Challenges in the achievement of a Net Zero Carbon Built Environment – A systemic approach to support the decision-aiding process in the design stage of buildings

Marco Scherz, Alexander Passer, Helmuth Kreiner
Working Group Sustainable Construction, Institute of Technology and Testing of Construction Materials, University of Technology Graz, Austria
marco.scherz@tugraz.at

Abstract. By limiting global warming to 2°C, the climate goals set by the United Nations in 2015 (Agenda 2030) will clearly be missed. The shrinking of our GHG budget has shown that the implementation of a weak sustainability concept - i.e. equal consideration of all sustainability dimensions (environmental, economic and social) - is not sufficient to meet the requirements of the Sustainable Development Goals (SDGs). Based on the strong sustainability concept - i.e. focusing on the environmental dimension of sustainability - this article highlights the challenges in the achievement of a Net Zero Carbon Built Environment by the implementation of a systemic design model in the early design stage of buildings. The visualisation of individual planning practices and their systemic behaviour in relation to other planning practices respectively to the SDGs support planners to manage the complexity and to reduce the additional effort within the implementation of sustainability aspects in the early design stage of buildings. Next to the visualisation of the environmental impacts of planning practices, the effects on other SDGs can be highlighted. Furthermore, the planner is supported in the decision-aiding processes in the early design stage. With the application of the systemic design model and the implementation of identified planning practices the contribution to the fulfilment of Agenda 2030 increases.

1. Introduction
The Sustainable Development Goal (SDG) 11 and thus the planning of buildings in the broader sense is in direct contact with the foundations of human life. It deals with crucial aspects of daily life, including housing, mobility, basic services and quality of life, which are also partly covered by other SDGs. As a result of ongoing urbanization, SDG 11 is facing one of the megatrends of the 21st century: by 2050, almost 70% of the world's population will live in cities. This generally accepted observation, however, is extremely important as it aims not only to improve current urban infrastructure and life, but also to design sustainable cities and communities that are being built now and in the future.

SDG 11 is the most spatially explicit SDG: it is about access to affordable housing, transport and green spaces, participatory spatial design and inclusive territorial justice. Increasing urbanization therefore not only leads to further construction activities, but also requires very special efforts in the sense of contributing to (more) resilient cities with high resource and energy efficiency, the achievement of climate targets [1-3] and the inclusive design of the social sustainability dimension [4].
Cities worldwide currently consume around 70% of all resources and generate more than 75% of all GHG emissions [25]. Therefore, the reduction of the resource consumption and the reduction of global GHG emissions are decisive factors in meeting the goals of the Agenda 2030. The average GHG emissions in Austria increased between 2010 and 2018 compared to the average emissions between 1990 and 1999. With regard to the EU 28 climate target path, Austria is in the final third (compared with the other EU member states) [5]. A closer look at global level reveals the cross-sector relevance of the construction sector and in particular of buildings. Around 39% (11% construction industry + 28% buildings) [6] of energy- and process-based GHG emissions from 2017 are attributable to the construction sector (see Figure 1).

![Figure 1. Global GHG emissions by sectors acc. to [6]](image)

The current research results of the Sustainable Built Environment (SBE19 Graz) conference [7] showed that the necessary organization and support for sustainable urban development, local decision makers and stakeholders along the value chain in construction poses or will pose complex challenges. In this respect, the urgent need for process-based decision support is pointed out, which makes the dynamic factors occurring in cities and municipalities (e.g. different stakeholder interests, a multitude of influencing aspects and their systemic behavior) manageable and offers local decision-makers recommendations for action in the realization of sustainable cities and municipalities.

2. Applied methodology
We illustrate how to identify planning practices in the design stage of buildings for the achievement of the SDGs using the systemic design model described in this article. To do so, we focus on the early design stage of buildings in section 2.1 in context to the SDGs and we analyzed the SDG targets and their indicators in section 2.2. In section 2.3, we outline the synergies and trade-offs of chosen planning practices by the application of used causal loop investigation.

2.1. Early design stage of buildings in context to the SDGs
In the early design stage of buildings, crucial decisions (e.g. choice of materials, room arrangement, green spaces, use of rainwater, choice of energy sources, compactness of the building) must be taken for the later building performance resp. building quality. Next to SDG 11, the construction industry
and therefore the design stage of buildings in a broader perspective are influencing areas like poverty (SDG 1) in terms of affordable housing; good health and well-being (SDG 3) with regard to the well-being inside buildings due to the comfort of housing; clean water and sanitation (SDG 6) for instance in terms of water treatment or water consumption by building services installations; affordable and clean energy (SDG 7) with regard to the energy sources used and the energy consumption in the use phase of buildings; decent work and economic growth (SDG 8) in terms of jobs over the whole life cycle of buildings; industry, innovation and infrastructure (SDG 9) with regard to the construction of urban infrastructure; responsible consumption and production in terms of building materials used and their service lives in the sense of a circular economy; climate action (SDG13) in relation to GHG emitted over the whole life cycle of buildings (embodied emissions and operational emissions); and life on land (SDG 15) in terms of additional land use for new buildings.

