Flexibility as Enabler of Sustainability

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# ABSTRACT

**Purpose:** There are changing expectations for sustainability coupled with demands for efficiency in planning, constructing and maintaining the built environment. We study modularization as a potential response to these changes.

**Background:** Adaption of sustainability principles is shaping construction, project and facility management. Balancing the social, economical and ecological dimension and handling the long versus short term perspectives is at the core of sustainability.

**Approach:** A literature review in the disciplines of project management, facility management and construction management provide an analysis of flexibility as enabler of sustainability. The building concept of “Super Cubes” is presented as an illustration of how modularization can provide flexibility and be an enabler of sustainability.

**Results:** Long-term thinking does not translate into “planning for everything”, but rather into realizing the need for incorporating flexibility in buildings. Initial experiences with the Super Cube for school buildings are mixed. Only a few Super Cubes are constructed . Benefits of modularization have only partially been realized. Its use has been limited, as construction costs and energy use have been higher than expected. Parents have strongly opposed its use, claiming that the cube is not a “proper” building.

**Practical Implications:** Construction costs of the modules have been high, partly due to the demands for flexibility. Economies of scale are not achieved. The problems with parents strongly opposing its use illustrates increased need for early involvement of stakeholders.

## Keywords

Flexibility, Sustainability, Modularization, Off-site construction.

# 1 INTRODUCTION

Balancing factors within the social, economical and ecological dimensions and properly handling trade-offs in time (the long and short term) and space (local, regional and global effects) is at the core of sustainability thinking. Buildings are constructed with expected lifespan of forty years or more. Their physical life spans can be almost indefinite when carefully designed, constructed and maintained (Ashworth 1997). This makes it likely that they will be used in ways other than what was foreseen during construction. Long-term thinking hence does not translate into “planning for everything”, but rather into the need for incorporating flexibility in buildings. The need for flexibility revolves around at least three types of current and future stakeholders in the building: the users of the building, the owners and society. Users typically focus on how the building supports their activities in the building. Owners focus on return on investment and life cycle cost of the building, and how the building support strategic objectives. The larger society has interest in how a building supports a sustainable and attractive environment and how the building interacts with other parts of the built environment.

Different disciplines have developed their distinct approaches to sustainability. We have reviewed literature from the disciplines of project-, facilities- and construction management to identify cross-cutting themes in the scientific literature related to sustainability. The interest for different aspects of flexibility as an enabler for sustainability is one such theme. Several authors have illustrated the connection between sustainability and adaptable buildings (e.g. Arge (2005); Bullen (2007); Kincaid (2000); Wilkinson, James et al. (2009)). Adaptability is a key design criterion applied on buildings were there is expected to be changing needs (Hansen and Olsson, 2011). Adaptability of buildings can be achieved through three approaches according to Bjørberg, Verweij et al. (2009); elasticity, generality and flexibility. In this terminology, flexibility is a sub-issue of adaptability, focusing on how easy it is to change the building by rebuilding it.

We present Oslo’s “Super Cube”, a modular building concept specially developed for the Norwegian capital’s schools, as an example of buildings were movability has been introduced at the potential cost of “ordinary” adaptability. The modules are factory made and can significantly reduce construction time as groundwork and module construction can be carried out in parallel. The cubes are flexible with regards to the initial configuration of modules and they can be demounted and moved if needed. The modules thereby provide a dimension of flexibility to their owner’s portfolio of buildings, but leave little room for changing user needs.

# 2 STATE OF THE ART

The following section is based on a literature review of the approach to sustainability in the three disciplines of project management, facility management and construction management. It will provide the foundation for an analysis of flexibility (and in particular, modularization) as enabler of sustainability. The following journals were subject to the literature study: *Facilities, International Journal of Project Management (IJPM)* and *Construction Management & Economics (CME)*. The searches were conducted using the terms “sustainable” and “sustainability” in article titles, keywords and abstracts. Articles that used the words sustainable or sustainability in other context than that of “*sustainable development*” were removed from the sample. An overview of the sample is shown in Table 1.

The adaption of sustainability-principles from sustainable development is shaping the development and innovation in construction, project and facility management. The most quoted definition of sustainable development is “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs”* as presented by the UN commission on Environment and Development (1987). Their report was pivotal in introducing the multi-dimensional approach to development; only when factors and effects within the environmental, economic and social dimension were accounted for would development turn “sustainable” in the long term.

