) defines occupancy rates for hotels as the number of rooms used in a given month, by the number of rooms available for the month [2]. Terms are less frequently applied in the context of schools, workplaces, and other similar settings. Thus, in order to provide some clarity, we define the terms "occupancy rate" and "space utilization -rate" as follows:

- The occupancy rate of a space as the ratio of the time in use, divided by the total availability time
- The space utilization -rate as the average percentage of capacity used when the room is occupied.

To illustrate, if a space with a capacity of 20 people and daily availability of 8 hours were in use for 4 hours per day by a group of 15 people, the occupancy rate of this space would be 50%, with a space utilization rate of 75%.

3. Literature Review

Given the importance of the subject, we find it interesting to note that O&SU -rate estimation methods during the design phase of a building have not received much attention in academic literature. This lack of attention can likely be attributed to the fact that the usage patterns of many non-residential buildings are difficult, if not impossible predict at a sufficiently precise level at an early phase, making ex ante O&SU-rate estimation obsolete. However, there are many cases where the amount and type of activities can be forecasted with a high level of certainty. A notable example of such a case are educational establishments.

In Finland, determining the required scope and layout of an educational building has typically been calculated using a direct driver-based approach, using area-ratios related to the desired student capacity [3,4,5]. However, the planned activity -based approach in the context of designing a building layout is also well documented, and presented thoroughly by Pennanen [6]. Pennanen presents an example case of designing a layout for a school building by taking advantage of the high degree of predictability of activities within educational establishments. Pennanen provides an extensive discussion on the benefits of applying an activity-based method to designing school buildings, such as its ability to adapt to special spatial needs of the establishment. Unsurprisingly, our findings on the benefits of applying activity-based methods in evaluating a school building layout share similar characteristics.

While numerous papers about building occupancy and its prediction methods have been presented in academic literature, most of these papers focus on predicting occupancy rates of existing buildings, using sensory data and advanced methods such as machine learning techniques [7,8]. One typical use case of such predictions is the optimization of the HVAC-system of a building, leading to reduced energy costs [9,10]. Per the knowledge of the authors, no prior research has been conducted on applying an activity -based approach to building layout evaluation through O&SU -rate estimation.

4. Methods for O&SU-rate estimation

4.1. Activity- vs. Driver-based methods

As opposed to using conventional, driver-based methods, the method presented in this paper can be classified as activity-based. The main difference between activity- and driver-based methods is that the former links the the underlying drivers of a process to the available resources by first converting the drivers to a list of activities, and ultimately allocating activities to available resources. The latter, on the other hand, links drivers directly to the available resources through multipliers. Figure 1 illustrates the differences between the two methods.

As already mentioned, in general terms, driver-based methods link the underlying drivers directly to available resources. In our example case of designing and evaluating the layout of a school building, a driver-based approach would entail linking the number of students in a school directly to available classrooms. Evaluating the layout through a driver-based O&SU-rate estimation procedure would entail calculating the ratio between available resources (i.e. number of distinct space types) and the driver (number of students), and comparing the result to a benchmark.

While this driver-based approach is simple to use, and typically used in designing layouts of school buildings, it is rather cumbersome when working in the opposite direction, and evaluating the efficiency of the proposed layout. Firstly, the obtained result ratios are rather uninformative by themselves, since they must first be compared with benchmark ratios from previous projects. Secondly, information on the goodness of the benchmark ratios (i.e. the corresponding O&SU-rates) might not be easily available, and their validity and reliability is difficult to assess. Thirdly, the driver-based approach cannot easily take into account special requirements, such as the above average need for certain types of teaching facilities in a school with an unusual or emphasized curriculum.

