E3S Web of Conferences **349**, 04006 (2022) https://doi.org/10.1051/e3sconf/202234904006
LCM 2021

Correlation between modular construction and sustainability in the building life cycle

Peter Schnell[1*]

[1]Institute of Construction Management, University of Stuttgart, Pfaffenwaldring 7, Germany

Abstract. Modular and prefabricated construction is increasingly regarded as a cost-effective and time-saving alternative to traditional construction methods; and is more than just a trend of the last few years. It is often described with the characteristics "fast and cheap" which gives the appearance of standing in great contrast with sustainability. However, modular construction and sustainability are more strongly correlated than one might think. The notion of sustainability in the life cycle of modular construction will be elucidated in this article. First, it is necessary to recognise the fundamental changes and possibilities that arise through modular construction in every phase of the building life cycle. Key differences are both the increased emphasis on early project stages with the need for obligatory statements and changing parameters for maintenance, repair, and renovation work. Likewise, there are differences between the possible types of modularisation, e. g. between MEP racks and ceiling panels. The more extensive and detailed the structure and degree of prefabrication of a module, the higher the potential of sustainable aspects. To evaluate the individual types of modularisation, categories, and subject areas from the certification systems BREEAM, LEED and DGNB were used. The result is presented in a matrix that shows the potential of each modularisation type for the defined subject area of sustainability. Based on this, the matrix has been refined for each party involved in the building life cycle. The result illustrates the existing potential between modular construction and the various aspects of sustainability and provides an overview on how much influence can be exerted by every individual stakeholder in the life cycle phases of a building.

1 Introduction

Modular and prefabricated construction is increasingly regarded as a cost-effective and time-saving alternative to traditional construction methods; and is more than just a trend of the last few years. As it is often described with the characteristics "fast and cheap" it could give the appearance of standing in great contrast to sustainability. However, modular construction and sustainability are strong correlated than one might think. The notion of sustainability in the life cycle of modular construction will be illustrated in this paper.

* Corresponding author: peter.schnell@ibl.uni-stuttgart.de

The three-pillar model of sustainability, on which common certification systems such as DGNB, LEED or BREEAM are based, addresses the three principles of environmental, economic, and social issues [1]. The aim is to provide future generations an intact living space with an environmental, economic, and social balance. In the construction industry, the pillars of sustainability are affected in all life cycle phases of buildings.

Component assemblies as basic elements of modular construction offer the possibility of creating new buildings according to one's construction kit. In case current requirements are met no longer, component by component can be removed which makes both site and components available again. Alternatively, additional elements can be added vertically or horizontally. The basic idea of modular construction is to adapt to the current needs and trends without wasting valuable resources. Modules can be not only various types of prefabricated elements, e.g., component groups such as MEP modules and facade elements, but also large volumetric elements such as bathroom pots, which all differ significantly in terms of the degree of prefabrication. The decisive difference to site-built construction methods is frontloading, meaning shifting decisions from the construction phase to the design phases by also reducing time due to the repetition effect [2].

2 Modular construction and its advantages

Based on literature research, the most common types of modular construction and their advantages were first identified. In addition, the advantages were utilized and combined to compare different degrees of modularisation within selected phases of the building life cycle [3-6]. The definition of the life cycle phases is based on the literature comparison of Schwerdtner [14].

The design phases are reduced using standardised component groups according to the degree of modularisation (figure 1) which results in considerable advantages, especially when using volumetric modules. Furthermore, due to the repetition effect, the production costs can be recorded more accurate. With a higher degree of prefabrication, the duration of the construction phase can also be reduced, which, among other things, reduces the general construction site costs [7]. The stationary prefabrication of the modules also achieves a better, homogeneous quality. Although the modularisation of components simplifies many processes in the construction phase, it restricts requests for changes to a certain extent [6].

