Urban pop-up housing environments and their potential as local innovation systems

Indicator-set and cross-disciplinary assessment tool

Deliverable D4

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PREFACE

As part of the interdisciplinary research project "Urban pop-up housing environments and their potential as local innovation systems", six deliverables (D1 – D6) were generated in accordance with the project proposal, which reflect in detail the working process and outputs of the diverse tasks in the working packages. An overview of all deliverables and their key messages is provided in the Executive Summary (Deliverable D0). The individual deliverables were developed chronologically according to the project schedule and progress, and thus, completed at different time points in the project, reflecting the state of knowledge at the respective project status at that time.

Different SCI publications were also generated within the work-packages and are based on the deliverables, whereby some contents were deepened and further developed in the papers. In some cases, terms and terminology have also been adapted. The contents of the deliverables therefore partly represent “work in progress” at the respective times of completion of the working packages and writing of the deliverables. The contents of the published SCI-papers and the key statements in the Executive Summary (D0) are to be understood as the most recent and solid outcomes and conclusions.

CONTENT

1 INTRODUCTION

1.1 SHORT PROJECT DESCRIPTION

In the interdisciplinary research project of temporary housing environments (THE), temporary forms of living are researched in the urban context from a fundamental basis on. Hereby, the problem of temporary forms of housing is being treated from many views: energy technology, architecture, circular economy, green chemistry, landscape planning, spatial planning, risk assessment, waste and waste water management as well as technology assessment and social science. Due to the lack of disciplinary methods that integrally cover all these areas and points of view and the lack of possibilities to make important aspects of the different considerations understandable to every discipline in a clear and simple way, a specific, tailor-made assessment tool has been developed in this project.

This deliverable deals with the development of this method to assess and evaluate the previously presented 6 scenarios and models of THE (see Deliverable D3 or Annex of Executive Summary or project webpage https://popupenvironments.boku.ac.at/index.php/project-results-outputs/project-results/) and depicts the numerical simulation results in easily readable evaluation graphs.

This report on D4 is divided into following parts:

- firstly, covering the development and theoretical structure of the assessment tool itself and
- secondly, providing the corresponding numerical results and brief interpretation of the graphical evaluation/graphs.
- The compendium of the indicator-set for the interdisciplinary assessment of temporary housing models is attached in the Annex, as well as the report and detailed data on the Life-Cycle-Assessment (LCA) that was conducted for the 6 temporary housing models.

2 DEVELOPMENT OF METHODOLOGY

2.1 METASTRATEGY

In this chapter, the used mathematical strategies for generating an applicable interdisciplinary assessment method are described. These serve as important background for developing a new methodical approach and for expanding the range of validity of existing methods.

The main theoretical and mathematical approach was as following:

Problem – target – solution

A common strategy, not only in the field of technics, is to comprehensibly describe the problem or given task. Based on these descriptions, a target/aim is formulated. Assuming a correctly defined actual situation, a transformation into the target state can be achieved by defining 'the problem' as (part of the) solution space.

Defining 'the problem' as solution

A – in mathematics and many other fields – commonly used methodical approach is to define 'the problem' as (part of the) solution. Generally speaking, this strategy aims for defining a suitable solution space according to the given problem/task. Finding a suitable solution space in such a way, yields a method for solving a complete 'problem category'

Example for illustration purposes

The problem:

Whole numbers $a, b, n \in \mathbb{N}$ are given through the link $+: \mathbb{N}x\mathbb{N} \to \mathbb{N}$ or $n = a + b$. This connection is closed in $\mathbb{N}$, meaning that for every pair $n, b \in \mathbb{N}_0$ an $a \in \mathbb{N}_0$ exists which satisfies the above-mentioned condition.

If you now face the problem that you have given n and b and you want to find an a that fulfills the above relation, then $a \notin \mathbb{N}$ can potentially happen. This means that the link $n - b = a$ in $\mathbb{N}_0$ is not completed. Now the problem arises: what must a set look like in which the connection $n - b = a$ is completed?

The target:

Find a set of numbers in which the problem is closed.

The solution:

Now, without loss of generality, let n be 0. From this we get $0 - b = a \leftrightarrow -b = a$ from which, with the definition $\mathbb{Z} \coloneqq \{\mathbb{N}_0 \cup -b\}$, a set is defined for all $b \in \mathbb{N}_0$ in which the connection is closed.

This definition is not as formal as the one of equivalence classes but illustrates the basic procedure.

2.2 THEORY OF METHOD DEVELOPMENT

When exploring and assessing temporary forms of living in an urban context the focus lies on ecological-, technical-, site-related- and social aspects. An evaluation system/assessment algorithm has been developed in order to enable a justifiable and balanced evaluation of temporary forms of living. The ‘solution strategy’, see meta-strategy above, was pursued to find a common value space for the different partial aspects of the problem. This value space was achieved with regard to all aspects, so called qualities (see also next chapter), considering the definition of acceptance-mapping. It was possible to use existing evaluation methods, and, in many cases, it was only necessary to map them in the common value space. This tool greatly simplified the collaboration between the various disciplines and made it easier to identify any dilemmas that might arise.

In the area of interdisciplinary and transdisciplinary research, problems are investigated that encompass many areas. Research effectiveness is hereby often limited by difficulties in the interplay of technical-, ecological- and social aspects.

In addition to very different terminologies, which are used by each of the respective disciplines, one can easily get into a ‘dilemma’ when evaluating different approaches: that means, that a solution approach might work very well for one specific discipline but is not acceptable for another one. Furthermore, the same terms are sometimes given different meanings in two different disciplines, e.g. the term ‘Impact’: while usually a negative/destructive meaning is being assigned in the ecological sense, that is in the sense of pollution, ‘impact’ often has a positive/constructive meaning in other disciplines, e.g. in the sense of ‘taking a measure’.

Due to the interdisciplinary or transdisciplinary problems, it is not easy to find a suitable value space, i.e. solution strategy that satisfies all the contributing disciplines.

In the following, we differentiate between ‘process’ and ‘aspect’ when considering the breakdown of the subject area: As an aspect, we want to name a fully defined sub-area. When considering an aspect while taking time into account, we speak of a process.

With regard to individual sub-aspects or qualities, suitable disciplinary evaluation approaches of scenarios already exist. However, these differ greatly in the choice of the evaluation space and the choice of a proper set of values. These differences make it difficult to find an evaluative comparison between individual scenarios that considers very different aspects fairly and comprehensibly. In any case, it would be advantageous to find an evaluation space that can be applied to each sub-aspect with a generally understandable set of values. Also, we need to apply a practicable method that can accompany the process over the required period of time.

We understand the term evaluation space to be that structured set, from which one can map into the set of values using a set function. Different interests (of various disciplines) often influence the choice of the evaluation space and the set of values, which again makes a fair comparison of two approaches difficult.

Question – Hypothesis – Objective

<u>Question</u>

The question now arises as to what an evaluation would look like, the structure of which is induced by the problem and the objective.

<u>Hypothesis</u>

'Based on the problem and objective, it is possible to create an evaluation system that maps all essential aspects into a uniform set of values and at the same time enables monitoring of all essential processes.' Some fundamental research questions concerning the development of the assessment tool are stated below:

1. Is it possible to split the assessment of THE into sensible sub-aspects?
- Can a decomposition be found which at least covers the essential partial aspects?
- Can this decomposition be used as the basis for a rating/assessment system?
- Can 'dilemmas' be identified and described on the basis of this decomposition?

2. Can a quantitative function be defined as acceptance mapping according to [0,1] for an interdisciplinary evaluation?
- Is it possible to define an acceptance map or a group of acceptance maps for each of the partial aspects found?
- Can additional information be obtained from these mappings when viewed as a total assessment?

3. Can the translation invariance with regard to the time be used as a monitoring approach for the acceptance mapping of eco^2-socio-technical processes?
- Can critical changes be identified in good time by defining a homotopy of the acceptance mapping?

<u>Objective</u>

The aim is to create an assessment tool with the help of which the interdisciplinary, holistic analysis of THE, in all its different sub-aspects, can be better understood and suitably visualized. Such a tool should make it possible to recognize dilemmas at an early stage and to track changes in the assessment process in order to be able to adapt to varying 'indicators' and assessment criteria. The tool is also intended to facilitate the exchange of information between the individual disciplines and with stack holders as well as society in general.