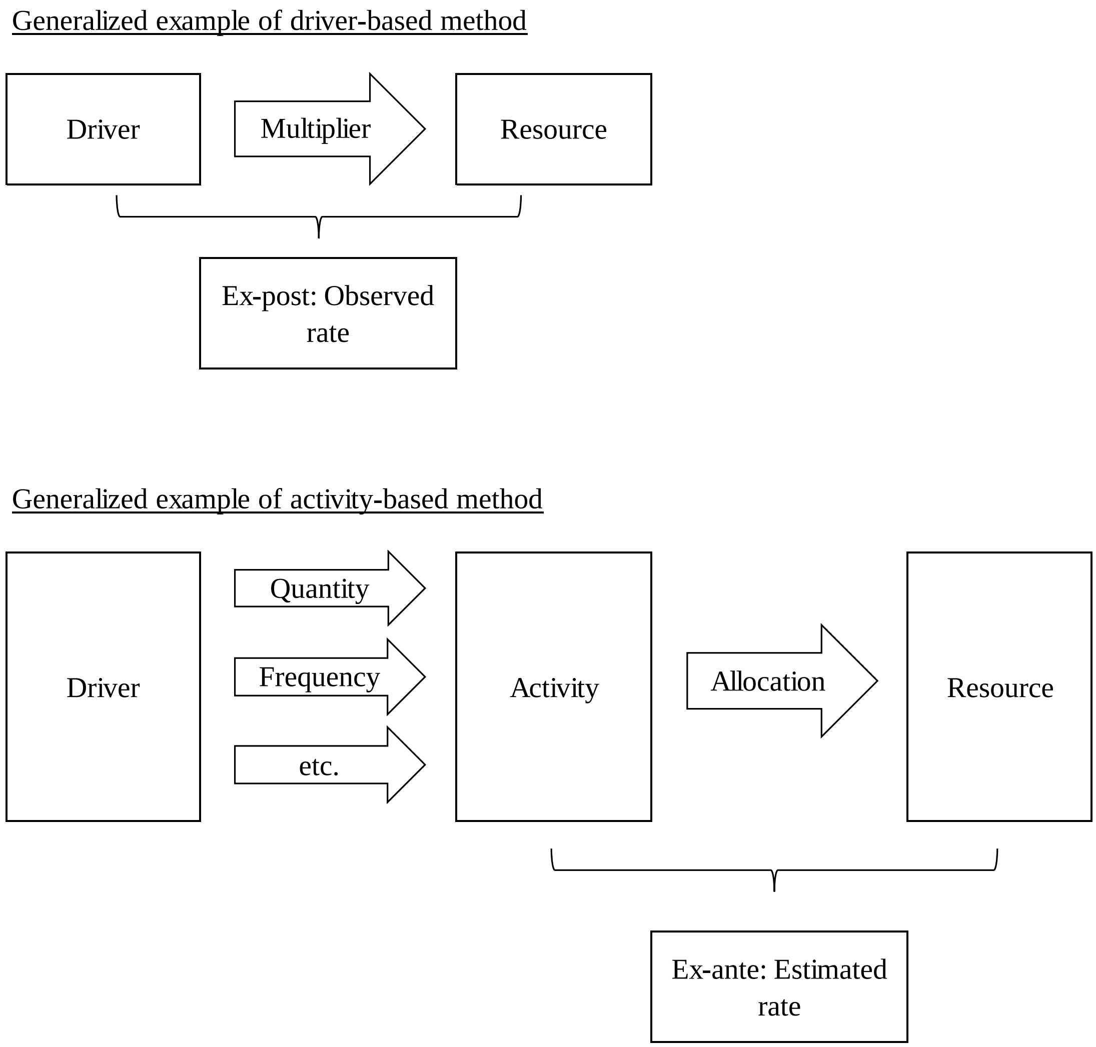

Fig. 1. Generalized examples of driver- and activity-based methods.

In pratice, the activity-based O&SU-rate estimation procedure for our case school building consist of 5 phases: *1. Gathering building-layout data, 2. Gathering planned-activity data for teaching hours, 3. Gathering planned-activity data for non-teaching hours, 4. Allocating activities to spaces, and 5. Iteratively improving on the building layout based on findings.* These steps are further elaborated in section 6 of this paper.