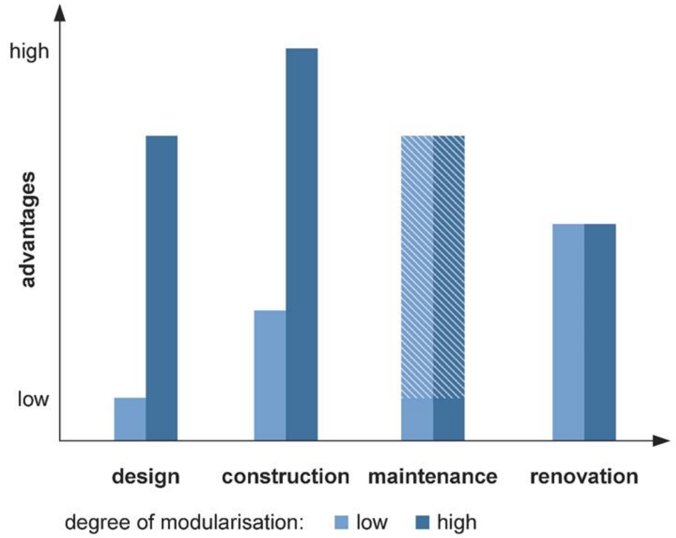

Fig. 1. Advantages in the building life cycle through modular construction

From the perspective of users, a modular building does not have a significant advantage for the operation phase. However, by contrast it can have an enormous impact on maintenance and repair work depending on the type of measures. Especially complex measures within the operation and maintenance phase benefit from a higher degree of modularisation. A high degree of modularisation can not only enable time advantages in the renovation phase, but also creates conditions that limit flexibility. For example, larger component groups may have to be dismantled even though only small parts have to be replaced. Likewise, design limits are set by the existing grid size, which count especially for a high degree of modularisation and larger modules.

3 Potential impacts of sustainability goals

To further specify the potentials of modular construction, subject areas were derived to assess the sustainability within the selected life cycle phases design, construction, maintenance and renovation. Therefore, common certification systems DGNB, LEED and BREEM were analysed, compared and correlations between them were identified [1, 8-13]. Subsequently, the main categories of the three certification systems were compared and combined to an overall list of subject areas. Table 1 shows the subject areas on the left and the main life cycle phases in the subsequent columns. Additionally, the involved parties of each life cycle phase were assigned.

Tab. 1. Influence of modular construction on defined subject areas of sustainability within building life cycle phases

subject area	design	construction	maintenance	renovation
involved stakeholders	client, architect, designer	client, architect, general contractor, construction companies	client, user, facility and object manager	client, architect, general contractor, construction companies, apt. user, apt. facility and object manager
design and quality for urban development	++	--	+	+
health and wellbeing	++	-	++	+
waste and pollution	+	+	-	+
location and space requirement	++	--	--	-
quality	++	++	+	++
materials and resources	++	+	-	+
energy balance and efficiency	++	-	+	-
water consumption	++	--	+	-
transport	+	+	--	+
innovation	++	-	--	+
process quality and on-site management	+	++	--	+
flexibility and potential of reutilization	++	-	-	+
life cycle costs and marketability	++	-	--	+
legend	very low (--), low (-), high (+), very high (++) influence			

As shown in table 1, the influence of modular construction on each subject area is different according to the involved party. During the design phase, the influence is high, but not all involved parties are already part of the project team. Furthermore, the overall influence and the amount of addressable subject areas is diminishing in the later construction, maintenance and renovation phase. Thus, the number of involved parties and the impact possibilities of the new subject areas are reciprocal. To identify the correlation potential between the advantages of modular construction and sustainable goals, each life cycle phase of modular construction methods was evaluated due to its suggestibility of the new categories. The main findings are presented in the discussion.