<u>State of research</u>

In the following, relevant literature is being cited as 'one-liner' and serves as 'starting point' in the assessment development process.

Ecological aspects

- (Goddin, 2010) describes a method for measuring circularity by specific indicators;
- (Grand, 2016) examines most frequently used indicators for decoupling emissions and economic activities;

Technological aspects

- Use of pyrolysis coal from agricultural waste as a net CO_2 sink with simultaneous energy generation is treated by (Pröll et al. 2017)
- Description of energy development scenarios with associated data is presented in (IEA 2018).

Sociological aspects

- The problem of the rate of change of industrialized societies with regard to the change to a sustainable society using multi-level perspectives is treated in (Kanger, 2021)
- (Henckens et al. 2016) describes a classification based on resource consumption considering the needs of future generations
- (Lucke, 1995) examines possible definitions and their meaning of the different expressions of the term acceptance.

2.3 ASSUMPTIONS

Basically, the following process steps are assumed for creating an assessment:

- Mapping of the object (THE) to be evaluated into suitable indicators
- Breaking down the individual indicators into their assessable sub-processes
- Definition of the sub-acceptance mapping

The breakdown into indicators is ambiguous and has been carried out under the following assumptions. The THE itself is evaluated and not a specific use and site of the THE. The reason for this lies in the durability of a THE. The specific utilization can be changed more easily than the THE itself. The decomposition should be carried out from the point of view that the needs of a specific utilization can also be linked/integrated (math.: by means of an operator) into the evaluation later in the assessment process. This applies to both the user groups and the site. Furthermore, the decomposition should be carried out in such a way that there is no ‘dilemma’ concerning a single indicator. This means that supportive and obstructive processes, that refer to the same input size, are not mapped in the same indicator, but are divided into different indicators; this is further on referred to as ‘dilemma-free’.

Indicator space:

- The indicator space is generated via the individual defined indicators or, as originally formulated, key success factors
- The segmentation into the indicators is dilemma-free
- The indicators are broken down into their generating sub-processes

Solution space:

- Multidimensional set of values with $\dim(\mathbb{S}) = \text{num(Indicators)} = n_S$
- The value set shall be $[0,1]^{n_s}$.

Acceptance mapping:

- The acceptance mapping is a mapping from the indicator space to the solution space $\text{am}: \mathbb{I} \to \mathbb{S}$ which is composed of the submappings am_i.
- The sub-images am_i are monotonously increasing or monotonically decreasing mappings

2.4 TOOL DEVELOPMENT – MATHEMATICAL THEORY

In this chapter the underlying mathematical theory and 'modelling' together with all necessary 'assessment components' are presented. The approach for an assessment can be identified and derived as follows: basically, we want to describe the structure of the method using two different aspects, qualitative- and quantitative ones. Qualitative aspects can be used to find the structure. These have already been well described in studies, see also quotation above. That is why we want to concentrate here on the quantitative aspects.

2.4.1 Quantitative aspects

In the following, the theoretical background that we want to use in the method section is introduced and described in detail.

Measure

To understand which assessment components are necessary for a quantitative comparison, we use the basic definitions of measure theory. In this theory, the required components and their properties were defined and described axiomatically, see e.g. (Schmidt 2009; Meintrup et al. 2005). In the following, the most important terms used are presented mainly for overview- and plausibility purposes.

- Measurement space: If Ω is a non-empty set and $\mathcal{F}$ is a σ-algebra on Ω, then the pair (Ω, $\mathcal{F}$) is called measurement space.
- Measure space: If (Ω, $\mathcal{F}$) is a measurement space and $\mu: \mathcal{F} \to \overline{\mathbb{R}}$ is a measure, then the triple (Ω, $\mathcal{F}$, μ) is called a measure space.
- W-space: If (Ω, $\mathcal{F}$, P) is a measure space and P (Ω) = 1, then P is called W-measure and (Ω, $\mathcal{F}$, P) is called W-space.
- Filtered W-space: A filtration on (Ω, $\mathcal{F}$, P) is an ascending sequence (F_t) _ (0≤t≤∞) with indices from [0, ∞] from under σ-algebras from F such that F_s⊂ F_t holds for all s≤t≤∞. Then (Ω, $\mathcal{F}$, (F_t), P) is called filtered W-space.

This (exemplary, not exclusive) list of definitions shows which main components are needed for a quantitative evaluation, i.e. a measure, with regard to different purposes. Regardless of the purpose, we need a basic set Ω which contains all the elements to be assessed and measured. A more technical necessity is a set system consisting of the elements of the basic set which describes which subsets can be considered. This system of subsets can also be interpreted as the amount of information available.

Now, if we want to carry out an evaluation, we must assign a value to each element from Ω and also to each subset from F. This is done using the quantity function or the measure μ for the value range [0, ∞], and using P as W measure for the value range [0.1]. In the event that new information is added in the course of the process to be assessed, this information gain can be mapped via a filtration, see also filtered W-space.

Acceptance (as basis for a set-valued function)

In this section, we show that, based on the properties of the acceptance term and its related terminology, e.g. tolerance, an ascending orderly evaluation can be defined. '*Acceptance*' is a concept that is used in many areas as described e.g. in (Lucke 1995).

"First of all, acceptance is a transitive term, i.e. it relates to an object or several objects, and is therefore a relational and relative term in several respects. Acceptance in this related sense denotes the appropriation and later appropriation of what is offered, what is available or what is proposed. In its "accepting" meaning that is geared towards constructive analysis of what is found, the term can in principle be applied to all social objectifications and cultural revelations. Objects of acceptance can include technical devices and things of everyday use, opinions, attitudes, situation interpretations, interpretations and proposals for solutions just like topics and problems, reasons and arguments. Potential objects of acceptance are behaviors, lifestyles, actions and patterns of action including the underlying values and norms, the reinforcing legal institutions and enforcing political measures. However, it can also be about people and groups of people and the personality traits and character traits assigned to them as members of certain groups, milieus, gender affiliations and professions - with content variations, changing (sub-) cultural preferences, historical and biographical conjunctions and in changing social constellations. Only in relation to these objects is the talk of acceptance a sociologically meaningful and empirically meaningful statement. This is all the more true as the question of acceptance is called "acceptance of what?" almost inevitable and compelling in terms of content" (Lucke 1995, 89).

Tolerance (related basis for a set-valued function)

As a subordinate concept, the *'tolerance'* can be described as follows.

"The concept of tolerance contains less the impetus of the affirmative and affirming" yes "of acceptance. He relates less than it to the appropriation actually practiced. It thereby neglects an aspect of meaning, such as the concept of acceptance, especially in the connotation of active "taking a stand" and committed "standing up for something". In the family circle, publicly or in private life, tolerance that is displayed and initially only presented can, like external conformity, change into internal conformity, into acceptance, just as the habitual sinner can

become a persuasive perpetrator in the long run. Seen in this way, tolerance represents a possible, albeit not mandatory, preliminary stage to acceptance" (Lucke 1995,63).

As already indicated above, there is a different valuation of the terms 'acceptance' and 'tolerance'. Whereby an active endorsement, saying yes or approving is implied in the acceptance. However, when it comes to tolerance, a more passive toleration or endurance is implied. If one now negates the meaning of acceptance, i.e. rejecting or saying no, i.e. not accepting, we get the term that is still missing. Finally, we have found a way to put these terms in order.

Homotopy

A homotopy describes a continuous deformation of one curve into another. For example, the interval [0,1] can be thought of as a time interval. At the time t = 0, the mapping h_t has the form of f. However, this changes in the course of time until it has assumed the form g for t = 1, as described e.g. in [Jänich, 2008]. The mathematical definition of homotopy is as follows:

Two continuous mappings f, g: $X \rightarrow Y$ between topological spaces are called homotop, $f \simeq g$ if there is a homotopy h: $X \times [0,1] \rightarrow Y$ with $h(x, 0) = f(x)$ and $h(x, 1) = g(x)$ for all $x \in X$.

2.4.2 Qualitative aspects

For a structured derivation and identification of the (mathematical) structure, the individual topics sometimes require a very different approach. The commonality is best tangible when looking at a generating system (Cite).