4.2. Drawbacks and benefits of activity-based methods

By using activity-based methods, we can alleviate the aforementioned issues related to using driver-based methods. However, the downside to using activity-based methods is the imminent increase in complexity. As described above, activity-based methods require an additional intermediate step: we must first convert the underlying drivers to a list of corresponding activities. In our school building example, we should first convert the number of students into the required number of teaching hours. The conversion is affected not only by the number of students, but also other factors such as the maximum class size and curriculum hours for each subject. For example the number of activity hours would be different for two schools with the same amount of students, but different maximum class sizes for physics teaching, or unequal curriculum hours of art teaching. The generalized example of an activity-based method is extended to our case school building in Fig. 2.

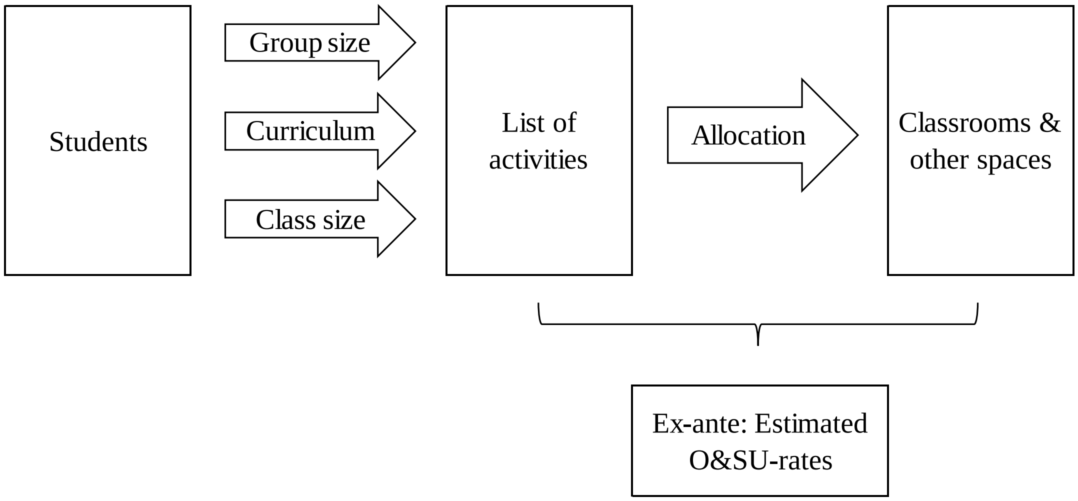

Fig. 2. Example of activity-based method for a school building

Even though the conversion from drivers to activities requires additional work, the benefits of using the activity-based approach are clear. Firstly, this approach allows us to get direct estimates of O&SU-rates, without the need to compare the obtained estimates to benchmarks from previous projects. Additionally, the activity-based approach allows us to easily take into consideration any potential idiosyncratic characteristics of the school, such as an unusually high emphasis on a particular subject.

Furthermore, another benefit of using an activity-based approach relates to the building adaptability and service flexibility of the building. When designing the layout of a building, we should keep in mind not only the currently planned activities of the building, but also how the layout would respond to changes in the activities. By using an activity-based approach, we can estimate both spatial requirements, as well as occupancy rates for different scenarios, which can be used in the flexibility analysis of a building layout. The ability to test alternative activity scenarios is also vital in planning layout-related changes during the renovation of an existing building.

Finally, arguably one of the biggest strengths of using activity-based methods is the fact that the approach can be applied in two distinctive contexts. Firstly, as described by Pennanen [5], activity-based thinking is a novel approach to workspace planning, or in broader terms, the design process of a building layout. Secondly, activity-based thinking can be used to evaluate proposed layouts, regardless of whether they have been designed using an activity-based approach or not. Thus, using activity-based methods allows for an iterative approach to fine-tuning the proposed building layout: the findings from an O&SU-rate estimation procedure can be used as an input in modifying the proposed layout, and the modified layout can then in turn be re-evaluated using the activity-based O&SU-rate estimation, and so on.