4 Discussion

A direct link exists between the principles of modular construction and the aspects of sustainability. Reasons for the connection of modular construction to sustainability are especially the serial off-site production, the subsequent shorten assembly time on the construction site, and the recyclability of each individual module [6]. The relocation of the manufacturing process to a weather-protected factory not only means considerable efficiency gains, but also extensive and sustainable alternatives for individual components and processes. Flow-oriented production processes enable the sustainable usage of resources such as materials and labour, both environmentally and ecologically [6, 15]. Moreover, it improves the social interests of society through improved working conditions. The assembly on the construction site has environmental benefits due to both a significantly shorter and more stable construction process and through a low-waste and low-emission construction site [7]. Economic potentials can be found by the reduced construction time due to the singular assembly of the modules. Finally, the opportunity to exchange single modules, to separate materials by type and to simply deconstruct individual components or entire parts of the building enable the return of used materials and resources to a closed material cycle. This means that these materials and resources can be used as efficiently as possible from an environmental, economic, and social point of view [16, 17].

In the conceptual and detailed design phase, the influence to change to modular construction methods is the highest. In the construction phase, modular alternatives can still be used to some extent for several component groups, whereas during the operating phase there are no possibilities without maintenance measures, as the building has already been completed [18]. In the renovation phase, the possibilities to apply modular construction methods increase again. This clearly demonstrates that stakeholders such as architects and other specialised engineers who are involved in the conceptual and detailed design phase, have a decisive influence on the choice of construction method. In comparison, the influence of executing construction companies is much smaller if alternative construction methods are contractually not possible. Likewise, there are no opportunities for facility managers and users to influence the construction of the building if they were not already involved in the design phases [19]. As the operation phase is responsible for a significant proportion of the complete duration of the building's life cycle, maintenance measures are even more important for customers and users of the buildings. Figure 2 illustrates the influence of each party involved for every life cycle phase.

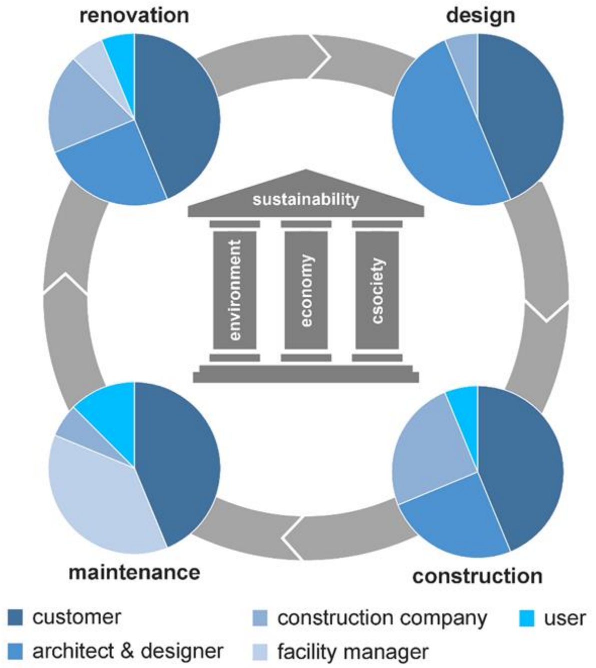

Fig. 2. Influence over the building life cycle by each party involved

5 Conclusion

Modular construction methods will not affect the life cycle phases of buildings dramatically, but will change, the length ratio and will further entail a clear separation of the individual phases. Furthermore, advantages and correlations between modular construction and sustainability exist in every life cycle phase. However, as figure 1 shows, the full potential of the subsequent phases can only be exploited when general conditions were already aligned in the design phases. The problem is, as figure 2 shows, the participants of the design phases are currently only involved to a limited extent in the further life cycle. In addition, participants in the maintenance phase are not yet involved in the early phases.

Due to various benefits, modular construction methods can have a great impact towards an earlier involvement of stakeholders during design and construction. To reach environmental, economic, and social goals through modular construction, integrated and holistic project approaches are needed.