In order to apply the method/assessment tool, a decomposition of the problem is necessary in the first step. This can build on existing disciplinary methods or existing indicators or, if necessary, require a completely new decomposition of the problem. The only important thing in this step is that the structure of the problem is well presented and substantiated. It is necessary to think in two levels: In the first level, the problem is broken down into sub-areas to be covered for an assessment. These sub-areas should represent the different viewing angles, such as disciplinary perspectives, as well as possible. In the second level, the individual sub-areas are broken down to the extent that a good evaluation or assessment is possible. A good basis for this is, for example, the decomposition into a generating system. The individual sub-elements of the decomposition are hereinafter referred to as partial aspects. The next step is an evaluation of these aspects with regard to their acceptance. For this purpose, simple tools for a simple first approximation are introduced below. In the last step, the partial aspects are to be put together again according to their natural consequences. Again, a few simple techniques are described below.

The principle application of this methodical approach in the underlying project is covered as follows:

In a first step, the underlying questions were broken down into partial aspects which in themselves did not lead to any thematic contradictions. These sub-areas were referred to as qualities. In this case, there has been defined an ecological quality, technical quality, site quality and social and living quality. This decomposition does not correspond to the picture that would have arisen in a decomposition with regard to the participating institutes. Rather, it enables a smooth cooperation of the different specialist groups with regard to partial problems which are free of contradictory views in this step. In the next step, partial aspects were defined to answer the questions which were defined and described as indicators. A total of 50 of these indicators were defined in the project. These served as the basis for the acceptance mapping described below.

Evaluation space – some useful considerations

The goal is now to define an evaluation space that allows to evaluate the above-mentioned aspects. In order to find a room that meets these requirements, the first thing you have to do is to do one. Property can be found which is contained in all aspects and can serve as a quantity function in the sense of a measuring room. One approach to this is to question whether a proposed solution can be accepted with regard to the underlying question and with regard to an aspect. A slightly weaker formulation would be the same question with the difference whether this solution can be tolerated. Of course, the question can also be asked whether a proposed solution is not acceptable (acceptance: legitimacy in the "voting society").

As can already be seen from these considerations, an order already exists in these terms. Furthermore, it is possible to assign these terms with regard to the individual aspects. In addition, these considerations also suggest a limited space as an evaluation space for the illustration. The method introduced here is not intended to replace existing methods or indicators, but only to define an evaluation space which can be used independently of the archetype space and by using the order concepts of acceptance, tolerable and unacceptable as evaluation variables. Through this common image space, consisting of set function and set of values, it should be ensured that assessments can be transported without the reader having to have a deeper understanding or knowledge of the otherwise necessary theories. This property has proven to be particularly helpful for very diverse and interdisciplinary problems.

Scheme/methodology for the evaluation approach/assessment method

The scheme for creating the assessment is outlined in Figure 1. The process can be described in 7 steps. We refer to those from the path above as problem description, objective and scenario. These steps describe a general process to come to a solution or scenario. In the lower path, the steps of decomposition, acceptance mapping, composition and evaluation are showed. Those steps go beyond simply finding a solution and describe the process of evaluation.

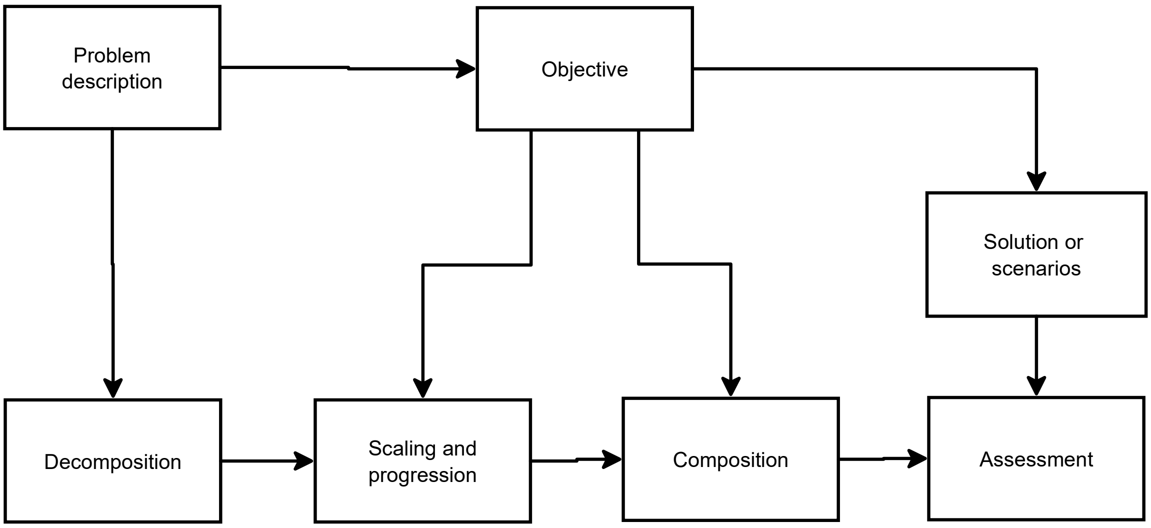

Figure 1: Evaluation flowchart.

- **Problem description:** The basis for creating the evaluation scheme or its structure is a description of the problem that is as precise as possible or an existing method or already existing indicators/assessment criteria.
- **Objective:** This serves as the basis for scaling the evaluation or determining the value history. At this point, the required or desired goals have to be described.
- **Decomposition:** At this point, the basis described in the problem definition will result in the easily manageable and coherent sub-problem as far as it is broken down. These sub-problems should cover all those aspects that are to be used for evaluation.
- **Scaling and progression:** In this step, the limits of the sub-problems for the illustration are defined, where 1 stands for the area from which a possible solution approach is to be regarded as acceptable and on 0 the area is depicted which is considered to be unacceptable. As has been shown, these two points are not necessarily sharply delineated. In many cases, there is an area in between. This area is designated as tolerable and, depending on the intensity of the necessary smears, is mapped to values in (0.1). This area describes the progression.
- **Composition:** Here, the individual sub-problems are linked again to a more comprehensive structure. Taking into account the required correlations, a structure is created again which represents the underlying indicator.
- **Solution or scenarios:** In this area, the solutions or scenarios proposed to solve the problem are prepared to the extent that they provide all the information necessary for an evaluation.
- **Assessment:** In this area, the information from the solution approaches or from the scenarios about the generally defined structure is evaluated.

3 METHODOLOGY - QUALITIES, INDICATORS, ACCEPTANCE MAPPING

3.1 DEFINITION OF QUALITIES AND SHORT DESCRIPTION

In order to cover and subsume all relevant topics/aspects from the various engaged scientific fields, it was necessary to firstly incorporate a formal structure/classification of the given aspects. It was decided to use terms and definitions primarily originating from the field of Life Cycle Analyses, LCA. In the end, four general areas were derived and determined to serve as ‘quality classes’ or simply ‘qualities’, namely

- ECOLOGICAL-,
- TECHNICAL-,
- SITE- and
- SOCIAL AND RESIDENTIAL QUALITY.

The *ecological quality* deals with all relevant aspects related to environmental consequences of the build, operation/use and deconstruction of the THE, covering aspects such as Global Warming Potential, GWP and emissions of $CO_{2,eq.}$ during the whole life cycle of a specific THE. Mainly, the parameters are taken from well-known LCA-guidelines and -standards.

The *technical quality* deals with building-relevant technical aspects like energy (consumption) figures (heating+DHW, cooling, primary energy demand etc.), degree of building automation, ease of (dis-)assembly and maintenance and other parameters which significantly influence the overall ‘behavior’ and operational quality of the building. Energy parameters are mainly taken from existing energy guidelines/standards and are all being calculated accordingly.

The *site quality* includes parameters like suitability of site and suitability for a specific building use. Parameters like ecologically sensitive area on site are also included. Various inputs derive from theory of open space planning (among others documented in publications of Kasseler Schule) as well as basics and values from publications by the City of Vienna (such as STEP 2025’s thematic concept Green and Open Spaces (Werkstattbericht 154) and Gender Mainstreaming in Urban Planning and Urban Development (Werkstattbericht 130)).