In conclusion, the benefits of the activity-based O&SU-rate estimation are not limited to providing estimates of the occupancy rates of a building already before it has been completed or even designed completely, but can also be used as an iterative tool to further improve proposed building layouts.

5. Project introduction

In our case project, we implement the O&SU-rate estimation procedure using planned-activity data for a school building project in the city of Järvenpää, Finland. The building houses both an elementary school, as well as a lower secondary school (grades 0 through 9 combined) with a combined student body of approximately 900 people. The building project’s cost budget is 32 million euros and the construction project is completed by August 2019. Morever, the project has particularly ambitious targets as the school aims to be best learning environment in Finland. The estimation procedure is executed with a computational tool developed specifically for activity-based O&SU-rate

estimation, built by the main author of this paper Matti Karjalainen of Boost Brothers Ltd, the company responsible for construction management in the project. While the use of the tool facilitates the O&SU-rate estimation process considerably, it is by no means mandatory in performing the analysis. In fact, the calculations needed for the process are extremely simple. It is only because of the large amount of activity data, and the built-in ability to change the underlying assumptions that make the use of special computational aid relevant.

The end result of the procedure are individual occupancy and space utilization -rates for the spaces in the school building. We only include spaces constituting the Usable Floor Area (UFA) in the analysis, and thus do not estimate the O&SU-rates of mechanical equipment rooms, staircases etc.

6. Occupancy & space utilization -rate estimation procedure

In this section, we describe implementing the planned-activity based approach to evaluating the layout through O&SU-rate estimation in our case project. The approach consists of five phases, which are elaborated in the following paragraphs. Fig. 3 illustrates the activity-based process extended to the estimation procedure.