References

1. T. Ebert, N. Eßig, G. Hauser, DETAIL Green Books, Zertifizierungssysteme für Gebäude, (2010)
2. N. Bertram, S. Fuchs, J. Mischke, R. Palter, G. Strube, J. Woetzel, Modular construction: From projects to products, 3 – 9, (2019)
3. J. Molav, D. L. Barral, Procedia Engineering, A Construction Procurement Method to Achieve Sustainability in Modular Construction, 145, 1362 – 1369, (2016)

4. M. L. De La Torre, A review and analysis of modular construction practices, 275, (2016)
5. D. Hořínková, *Advantages and Disadvantages of Modular Construction, including Environmental Impacts*, in: IOP Conf. Ser.: Mater. Sci. Eng., 1203 032002, (2021)
6. K. Subramanya, S. Kermanshachi, B. Rouhanizadeh, *Modular Construction vs. Traditional Construction: Advantages and Limitations: A Comparative Study*, in Proceedings of the Creative Construction e-Conference 2020, CCC 2020, 11 – 19, (2020)
7. L. Loizou, K. Barati, X. Shen, B. Li, Buildings, Quantifying Advantages of Modular Construction: Waste Generation, 11, 622, 2021
8. A. Z. Hamedani, F. Huber, *A comparative study of DGNB, LEED and BREEAM certificate systems in urban sustainability*, in: 7th International Conference on Urban Regeneration and Sustainability, 121 – 132, (2012)
9. S. Eberl, *DGNB vs. LEED: A comparative analysis*, in: Conference on Central Europe towards Sustainable Building, 1 – 5, (2010)
10. M. Orova, A. Reith, *Multiscalarity in International Sustainable Assessment Systems: A Qualitative Comparison of LEED, CASBEE, BREEAM, DGNB and ESTIDAMA on Building, Neighbourhood and City Scale*, in: IOP Conf. Ser.: Earth Environ, 290 012056, (2019)
11. R. K. Zimmermann, O. Skjelmose, K. G. Jenson, K. K. Jensen, H. Birgisdottir, *Categorizing Building Certification Systems According to the Definition of Sustainable Building*, in: IOP Conf. Ser.: Mater. Sci. Eng. 471, 092060, (2019)
12. DGNB GmbH, https://www.dgnb-system.de/de/gebaeude/neubau/kriterien/
13. A. Rezaallah, C. M. Bolognesi, R. A. Khoraskani, *LEED and BREEAM; Comparison between policies, assessment criteria and calculation methods*, in: Proceedings of the 1st International Conference on Building Sustainability Assessment, (2012)
14. P. Schwerdtner, T. Kessel, C. Roth, S. A. Kian, M. Bucherer, D. Möhlmann, F. Schippmann, R. Sonntag, T. Uhlendorf, S. Wahnes, OI + BAU – Optimierung der Initiierung komplexer Bauvorhaben, Forschungsbericht im Rahmen der Forschungsinitiative Zukunft Bau, F 3140, (2019)
15. J. Lara, C. S. Poon, Construction Management and Economics, Sustainable construction aspects of using prefabrication in dense urban environment: a Hong Kong case study, 26.9, 953 – 966, (2008)
16. R. M. Lawson, R. G. Ogden, *Sustainability and Process Benefits of Modular Construction*, in TG57 - Industrialisation in Construction, CIB World Building Congress 2010, 38 – 51, (2010)
17. M. Kamali, K. Hewage, Journal of Cleaner Production, Development of performance criteria for sustainability evaluation of modular versus conventional construction methods, 142-4, 3592 – 3606, (2017)
18. N. Banaitienea, A. Banaitisa, A. Kaklauskasa, E. Zavadskas, Omega, Evaluating the life cycle of a building: A multivariant and multiple criteria approach, 36-3, 429 – 441, (2008)
19. H. Xue, S. Zhang, Y. Su, Z. Wu, R. J. Yang, Journal of Cleaner Production, Effect of stakeholder collaborative management on off-site construction cost performance, 184, 290 – 502, (2018)