Table 1: Overview of journals for the literature review

|  |  |  |  |
| --- | --- | --- | --- |
| **Journal** | **Keyword hits in search** | **Articles removed based on abstracts** | **Final sample of articles** |
| Facilities | 12 | 2 | 10 |
| International Journal of Project Management (IJPM) | 23 | 8 | 15 |
| Construction Management & Economics (CME) | 20 | 4 | 16 |
| **Total** | **55** | **12** | **43** |

The short form *“sustainability”* is used to describe the endurance of systems and processes. The term may be used with a set of criteria to describe the result of a short-term decision (providing *a sustainable outcome as the solution to a limited problem*) or as the result of a long-term development (*providing sustainable solutions to a wide set of issues*). It might also be used as a *characteristic* of a development and a *quality* of a process. “Sustainable development” and “sustainability” are vague terms by intention; their position at the top of the global agenda requires them to be. The UN’s work on developing “Sustainable Development Goals” incorporate 17 goals and 169 related targets (UN 2016). The ambiguity has a price in the form of confused stakeholders, effectively diluting actions taken to incorporate sustainability principles in practice. Different disciplines’ interpretations of “sustainability” vary with traditions and with regards to *what* it is that is to be sustained. Kidd (1992) presented six traditions or roots from witch the interpretations of sustainability trace their origin; *ecological carrying capacity, resource depletion, biosphere, critique of technology, slow/no-growth and eco-development.*

**2.1 Sustainability in construction**

The construction sector has long been identified as a culprit with regards to sustainability, and especially environmental impacts. It uses three million tons of raw material and generate 20 % of the solid waste stream (Graham 2000). The construction industry is an important sector with regards to the economic and social dimension, contributing 10 % of EU GDP along with 20 million direct jobs (EU 2015). In response to increased attention and changing expectations from customers and mounting pressure from regulators, “sustainable construction” evolved. 11 out of the 16 CME-articles in the sample represent or refer to “sustainable construction” (Hill and Bowen 1997, Bossink 2012, Mokhlesian and Holmén 2012). “Sustainable construction” encompasses design and planning phases of projects, as well as the phases following the construction (Hill & Bowen, 1996). The majority of the articles in the sample that deals with the subject, adapt a primary focus on resource use and emissions during the construction phase. In the long term, environmental impacts in the form of emissions during construction, creation of materials and demolition are small compared to energy consumption in buildings operational phases. Buildings are responsible for 30 % of climate gas emission and 40 % of energy consumption (UNEP 2009). However, operating energy represents by far the largest part of energy demand in a building during its life cycle (Sartori and Hestnes 2007). Ross, Bowen et al. (2010), Shi, Zuo et al. (2012) and Chen and Chambers (1999) show how certain aspects of sustainability (such as water usage) can be of special importance due to the projects locations. Industrialized construction (Eriksson, Olander et al. 2014) and the use of prefabrication and modularization (Jaillon and Poon 2008, Jaillon and Chi-Sun 2010) are proposed as approaches to sustainable construction.

**2.2 Sustainability in project and facilities management**

Sustainability is a fairly new topic in project management literature, with the majority of publications dating from the last ten years (Silvius and Schipper 2014). There is ongoing debate about the extent of which “traditional” project management tools and methods are sufficient to incorporate sustainable principles, or if a new paradigm must be established within the field (Schipper, Rorije et al. 2010, Eskerod and Huemann 2013). The sample articles from the project management journals cover several types of projects including construction of buildings (Herazo, Lizarralde et al. 2012) and infrastructure (Lenferink, Tillema et al. 2013, Zeng, Ma et al. 2015, Zhang, Gao et al. 2015). There is a special emphasis on sustainability in project appraisal (Abidin and Pasquire 2007, Al‐Saleh and Taleb 2010) and on sustainability competence (Beauséjour 2009, Hwang and Ng 2013).

Facilities management (FM) is an interdisciplinary approach integrating principles of business administration, architecture and the behavioral and engineering sciences (Cotts et al. 1992, Cotts 1999, IFMA 1998). Alexander (1992) created an early structure for the FM work field. He identified processes, services, facilities and objectives as important categories with regard to the organizations’ primary activities and encircled FM from other disciplines. Jensen, Voordt et al. (2014) and Jensen, Andersen et al. (2014) identify sustainability as important elements in future development and research within FM. Several authors state that FM is a discipline in transition and that FM departments and personnel are well-suited to promote sustainability initiatives (Price, Pitt et al. 2011, Sarpin, Yang et al. 2016). Development towards “Sustainable FM” is driven by enterprises adapting strategies for sustainability in their mission statements as well as new legislation (Elmualim, Shockley et al. 2010). Price, Pitt et al. (2011) found that medium and large enterprises were more likely to have adapted sustainability policies. Their study also identified that having a sustainability policy in place increased the likelihood of sustainability initiatives being embedded in the company. Although the social dimension of sustainability is at the core of FM, environmental sustainability receives special attention in the sample articles. Energy efficiency is identified as a key component in contributing to environmental sustainability in Adewunmi, Omirin et al. (2012), Aaltonen, Määttänen et al. (2013), Junghans (2013). Langston (2012) approaches sustainability through the adaptive reuse of buildings.