The *social and residential quality* includes indicators that refer to the quality of life that is facilitated by the organizational, built- and spatial structures of the building and open spaces on plot. Indicators that are majorly influenced by organizational arrangements or indoor structures were primarily developed by Junior- and Senior Scientists of ITA (‘social quality’), indicators that are influenced by arrangement of the buildings and open spaces were generated by members of ILAP (‘residential quality’). The indicator ‘Gender+ and diversity aspects of built and open space structures on the plot’ was built together by members of both institutions and gathers several other indicators; it is used to show the housing model’s performance regarding gender+ and diversity aspects at a glance.

3.2 DEVELOPMENT OF INDICATORS AND ACCEPTANCE-MAPPING

The underlying idea is as follows: the order presented in the chapter on acceptance as a basis for a set function with regard to different acceptance terms serves as an approach to the definition. The first step is to identify a set that is suitable for describing the aspect and representing it to a sufficient extent. In the second step, the part of the quantity that is considered acceptable in the sense of the aspect is mapped according to Fig. 1. That part of the set which represents the range at which the aspect is in a tolerable range is mapped to (0,1). That part of the set that represents the area where the aspect cannot be accepted is mapped to 0. As a pool of applicable formulation functions, parameterized cumulative density functions can be used in general.

Objectives

In the following, it is shown how the indicators, developed in the present THE project, are rendered comparable. Special attention is paid to the following characteristics:

- Equality of the individual indicators (comparability).
- Evaluation via expert methods or expert assessment.
- De-dimensionalized and standardized representation.
- Comprehensibility and traceability without expert knowledge.

For this purpose, a measure in the sense of an acceptance measure is developed for each indicator. This measure should reflect the expert's assessment about the quality of the fulfilment for the respective indicator. In the following, also referred to as expert representation due to a shorter spelling. In case an applicable method for describing an indicator exists, in the following referred to as expert method, this method is used. If no expert method exists to describe an indicator, an expert assessment in the sense of a-priori estimates is used.

Definition 1: Let A be an algebra over a non-empty basic set Ω. A function $\mu: A \rightarrow [0, \infty]$ is called measure on A, if the following two conditions are fulfilled.

- $\mu(\emptyset) = 0.$
- $\sigma-$ Additivity: for each sequence of pairwise disjoint sets from $(A_n)_{n\in\mathbb{N}}$, $\mu(\bigcup_{n=1}^{\infty} A_n) = \sum_{n=1}^{\infty} \mu(A_n)$ applies.

In our case we restrict ourselves to finite measures or more precisely to normalized measures, which means $\mu(\Omega) = 1$ where μ denotes the measure (mapping) and Ω denotes the whole set on which μ is defined. In this case the measure u is usually written as $\mathbb{P}$ and is called $\mathbb{P}$-measure (probability measure).

As σ –Aalgebra a set system is called which contains the basic set and is stable in relation to complement building and countable union.

Outline of the method of resolution

In order to achieve the goal, each indicator is mapped to the interval [0,1] in a de-dimensionalized form with respect to an expert mapping. To determine the course of the process please consider the following assistance.

- Identify the elementary (generating) processes of the indicator.
- Identify the support. (This means: Let $\mathcal{I}$ be the indicatorspace "topological space" and *G:I→[0,1]* is the expert mapping then the support is defined with $G' = g$ and by $Tr(g) = supp(g) := \{x \in \mathcal{I} | g(x) \neq 0\}$. The support is the set or the area where the function $g \neq 0$ is. In our case we mean the area where the indicator changes.)
- Identify the optimal or ideal range or state (from where the indicator is mapped to 1).
- Identify the area or state to be rejected (What is no longer acceptable).
- Identification of necessary intermediate states and their evaluation regarding acceptability (Which areas are not optimal or not desirable but still acceptable).
- Specify the shape of the mapping.

"*Topological space is the combination of an open basic set with a system of open subsets, where the average of two open sets is open and the union of open sets is open.”*

Identification of the elementary processes which generate the indicator

It is helpful to check if an indicator is generated by one component. If this is not the case, a decomposition into the generating processes is recommended. This decomposition is important for identifying a suitable mapping according to [0 1]. Thereby an essential simplification is achieved. In this point it should also be considered whether the indicator can be described directly. This means it could be easier to describe the complement of a statement or to evaluate it. In this case the construction as P-measure helps us. Let A be the process (the indicator) and A^C its complement, i.e. $A^C := \Omega \backslash A$. From the normality and the subtractivity follows $\mathbb{P}(A) = \mathbb{P}(\Omega \backslash A^C) = \mathbb{P}(\Omega) - \mathbb{P}(A^C) = 1 - \mathbb{P}(A^C)$.

Identify the support

The following describes what is meant by the support or which properties are important for the further process. Basically, the support of a function or a mapping is understood to be the completed set on which the mapping is not equal to zero. As a justification for this, we refer to the following context. If $G = \int g$ is our expert mapping then the support is defined on g.

Identify the ideal range or state.

In this step we will describe which subsets of the support are assessed with 1.

Identify the area or state to be rejected.

In this step we will describe which subsets of the support are assessed with 0.

Identification of necessary intermediate states and their evaluation with regard to acceptability.

At this point it is particularly important to evaluate jump points (non-continuous points "e.g. discrete quantity"). It is usually also helpful to consider whether each area or point is equivalent. It should also be checked whether a "generating system" exists. On this basis it is then relatively easy to define (evaluate) the overall system. (In mathematics a generating system is a subset of the basic set of a mathematical structure, from which, by applying the available operations, each element of the entire set can be represented).

Identify the shape of the mapping.

In many cases the shape of the image is already clearly determined by the evaluation of the intermediate states and the support. In case of a definition to quantities which are not linked to subsets of $\mathbb{R}^n$ via a relation and which are not based on a generating system, the evaluations of the individual subsets determine the shape of the image.

Trial functions

In order to develop the individual acceptance mappings, simple and highly adaptable trial functions for mapping the individual indicators to [0,1] were required. To achieve this, the following approach was undertaken:

Steady fall with finite carrier

In order to obtain the most flexible output function possible, a cumulative density function (CDF) was selected on the interval [0.1].

$$1-\left(1-x^k\right)^l \qquad \forall x \in (0,1) \qquad (1)$$

In order to achieve the desired flexibility with regard to the carrier, means to achieve a generalization from the interval (0,1) to an interval [a,b]. Whereby values outside the standard range with 0 or 1 should be continued appropriately. We achieve this by extending the selected function as follows.

$$1-\left(1-\min\left(\max\left(\frac{x-a}{b-a},0\right),1\right)^k\right)^l \qquad \forall x \in \mathbb{R} \qquad (2)$$

In the case of equation (2), increasing processes can be mapped. In the event of falling processes, the function can be adapted as follows.

$$\left(1-\min\left(\max\left(\frac{x-a}{b-a},0\right),1\right)^k\right)^l \qquad \forall x \in \mathbb{R} \qquad (3)$$

Promulgation of sub-indicators by means of p-norm

In some cases, it may happen that an indicator e.B. is composed of data from individual residential units and these are not executed immediately throughout the building. On the other hand, it may be that an indicator from several different implementation possibilities because the same need satisfies but not all possible implementations are needed. In these cases, it is very helpful to be able to link the implemented versions with each other without increasing the complexity of the illustration too much with the number of implementation possibilities. However, conditions such as deprivation or oversupply can be considered.

$$\|x\|_p := \left(\sum_{i=1}^{n} |x_i|^p\right)^{\frac{1}{p}} \quad \forall x \in \mathbb{R}^n \tag{4}$$

The value of the figure can be influenced by the parameter p. For p=1 the value corresponds to the amount norm, for p=2 the value corresponds to the Euclidean norm and for p→∞.

Development of indicators – chronological background

For the development of indicators, it was decided within a project meeting on the 29.05.2019, that a group of junior researchers would start collecting and structuring a first set of indicators. First considerations were made within this group on how to collect the relevant input factors for the modelling from all the disciplines involved in the project. The team members were asked to make their own considerations about potential indicators within their field and met in face-to-face meetings to explore these in more detail. After a structure had been developed for the documentation of the indicators, the responsibilities were divided into the different disciplinary fields and the indicators were developed further within these working groups.