2.2. Feedback on the UN SDG indicators for achieving a Net Zero Built Environment
Within SDG target 11.6, emission-related environmental pollution is addressed by the reduction of particulate matter (indicator 11.6.2). This is too restrictive, as the proportions of emission-related environmental impacts from the construction sector are not adequately reflected. Due to the long service lives of buildings, for example, (planning) practices implemented today will continue to have an impact in 2050 and beyond.

Planning and construction-accompanying consideration of GHG emissions during the whole life cycle of buildings is crucial on the way towards a decarbonized construction industry. In addition to the holistic consideration of GHG emissions, a distinction must also be made between embodied and operational GHGs of buildings. A comprehensive review and discussion can be found in [8].

The overarching objective was developed on the basis of SDG target 11.6. As GHG emissions are not covered by any indicator in SDG 11, a new indicator 11.6.3 “GHG emissions of buildings in kg CO₂ eq./m² NFA *year (50 years reference study period)” is proposed.

2.3. Causal loop investigations to visualize synergies and trade-offs of planning practices
In order to be able to identify the interactions among planning practices, two partial steps are necessary. The first step is to identify the effects (synergies and trade-offs) of all chosen planning practices on the SDG indicators and thus on the SDG targets respectively SDGs. For this purpose, all relevant stakeholders were interviewed within the UniNEtZ project [9] and the interactions were identified in joint workshops. The know-why method [10] was used for the identification of interactions. This method requires answers to the four know-why questions, which have to be answered separately for each interaction. The four questions are as follows:
- What leads directly to more of a factor?
- What leads directly to less of a factor?
- What might lead directly to more of a factor in the future?
- What might lead directly to less of a factor in the future?

In the second step, the interactions among the SDG targets reps. the SDGs must be determined. For this purpose, existing studies [11-18] were used, analyzed and summarized.

3. Systemic design model
The underlying modeling strategy comprises the three sustainability strategies (consistency, efficiency and sufficiency), which should equally contribute to the achievement of the objective of a decarbonized construction industry. For each of these strategies there are different possibilities for planning practices, whereby one planning practice can contribute to several sustainability strategies (see Figure 2).
Figure 2. Sustainability strategies to achieve a decarbonized construction industry

Table 1 shows an extract of planning practices assigned to the sustainability strategies.

| Planning practice                                      | Sustainability strategy |
|--------------------------------------------------------|-------------------------|
| Use of highly efficient energy technology              | Efficiency strategy     |
| Optimize energy demand                                 | Efficiency strategy     |
| Use of renewable energy sources                        | Consistency strategy    |
| Use of low embodied carbon materials                   | Consistency strategy    |
| Less living space                                      | Sufficiency strategy    |
| Less heating/cooling                                   | Sufficiency strategy    |

3.1. Interactions among SDGs

The systemic design model also takes into account the interactions among other SDGs respectively other SDG targets. After analysis and compilation of the relevant literature, the existing SDG models [19-20] were supplemented and served as a basis for the developed systemic design model. Figure 3 shows an excerpt of the systemic design model. The systemic design model consists of an SDG part (see Figure 3 – upper part) and a planning practices part (see Figure 3 – lower part). The SDG part includes 215 model elements and 469 connections. The planning practices part is the result of an already completed research project, which includes more than 850 model elements and more than 3190 connections. Detailed explanations on the methodological development of the systemic design model and on the meaning of the individual model elements can be found in [26].
Figure 3. Excerpt of the systemic design model: SDG part (upper part) and planning practices part (lower part)
3.2. Modeling principles
SDG 11 respectively SDG target 11.6 are used to illustrate the methodological approach and the developed systemic design model. The following modeling principles are applied:
- A bundle of planning practices (= planning package) has a direct impact on an indicator (starting point for modeling).
- In order to make the model levels consistent, planning practices can also act on factors (auxiliary model elements).
- Only a measurable variable can affect the planning package. This modeling principle is necessary for a later quantification of the planning package.
- Factors act directly on measurable variables or on other factors.
- The planning practices required to implement the planning package have a direct effect on the measurable variable or on a factor.