**2.3 Sustainability and uncertainty**

Uncertainty limits the ability of the organization to preplan or make decisions about activities in advance of their execution (Galbraith 1977). Uncertainty is a key driver for project *flexibility* (Olsson 2006). Pinder, Austin et al. (2011) in Finch (2011) state that rising expectations can serve to reduce a buildings service life even though the building remains in good condition. A building’s *service life* extends as long as it functions above a minimum acceptable level of performance (Iselin and Lemer 1993). Pinder, Austin et al. (2011) point to three interrelated factors that explain why buildings can be subject to obsolescence; buildings tend to be fixed, designed to be durable and with a particular use in mind.

**2.4 Modularity**

Modularity is a concept within both construction and project management, as an enabler of flexibility. By applying modularization, a project can be split in several sub-projects with the freedom to explore and apply particular solution suited their needs. In construction, modularity is an approach where components of the building are preassembled in modules at a factory before being transported to the construction site for installation. It is often associated with concepts such as prefabrication, pre-assembly and off-site fabrication. Modularization allows for parallelization of tasks in construction projects, as groundwork and module construction can be executed at the same time. Modularization also provides for potential cost savings due to specialization in tasks, application of manufacturing approaches in production and increased ability for learning. Blismas, Pasquire et al. (2006) point out that evaluations of off-site construction versus on-site tend to have a narrow focus on cost, ignoring both “hidden costs” and benefits. Modularization provides potential for reducing common sources of construction waste. Faniran and Caban (1998) point to reductions in waste due to design changes, leftover material scraps, wastes from packaging and non-reclaimable consumables, design/detailing errors, and waste due to poor weather. Modularization can also facilitate planning and design, saving both time and resources. Modularization generally provides reduced internal uncertainty. Modularization can also reduce external uncertainty as shortened lead times means decisions in planning and design can be made closer to the point in time when the building will be in use. The effects of using modular construction are summarized in Table 2.

Table 2: Effects over the project life-cycle of module-based construction

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Front-end** | **Planning** | **Execution** | **Operations** | **End-of-life** |
| Project management | Reliability in estimates (cost & time) | Reductions in planning time | Reductions in construction time, reliability, less re-work | Fewer “start up” issues, known maintenance/operations needs and costs | Reliability; modules are well-known |
| Sustainability | Known resource use |  | Predictability, shortened construction time | Opportunity for modules to be “optimized” for their operative phase | Facilitates design for end-of-life/cradle to cradle |
| Uncertainty | Reduced uncertainty due to reduced lead-time | Reduced internal uncertainty | Experience in constructing and operating modules lead to predictability | Reduced uncertainty due to experience from use of modules in similar settings | Reduced uncertainty due to reduced “uniqueness” in product |
| Facilities management | Client, owner and user needs | Efficient implementation of needs in the design | Ensuring that design intentions are fulfilled | Efficient management of the building, user satisfaction, return of investment for owner | Experience feed-back to future projects |

# 3 Illustrative case: Oslo’s Super CUbes

The Super Cube was conceived by Oslo Municipality in 2010-2011. It would serve as an alternative to traditional custom-built school buildings. The City Council had signaled that *cost efficiency* on the municipal level were to be the decisive factor in constructing the school portfolio. Standardization was to be key in the construction and rehabilitation of schools. Guidelines were developed for all types of buildings in the municipality’s portfolio from kindergartens to retirement homes. The rationale behind the drive for standardization was potential cost-savings (due to economies of scale) and predictability in operations and maintenance, uniform and plain demands to suppliers and contractors, increased ability to transfer experiences and a drive for sustainable, environmentally friendly buildings.

Illustration 1: Interior and exterior of Super Cube at Skøyen (photo: Undervisningsbygg)



The drive for standardization has so far not resulted in two identical schools ever being constructed. The Super Cube was supposed to be both cost-effective and efficient in planning and construction. The concept consists of factory-built units of 3x3m, 3x6m or 3x9m. The Super Cube fulfills the demands for permanent school buildings, even though it is developed to provide temporary capacity when needed. The units are between 85 % and 90 % finished when leaving the factory, yet leave sufficient room for both external and internal customization to not render a “temporary” feel. Each unit consists of a steel frame, enabling stacking height of 4 units. Technical installations are put above the ceiling, providing simple access. Factory building would ensure predictability (no moisture in the construction), economies of scale and learning effects would provide the grounds for additional reductions in cost and failures/mistakes. The units can be produced in the factory simultaneously as the groundwork was executed on site. Each Super Cube project incorporates a contractor for the groundwork (preparing play areas and landscaping), adding some complexity to each project. However, compared to custom building, each Super Cube project is less complex. Using the Super Cube has reduced the time spent in the planning process. Super Cubes are regarded as “pre-approved” as long as the project is included in the “school capacity evaluation”, a 10-year plan for development of school capacity revolving on a 5-year basis.