It was decided within the project team to restrict the number of indicators per field to keep the complexity of the modelling as low as possible. The project meeting on the 20.09.2019 was used to allow the entire project team to vote on relevant indicators to include in the modelling in order to trim down the extensive list (from about 150 to about 70 to 80 indicators). On the 17.09.2019 the junior team had a preparatory meeting with a senior researcher who assisted in developing a systematic way of sorting and presenting the indicators in a table arranged by what were defined as “thematic fields” (“Themenfelder”), “set of criteria” (“Kriteriengruppen”), “target criteria” (“Erfolgsfaktoren”) and “indicators” (“Indikatoren”). This served to give a better overview of who (which disciplines) are responsible for what and meant to provide a uniform frame for everyone. At that time the “thematic fields” consisted of “socio-economic and functional quality”, “economic quality”, “ecological quality”, “technical quality”, “site-quality” (“Standortqualität”) and “process quality”.

Two smaller-scale meetings between seniors and the junior team were held on the 14th. &18th Oct. 2019 to collect feedback on the indicators of the respective fields of the present seniors. The decision was made to prepare a brief presentation of the existing indicators on a meeting on the 27th Nov. 2019 and judge them according to the traffic-light-system based on the criteria “influencable” (can we influence the values?), “relevant” (is the indicator of high relevance for the project setting (temporary aspects)?), “unique” (is the same phenomenon not already described by another indicator?) and “targeting” (is the indicator well-suited to describe my phenomenon?). These criteria were referred to as IRUT factors.

“Green” indicators were indicators which the juniors deemed as necessary “fix-starters” for the modelling not worthy of much discussion, while “orange” indicators had not scored a “yes” on all IRUT factors. The “orange” indicators were discussed within the entire project team on the 27th Nov. 2019.

The indicators were developed further within the respective disciplinary teams. On the 22nd April 2020 the status of the indicators was presented within the entire project team at a two-days workshop. Everyone on the project team had the opportunity to provide feedback on the indicators which were at a more advanced stage of development via a google form, noting whether they accept the indicator or reject the indicator, and having space to formulate an open comment. On the 23rd April 2020 this feedback was discussed within the project team.

Another project meeting was held on the 14th May 2020 to discuss the indicators, with particular focus being placed on the methods required to assess them. The adaptations following the feedback from the meeting on the 22nd & 23rd April 2020 were presented.

On the 30th June 2020 a project meeting was held during which feedback was provided for the next group of indicators at an advanced stage of development. During the project meeting on the 21st November 2020 the first calculations of the indicators were presented and discussed. Within the next months (till August 2021) the indicators and the cross-disciplinary tool in general were tested interactively using the 6 temporary housing models as case studies, and both the indicators and the housing models were adapted in several interdisciplinary feedback loops. The overall approach took nearly two years of intensive interdisciplinary discourse (see Figure 2). Finally, a set of 51 indicators was generated (see Figure 3).

In Figure 2 the main steps of the overall methodological approach are presented in an abstracted flow-chart.

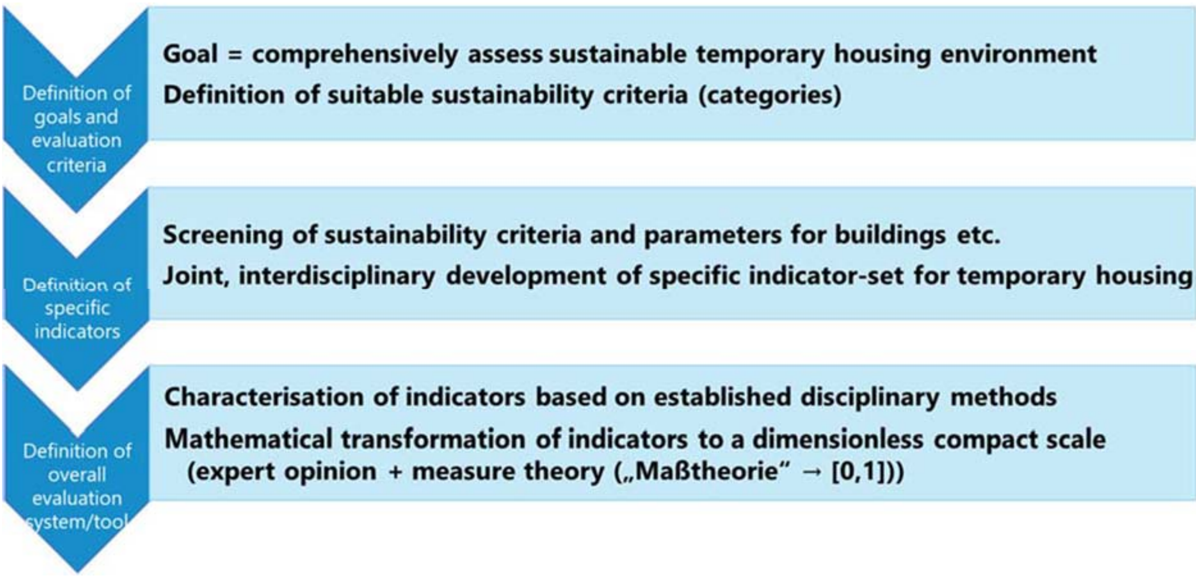

Figure 2: Approach for the definition of the indicator-set and the cross-disciplinary (mathematical) transformation model

3.3 FINAL INDICATOR-SET AND ITS DEFINITIONS/-DESCRIPTIONS

From this intensive interdisciplinary process, 51 indicators were ultimately developed within these 4 thematic fields (“qualities”) (see Figure 3).

For each indicator a specific indicator-sheet has been compiled, describing the background considerations, instructions regarding data collection and measurement, the mathematical implementation, its normalization and mapping mathematically "constructed" as described in the previous chapter, and the scaling in detail. The compiled indicator-sheets can be found in the annex.

Figure 3: Set of indicators for the sustainability assessment of temporary housing environments

4 RESULTS

4.1 ASSESSMENT PLOTS

The above described assessment tool has been iteratively adapted and tested using the six housing models (descriptions see fact-sheets on webpage or in the executive summary) as “theoretical case studies”, which show in general a high level of diversity, thus also demonstrating the quality of the assessment method. Although a more in-depth sensitivity analysis has yet to be carried out, particularly regarding the scaling for each indicator, and the derivation and abstraction of general principles and interrelations between the assessment indicators (e.g., the investigation of the tolerance limits of the indicators as well as the analysis of the dependencies and influences among each indicator), this first set of indicators and the principle method can now serve as an adequate, basic assessment approach for the sustainability evaluation and refinement of temporary housing options regarding technical, site, social and ecological aspects. Economic considerations are not covered in this approach so far but should be investigated in detail in the future and necessarily integrated at a later stage.

In the following chapters the results, illustrated in the plots, for each housing model are presented and briefly discussed. Figures 4 to 9 thus show the visualization of the interdisciplinary assessment using the housing model as “case studies”. All 51 indicators were normalized and scaled between 0 (low quality) and 1 (high quality) and grouped into four assessment plots by ecological, technical, site and social/residential quality. The closer the indicator is to "1”, the higher the quality. For the whole plot that means, if a larger area of the plot is covered, the higher the quality (respectively "sustainability") in these four categories. Overall, it can be concluded from the ratings of all six housing models that a higher social/residential quality usually corresponds with a lower technical and ecological quality.

In general, it must be said that the design of all six housing models was developed within the Viennese context and the associated high housing standards. Thus, the housing/living quality was given a priori a quite high priority, which required a higher technical and a more complex configuration (compared to other temporary forms of housing such as, e.g., tents or containers). This is reflected in the evaluation in the partly quite low ratings of some of the technical and ecological indicators.

The symbols/ abbreviations of the indicators used in the plots can be found in the list of symbols in the annex.

4.1.1 Beat the heat

Figure 4 shows the visualization of the interdisciplinary assessment using the housing model "Pallet Shelter" as a “case study”. As already mentioned above, the design of all six housing models was done with focus on a high housing/living standard, thus, the housing/living quality was given a quite high priority, which required a higher technical and a more complex configuration. This is reflected in the evaluation in the partly quite low ratings of some of the technical and ecological indicators (e.g., Lass/Ldisass, GWP).