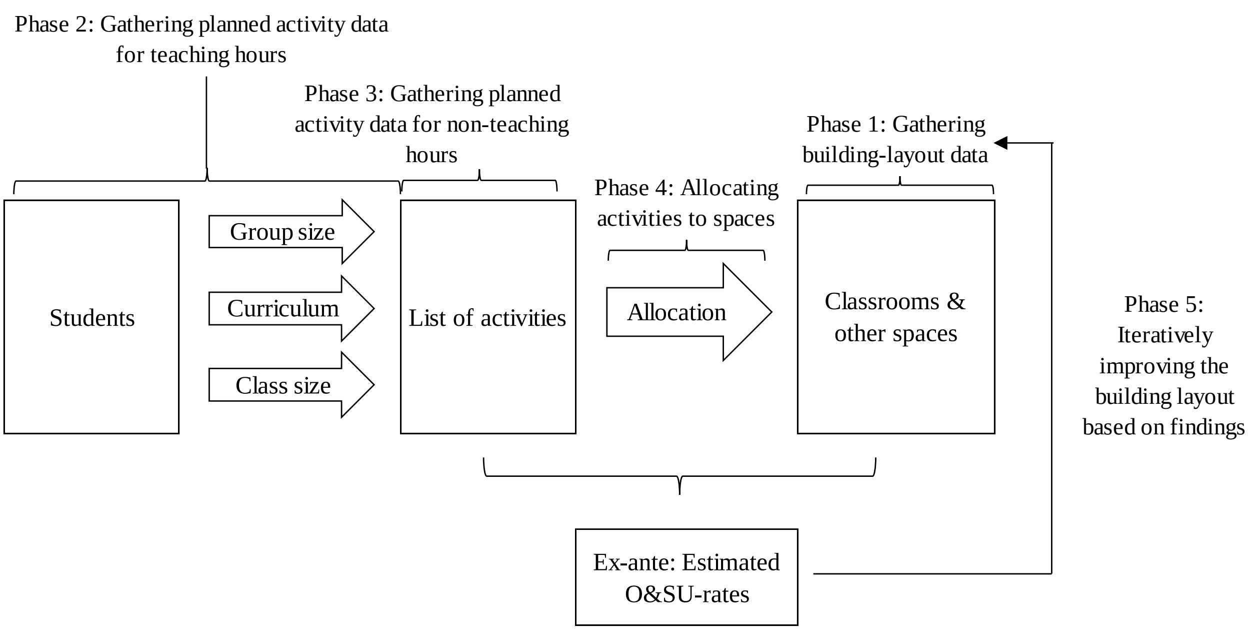

Fig. 3. O&SU-rate estimation procedure

6.1. Gathering building-layout data

We begin by transforming the proposed building layout into a listing of the different types of spaces, along with their areas, student capacity and number of instances. For each type of space, we also define availability during different time periods. Most likely, the typical daily maximum availability for most types of spaces in a school building lies between 10 and 18 hours, but taking a 24-hour availability approach is also possible, and in some cases desired. Moreover, it should be taken into consideration that the availability for different spaces is likely to vary not only between different weekdays, but also between seasons. This issue can be most conveniently tackled by making separate occupancy rate estimations for different seasons, as was done in our example case.

In addition to availability, maximum and target rates of occupancy should be defined. According to Pennanen [5], the degree of predictability of the planned activities in the space should influence our setting of target rates. For instance, occupancy rates of over 50% tend to cause collisions when activities are unpredictable, whereas spaces with more scheduled and predictable activities allow for greater occupancy rates. Previous experience has shown that when the occupancy rate exceeds 80% in schools (activities with mostly high degrees of predictability), a shortage of space tends to occur. The target occupancy rate should thus not be set at 100%, even when the degree of predictability is high. However, we must be careful when setting our target occupancy rates for school buildings with a high number of younger students, as the scheduling of activities is not only bounded by spatial restrictions, but also the schedule-related restrictions of younger students. Thus, we set out initial target occupancy rate rather conservatively at 70%.

6.2. Gathering planned activity data for teaching hours

The second part of the estimation procedure entails composing a list of the activities that are planned to take place in the school building. We begin composing the list by turning to the curriculum. In Finland, the curriculum for elementary and lower secondary school students is very standardized, and well documented. We can thus construct an exhaustive list of planned teaching activities, simply by defining the amount of class-groups in each grade, general class size, as well as teaching class size for each subject. For each subject and each grade, we simply multiply the weekly teaching hours of the subject in the curriculum by the general class size and the number of class-groups for the grade, and then divide this number by the teaching class size for each subject. This gives us the total planned activity hours for the subject for each grade. When repeating this procedure for all classes and all subjects, we get an exhaustive list of the planned teaching activities in the school building.

Then, we add further extracurricular activities such as individual and group studying hours, lunch-time eating, cleaning etc. Determining the amount of such activities requires more judgement, but can be rather easily estimated by generalizing the average amount of daily time spent on each activity at each grade, and using the described multiplication-division procedure. Finally, we estimate the amount of non-teaching activities of the staff (such as grading, breakroom activity, meetings etc.) which can be obtained through interviews with the school staff, if direct data on these activities is not available.

6.3. Gathering planned activity data for non-teaching hours

One should note, that the activities described above only account for the teaching hours of the building. To estimate the total O&SU-rates of the building, we should also consider activities outside of the teaching hours. In Finland, school buildings generally stay open past the teaching hours, to be used by external users such as local sports clubs, orchestras, meetings etc. In our case example, we constructed a list of such activities mostly by interviewing local clubs, and relying on information from similar school buildings in the region. A key finding from constructing such a list (beyond using it to generate O&SU-rate estimates outside of the teaching hours) is that it seems facilitate in communicating to the stakeholder groups of the building, if expectations for O&SU-rates outside of the teaching hours seem to be set at unrealistic levels. While the list of activities is prone to be heavily assumption-dependent, we found that it serves as an efficient way of communicating the mismatch between activity demand, and initial expectations of efficiency.