**3.1 Flexibility aspects of Super Cube compared to traditional school buildings**

The time savings in using the Super Cube are mainly due to parallelization of groundwork and module-production. The Super Cube has thus made the agency more responsive to events and reduced the uncertainty related to certain decisions. The introduction of the Super Cube has also reduced lead times for adding capacity to existing schools due to “fast tracking” in the Municipality’s project quality assurance scheme. Time-savings made possible by these two traits of the Super Cube (parallelization and fast-tracking through planning and approval) have had an unforeseen effect in the form of unhappy neighbors and school-parents. Both school-parents and neighbors are key stakeholders in school construction or extension projects. The reductions in lead-time create a sense of urgency and a risk of stakeholders feeling “not heard or listened to”. In custom-built school-projects, there might be sufficient room to adapt plans and designs to stakeholders’ input even after the early phases of groundwork and construction has started (even though this is rarely ideal for progress). Stakeholders’ concerns resulted in delays in the construction of the two first Super Cubes, and stakeholders making sure they were heard through the media. Although the Super Cube reduces the lead-time for project delivery, there is still significant rigidity in the decision process leading up to the decision, and external factors that influence the lead-time after the decision point (such as the module-supplier’s production capacity).

The flexibility in the Super Cubes has not been fully exploited at the current point in time, as there has not been need for adding (or removing) additional capacity at the schools equipped with Super Cubes. It is not expected, however, that capacity needs change so quickly. The movability of the modules are incorporated as a response to uncertainty in demand for capacity for the medium-long term and not the short-term fluctuations. The “fluency” of the Super Cubes can be expected to increase over time however, as more schools are equipped with Super Cubes. The flexibility in the Super Cube is primarily in the form of capacity. Once the modules have been installed, there is little (or no) flexibility with regards to adaptability to changing user requirements. The modules are designed to accommodate changes and upgrades to surface materials (due to wear and tear). Functional changes will imply “customization” of the Super Cubes, taking them one step closer to “traditional” custom-built schools.

The development of the Super Cube is still an ongoing process. Many of the benefits of modular construction can only materialize once there has been produced a significant number of modules. Learning effects have been observed in both the fabrication of modules, as well as in installing them. Earning effects are key to limiting re-work and on-site adaptions. Future modules will also benefit from feedback on how the current modules work in practice.

The investment cost (per square meter) for the constructed Super Cubes have been higher than the average investment cost for custom-built schools in Oslo. Two factors driving the cost associated with each module are the movability (for reuse) and ability to stack modules. These properties are essential for the flexibility aspects of the Super Cube, but come at the price of high demands for structural integrity of each module. The operational costs of the Super Cubes have also been higher than expected, and they have been plagued by “start-up”-issues with ventilation and heating systems. The Super Cube concept will be developed and pursued further in the coming years. Several options are being investigated in order to reduce the costs associated with each module. One such option is in reducing the movability and ability to stack modules. These modules will have lesser demands for structural integrity, at the expense of flexibility. Introducing these alternative modules will also potentially reduce some of the economies of scale in producing and handling (or organizing) the modules. Another option currently being investigated is extending the Super Cubes to kindergarten and nursing homes. Adding production volume will make it more attractive for potential suppliers of the modules, along with the potential for further cost-savings due to economies of scale. The modules must most probably be thoroughly re-designed in order to accommodate the requirements for alternative use.

# 5 Practical implications

We have studied how flexibility and module-based construction are a shared approach to sustainability in the disciplines of project, facilities and construction management. Although the rationale for modularization and flexibility is interesting, there exists a trade-of in flexibility as expressed by potential adaption of the building for other uses vis-à-vis movable buildings with “fixed” use. This paper has presented some of the experiences from Oslo’s “Super Cube”, a modular building concept specially developed for the Norwegian capital’s schools. The modules are factory made and can significantly reduce construction time as groundwork and module construction can be carried out in parallel. The cubes are flexible in the sense that modules can be added or demounted and moved if needs change. However, high construction costs have limited the use of the cube, making economies of scale hard to achieve. Alternative means for reducing costs of the modules have therefore been explored. The cube has also run into problems with parents strongly opposing its use under the pretext that the cubes are not “proper” buildings illustrating increased need for early involvement of stakeholder when the lead-times are reduced.

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