As a special feature of the "Pallet Shelter" it has to be mentioned that the housing model itself can be built and dismantled quite easily and quickly (indicators "level of ease of assembly/disassembly" (Lass/Ldisass)), but in our specific scenario it was assumed that well ventilated, cooler but sealed areas serve as a location (in order not to occupy high-quality public green spaces) and this location would have to be greened and adapted extensively for a high living quality, which results in the low values of these two parameters. Another specific feature of this housing model is that the daylight quality (DLQ) resulted in poor values due to the extensive shading for natural cooling.

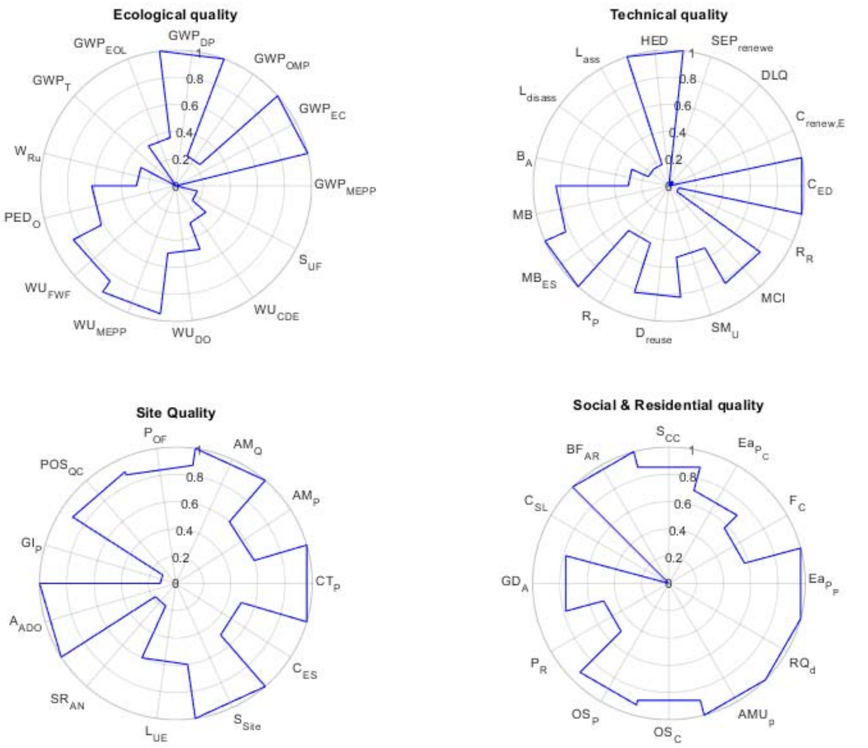

Figure 4 : Exemplary assessment plots for the scenario "Beat the Heat" (model Pallet Shelter); all 51 indicators are normalized and scaled between 0 (low quality) and 1 (high quality); symbols/ abbreviations of the indicators used in the plots can be found in the list of symbols in the annex.

4.1.2 Don Autonom

Figure 5 shows the visualization of the interdisciplinary assessment using the housing model "Binnen Bleiben" as the theoretical "case study".

The main striking issues are: Many aspects of social quality are also rated well in this model, with the exception of the indicators "changeability of room size and layout (C-SL)" and "barrier-free accessible rooms (BF-AR)", which was rated comparatively lower due to the rigid container design and accessibility particularly in the lower deck of the ship.

In terms of environmental quality, the parameters GWP-MEPP (GWP in material extraction and production phase) and “primary energy demand during operation” (PED-O) scored poorly. In the case of GWM-MEPP, this is mainly due to the high use of steel (even though the housing containers were assumed to be re-use containers and the amount of steel used was also calculated with a high recycling content), while in the case of PED-O it is mainly due to the special situation of ship operation. With respect to the technical aspects, more complex structures are needed (special ship-situation) and some issues like “daylight quality (DLQ)” had to be ranked lower due to ship-specific construction (e.g., no natural light in the corridors of the lower deck), although the living-units are well exposed to day-light.

The parameters "level of ease of assemble/disassemble (L-ass/disass)" also have to be considered in a more differentiated way: of course, the whole construction is not easy and quick to assemble/disassemble, but the entire ship can be moved relatively easily and quickly from one location to another, and can thus definitely be considered “easy to assemble and disassemble in terms of temporary use at one site. In general, this case study showed very well that the specific application and consideration of the indicators plays an important role in the evaluation.

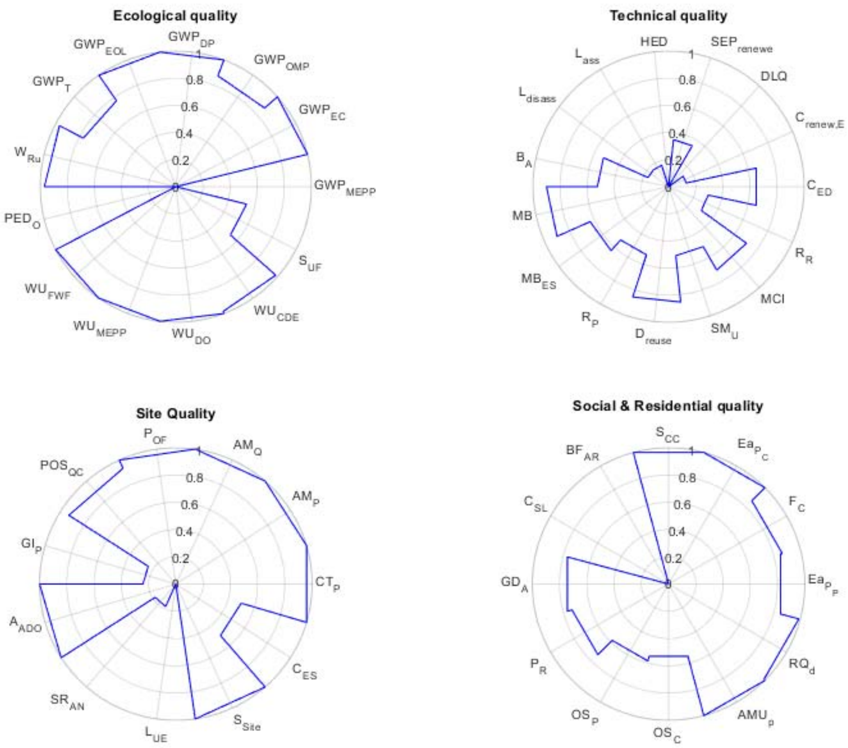

Figure 5 : Exemplary assessment plots for the scenario “DonAutonom” (model “ Binnen Bleiben”); all 51 indicators are normalized and scaled between 0 (low quality) and 1 (high quality); the symbols/ abbreviations of the indicators used in the plots can be found in the list of symbols in the annex.

4.1.3 Gap Module

Figure 6 shows the visualization of the interdisciplinary assessment using the housing model "Gapsolutely Fitting" as the theoretical “case study”. Also for this housing model, the housing/living quality was given a high priority, which required a higher technical and a more complex configuration. This is reflected in the evaluation in the partly quite low ratings of some of the technical and ecological indicators. Moreover, the model assumptions for the site quality were selected as very appropriate, resulting in a very high score for these indicators.

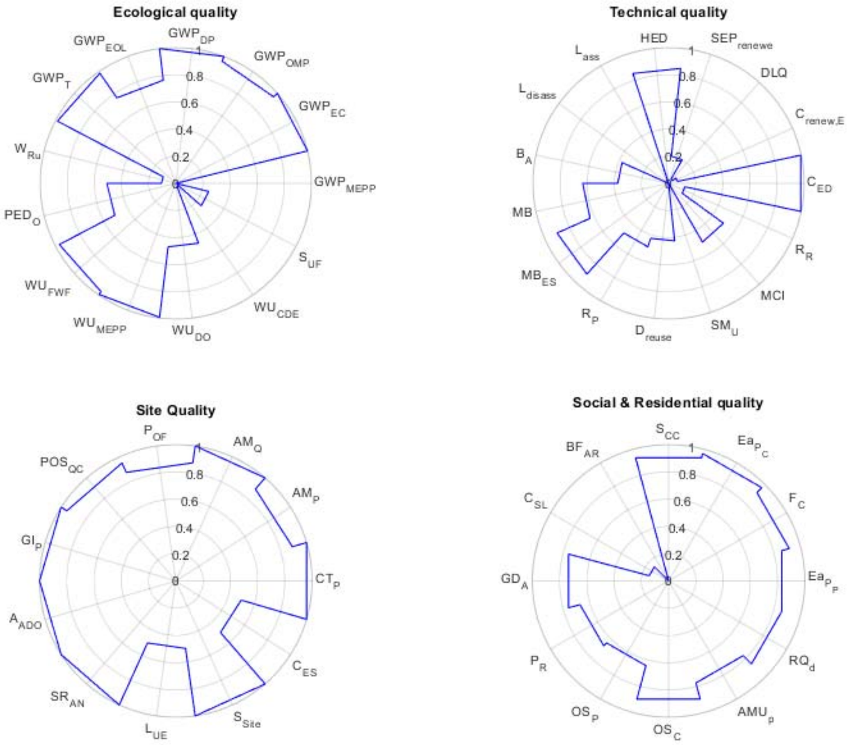

Figure 6 : Exemplary assessment plots for the scenario “Gap Module” (model Gapsolutely Fitting); all 51 indicators are normalized and scaled between 0 (low quality) and 1 (high quality); symbols/ abbreviations of the indicators used in the plots can be found in the list of symbols in the annex.