4. Results
To visualize the results of the systemic design model, tornado charts (see Figure 4) as well as insight matrices (see Figure 5) are calculated.

4.1. Synergies and trade-offs shown in tornado charts
Tornado charts can be created for all model elements, showing the positive and negative effects of planning practices for the centered/selected model element. When interpreting the tornado charts, it is important to emphasize that the effects (positive or negative) on the centered/selected model element are always the direct effects. In figure 4, a selected planning practice was placed at the center of the model. The linguistic interpretation of the red bars is defined as "More of the centered/selected model element X leads directly to less of a model element Y". For the green bars the definition is "More of centered/selected model element X leads directly to more of a model element Y". The tornado charts can be displayed for three time spans (short-term, mid-term and long-term).

![Tornado Charts](image)

Figure 4. Exemplary representation of a planning practices’ synergies and trade-offs in tornado charts (short-term, mid-term and long-term)

4.2. Effects over time shown in insight matrices
The insight matrix contains four result areas (blue, green, red and yellow). Within these areas, all model elements (points) acting on a centered/selected model element X are shown.

From the total sum of direct and indirect influences, which result from the qualitative weighting of the chains of effects and delays, as well as from the effects of balancing and reinforcing loops, the influence of other model elements can be output for each model element. The horizontal x-axis represents the sum of all effects overall effect paths. The vertical y-axis shows changes in the effects due to loops and delays.

The four result areas of the insight matrix can be interpreted as follows (see Figure 5):

![Insight Matrix](image)
• blue: Model elements in the blue area represent decreasingly decreasing model elements. This means that these model elements reduce their negative effects over time. This can lead to positive effects on the centered model element over time.
• green: Model elements in the green area represent increasingly increasing model elements. This means that over time, these model elements will have a more positive effect on the centered model element. These model elements cannot have any negative effects over the entire time span.
• red: Model elements in the red area are increasingly decreasing model elements. This means that over time, these model elements have increasingly negative effects on the centered model element. These model elements cannot exert any positive effects over the entire time span.
• yellow: Model elements in the yellow area are decreasingly increasing model elements. These model elements should be viewed particularly critically because they can have a positive effect on the centered model element at the beginning, but over the time span they can develop negative effects on the centered model element.

Figure 5. Exemplary representation of the short-term, mid-term and long-term effects of selected planning practice in insight matrices

Planning practices in the blue area lose their negative effects (trade-offs) on the model element under consideration over time. This can either cause planning practices to shift to the green area, if the positive effects constantly increase over time, or to shift to the yellow area, if positive effects only occur in the mid-term, but in the long term negative effects develop again. Planning practices in the green area gain on positive effects on the model element under consideration over time (therefore they are always in the green area), instead planning practices in the red area gain on negative effects on the model element under consideration over time (therefore they are always in the red area). Especially planning practices in the yellow area have to be analyzed in detail, because they have positive effects at the beginning, but develop negative effects over time.

5. Discussion
Sustainable construction in the context of applying the principles of sustainable development to the construction sector has a crucial part to play because of the tremendous material and energy flows and the related environmental impacts. The goal is to plan, build and operate a building respectively a city in a holistic way, taking into account its life cycle, so that it is an asset for later generations and not an inherited burden. The recent shift towards more and more energy-efficient buildings respectively cities is increasingly focusing on the design stage of new buildings in context to embodied energy and embodied GHG emissions. A holistic, integrative approach at the building respectively city level requires the merging of various requirements and functionalities of the individual building elements into the context of a larger whole. To achieve this, specific tools or strategies [21-24] are required to meet these complex challenges. The systemic approach used for the development of the systemic design model will also support in managing complexity and will reduce additional effort in the early
design stage. Project managers, planners and building owners are given a starting tool to structure sustainability requirements respectively sustainable development goals, process them in a comprehensible manner and carry out monitoring from a holistic perspective.

6. Conclusion
From today's perspective, it appears that Austria will only be able to meet its international climate commitments and the European strategies (circular economy, resource efficiency and other macro objectives) with substantial efforts, i.e. with much more ambitious, specific and resilient measures. This mainly refers to the shift to a systemic approach in the construction sector. The current additive implementation of specific and resilient measures will not lead to the achievement of the Agenda 2030 goals due to the lack of systemic understanding of emerging trade-offs.

The increasing complexity of planning and implementation processes calls for a new, essentially different approach for the realization of (more) sustainable buildings or cities. The optimization of individual parts (e.g. building elements) is not the sum of the optimization of the whole (building).

Against this background, a further development into a networked, integrated sustainability assessment in the construction sector is essential to ensure the development of a resilient built environment.

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