6.4. Allocating activities to spaces

The next step in our O&SU-rate estimation procedure is to allocate each activity to a corresponding space. We must point out, that many activities should be fully allocated to multiple spaces (such as physical education in both the gym, as well as the locker rooms), even though the students will only be physically present in one space at a time. By allocating activities with given durations, we arrive at an occupancy rate estimate for each space. Simultaneously, since each activity has a user amount, these add up to form an estimate of the space utilization rate.

In our case example, simply the teaching activities consist of 271 distinct activities, allocated initially into 46 distinct spaces. For the initial layout proposal, we arrived at an estimated average occupancy rate of approximately 63% during teaching hours, with a space utilization rate of 93%.

Following that, the results of O&SU-rate estimation procedure were carefully reviewed and evaluated by the building project's client and user organizations. In addition, the client and user organizations utilized the results both in investment and project management decision-making.

6.5. Iteratively improving the building layout based on findings

Finally, we take advantage of an activity based approach through iterative improvement of the layout. Based on the findings of our initial O&SU-rate estimation, the proposed layout seemed to be slightly inefficient, falling short of our target occupancy rate of 70%. After a round of iteration, a revised layout proposal was once again evaluated using the described O&SU-rate estimation procedure. This time, the estimated average occupancy rate was 69%, close to our target rate of 70%, with a marginally reduced space utilization rate of 92%. Additionally, at this point, the non-teaching hour occupancy rate was estimated to be approximately 29%.

7. Summary of results and findings from case example

This exploratory study was set to describe a method for estimating the occupancy- and space utilization rates in non-residential buildings using planned-activity -based data. After covering previous studies on O&SU rates, the quantitative procedure for estimating O&SU rates was described in real life case study. The case study was a school building project in Southern Finland aimed for 900 students with a budget of 32 million euros.

The planned-activity based approach to evaluating a school building layout through O&SU-rate estimation consists of five phases: *1. Gathering building-layout data, 2. Gathering planned-activity data for teaching hours, 3. Gathering planned-activity data for non-teaching hours, 4. Allocating activities to spaces, and 5. Iteratively improving on the building layout based on findings.*

As described above, performing an identical O&SU-rate estimation procedure for the initial layout, as well as the second iteration allowed us to not only compare the efficiency of the layouts, but also get a tangible, numerical estimate of the magnitude of the changes to the occupancy and space utilization rates. Moreover, this enabled to improve building layout design and decision-making process in the project. Obtaining such estimates using a direct driver-based approach would have been extremely difficult, if not impossible.

Based on the observations from the case study we find that the ability to obtain estimates of O&SU-rates during the design process of a building seems to provide value to multiple stakeholder groups. Firstly, for tenants, the risk of a building with problematically high occupancy and space utilization rates is alleviated, improving tenant satisfaction. For building operators, an estimate of O&SU-rates helps in optimizing the maintenance schedules and budgets, as well as the HVAC-systems of the building. For building owners, the O&SU-rate estimates help with managing the project scope, and setting realistic expectations for possible rental income cash flows.

Moreover, in our case example, introducing the O&SU-rate estimation procedure during the design process received positive feedback from the client. While the procedure provides only tentative estimates of O&SU-rates, the clients's management felt that it serves as a handy tool when evaluating the scope of the project. However, as the concept of using planned-activity data in O&SU-rate estimation is new and not widely in use, we observed that it is extremely important to thoroughly introduce the methodology behind the obtained estimates when communicating them to the client and other relevant stakeholders. Once the client and other stakeholders fully understand the methodology of the procedure, an objective re-evaluation of the building layout and scope in collaboration between the stakeholder groups becomes possible.

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