4.1.4 Life on Tracks

Figure 7 shows the visualization of the interdisciplinary assessment using the housing model "Tinytainer" as the theoretical “case study”. In this model, the parameters "level of ease of assemble/disassemble (L-ass/disass)" also have to be considered in a more differentiated way, similarly to the scenario “DonAutonom”, meaning that the whole construction is not easy and quick to assemble/disassemble, but the entire wagon can be moved easily and quickly from one location to another, and can thus definitely be considered “easy to assemble and disassemble" in terms of temporary use at one site. Here again, the appropriate adoption and modelling of the site parameters plays an important role in the high rating in this category.

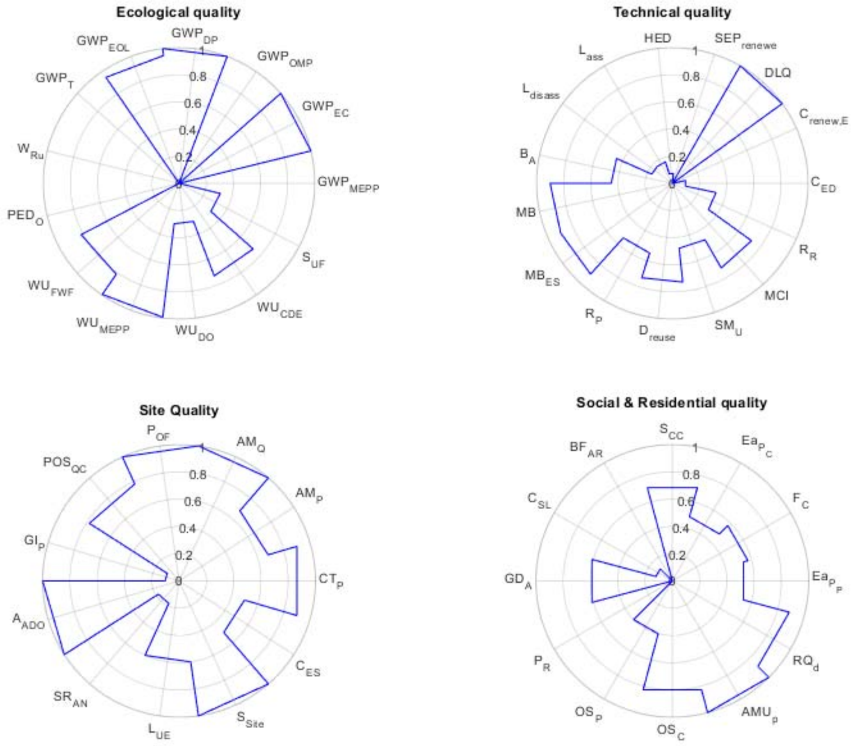

Figure 7 : Exemplary assessment plots for the scenario "Life on Tracks" (model Tinytainer); all 51 indicators are normalized and scaled between 0 (low quality) and 1 (high quality); symbols/ abbreviations of the indicators used in the plots can be found in the list of symbols in the annex.

4.1.5 Life Sharing to Go

Figure 8 shows the visualization of the interdisciplinary assessment using the housing model "Infactory" as the theoretical "case study". The peculiarity of this model is that the residential units are built in an existing hall, therefore, for example, the indicator "stock-usage factor" has been evaluated comparatively well, even if it has been assumed that some substantial adaptations and renewals have to be carried out in the exterior of the building. Due to the reuse of the hall, some of the ecological indicators (e.g., the GWP-indicators and water usage indicators) are also rated very well. Site and social qualities are assumed to be appropriate, too.

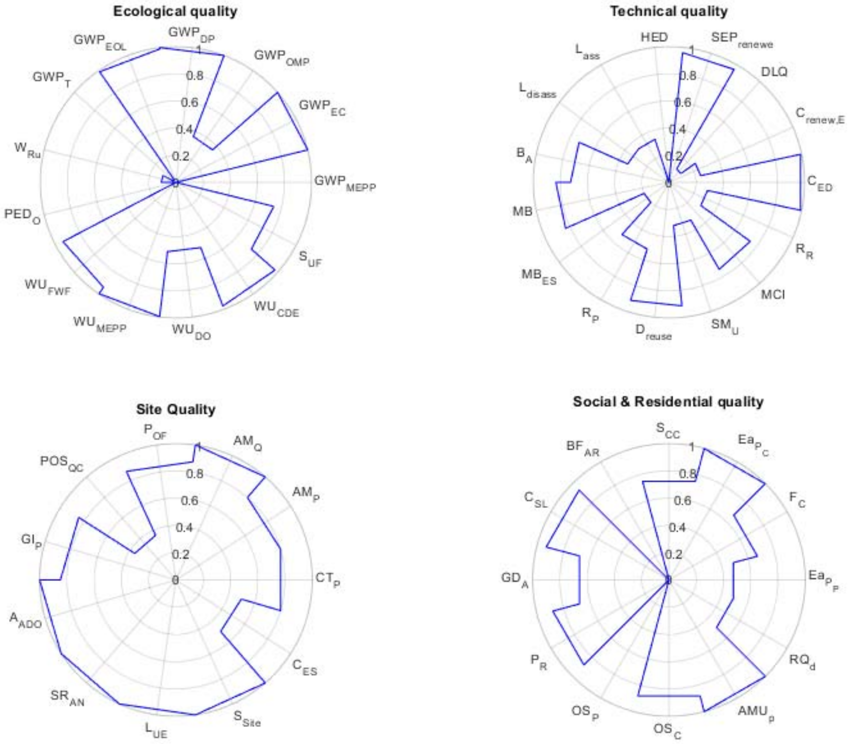

Figure 8 : Exemplary assessment plots for the scenario "Life sharing to go" (model " Infactory"); all 51 indicators are normalized and scaled between 0 (low quality) and 1 (high quality); symbols/ abbreviations of the indicators used in the plots can be found in the list of symbols in the annex.

4.1.6 Flat-Pack

Figure 9 shows the visualization of the interdisciplinary assessment using the housing model "Shop hopping box" as the theoretical "case study". Similar to the scenario "Life sharing to go", the peculiarity of this model is that an existing building (small store in the inner city) is used for temporary living. Thus, in this model the indicator "stock-usage factor" has been evaluated comparatively well, and due to the reuse of the shop, some of the ecological indicators (e.g., the GWP-indicators and water usage indicators) are also rated very well. Site and social qualities are assumed to be largely appropriate as well.

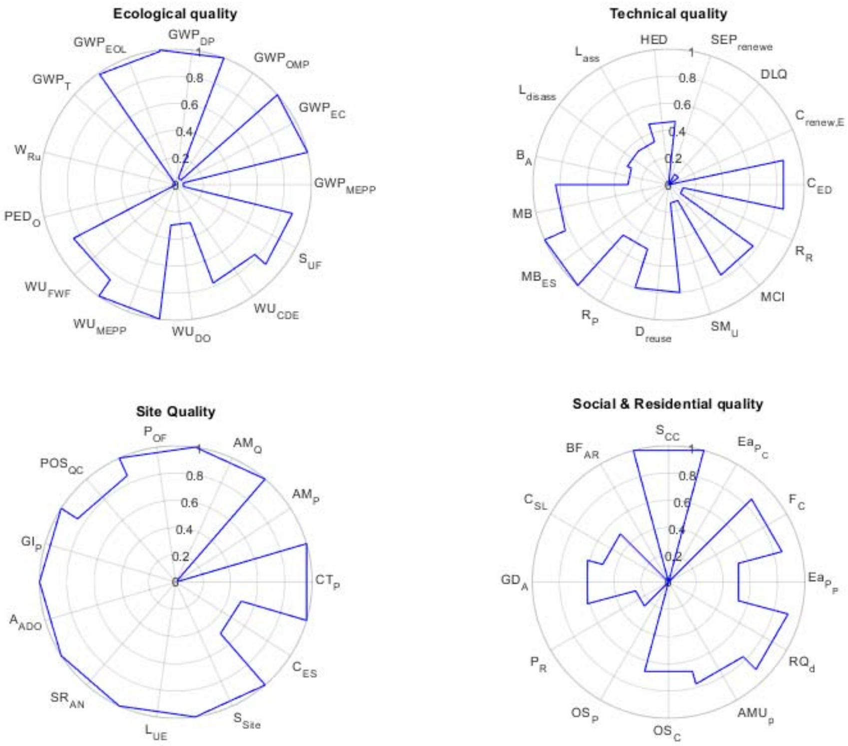

Figure 9 : Exemplary assessment plots for the scenario "Flat-Pack" (model Shop hopping box"); all 51 indicators are normalized and scaled between 0 (low quality) and 1 (high quality); symbols/ abbreviations of the indicators used in the plots can be found in the list of symbols in the annex.

5 CONCLUDING SUMMARY AND OUTLOOK

For the interdisciplinary evaluation and to answer the research hypotheses, an interdisciplinary (assessment) method was needed in the project. Due to the lack of suitable existing methods, a new methodological approach for the evaluation of eco-site-socio-technical processes has been developed. During the development it was important to find a quantitative method, which not only allows an evaluation, but also accompanies and supports the interdisciplinary cooperation in general. At the beginning of the project work, it was determined that, in addition to an interdisciplinary working language, the acceptance of individual solution approaches in the respective disciplines related to individual research questions. This circumstance can go so far that a partial aspect is regarded as supposedly ideal by one discipline and is not considered acceptable by another.

Therefore, a mathematical solution space was defined in which the acceptance can be mapped, called acceptance mapping. It was broken down into an acceptable range (which corresponds to an active endorsement), a tolerable range (which corresponds to a passive approval) and a range that can no longer be tolerated (which corresponds to an active rejection). For this purpose, in the first step, the essential properties or sub-processes of the solutions to be evaluated were identified. In the following, the indicators were constructed from these. When constructing the indicators, care was taken to ensure that they were as self-contained as possible and that their acceptance could be assessed as simply and with an interdisciplinary manner as possible. Care was also taken to ensure that no dilemma can occur in an indicator. To identify a possible dilemma, a later non- monotonic acceptance mapping was identified as a necessary condition, but whether this is also sufficient could not yet be clarified in the project. Likewise, in constructing the indicators, care was taken to ensure that a general view of a solution approach emerged from the indicators. Regarding pop-up housing environments, this means that rapidly changing characteristics (such as a change of location, a change of use or users) can be generated via a subsequent linkage of the pop-up housing environment assessment. The problem space thus found and spanned by the indicators was mapped into the interval [0,1] monotonically increasing or monotonically decreasing via the acceptance mapping developed for each indicator. During the development, each indicator was considered equal. This should allow for a later definition of an operation to incorporate location, usage, or users, and possibly provide a basis for the development of an algebraic structure.

The core of this assessment tool is the set of 51 indicators, which was developed in an interdisciplinary way and grouped according to the 4 categories “ecological quality, technical quality, site quality and social/residential quality”. The indicator set has been proven in a first step using the six temporary housing models as theoretical case studies. Although a more in-depth sensitivity analysis has yet to be carried out, particularly regarding the scaling for each indicator, and the derivation and abstraction of general principles and interrelations between the assessment indicators (e.g., the investigation of the tolerance limits of the indicators as well as the analysis of the dependencies and influences among each indicator), this first set of indicators and the principle method can now serve as an adequate, basic assessment approach for the sustainability evaluation and refinement of temporary housing options regarding technical, site, social and ecological aspects. Economic considerations are not covered in this approach so far but should be investigated in detail in the future and necessarily integrated at a later stage.

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ANNEX

List of symbols

Ecological Indicators

Abbreviation	Indicator
GWP_MEPP	GWP Material extraction and production phase.
GWP_EC	GWP construction phase
GWP_OMP	GWP operational phase and maintenance.
GWP_DP	GWP deconstruction phase.
GWP_EOL	GWP End of Life phase.
GWP_T	GWP emissions Total.
W_Ru	Water reuse.
PED_O	Primary energy demand – operation.
W_Fp	Full water footprint.
WP_FP	Product water footprint of materials used in building
WU_DO	Water use during operation.
WU_CD	Water use during construction and disassembly.
S_UF	Stock usage factor

Technical indicators

Abbreviation	Indicator
C_{ED}	Energy demand- cooling
$C_{renewe,E}$	Coverage energy, electrical.
DLQ	Daylight quality.
SEP_{renewe}	Share Energy Production Renewable.
HED	Energy demand- heating.
L_{ass}	Level of ease of assemble.
B_A	Level of building control.
MB	Maintenance building.
MB_{ES}	Maintenance building eng. Services.
R_P	Recycling potential.
D_{reuse}	Reuse Potential (End Of Life).
L_{disass}	Level of ease of disassembly.
SM_U	Secondary material utilization
MCI	Material circularity indicator
R_R	Realizable recycling factor

Site indicators

Abbreviation	Indicator
CT_P	Connection to public transport.
AM_P	Active mobility on the plot.
AM_Q	Active mobility in the quarter.
P_{OF}	Proximity to use-specific objects and facilities.
POS_{QC}	Access to public open spaces in the quarter and city.
GI_P	Green Infrastructure on the Plot.
A_{ADO}	Accessibility for assembly, dismantling and operating phase.
SR_{AN}	Suitability for residential use depending on ambient noise.
L_{UE}	Land use efficiency.
S_{Site}	Suitability of site
C_{ES}	Consumption of ecologically sensitive areas.

Indicators social and residential quality

Abbreviation	Indicator
Ea_{P_P}	Effective area per person.
F_C	Facility category.
Ea_{P_C}	Effective area per person (Community).
S_{CC}	Spaces conducive to communication.
BF_{AR}	Barrier-free accessible rooms.
C_{SL}	Changeability of the room size and layout.
GD_A	Gender+ and diversity aspects of built and open space structures on the plot.
P_R	Empowerment & type of participation.
OS_P	Private open spaces.
OS_C	Communal open spaces.
AMU_P	Open spaces of areas with mixed use.
RQ_d	High residential quality in the district.

Documentation **LCA Urban pop-up housing environments**

Julia Zeilinger, Sebastian Gollnow, Thomas Ladurner, Marion Huber-Humer

This document presents details of the LCA carried out for 6 pop-up housing models, which forms the basis for part of the indicator calculations described in detail in Deliverable D4 (ecological indicators). The following indicators are based on LCA calculations:

- Global warming potential
  - GWP Material extraction and production phase
  - GWP construction phase
  - GWP operational phase and maintenance
  - GWP deconstruction phase
  - GWP end of life phase
  - GWP total
- Fresh Water use
  - Product water footprint of materials used in building
  - Water use during construction and disassembly
  - Full water footprint[1]

The indicator values included in Deliverable D4 are calculated based on the detailed description of the 6 pop-up housing models shown in D3:

Name of pop-up housing model	Info	Total years in use (including relocations)
Pallet Shelter	Pallet Shelter is located at a brownfield / car park within the urban fabric. It is not placed	10, inhabited for max. of 3 months per year
Gapsolutely fitting	A single-use concrete staircase is used.	10
InFactory	InFactory makes use of a vacant hall.	30
BinnenBleiben	BinnenBleiben is implemented using discarded containers	15
TinyTainer	TinyTainer is implemented using discarded containers	10
Shop hopping box		10

Additional calculated variations are included in this LCA report, ranging from different total lifetimes of the pop-up housing models, including varying numbers of relocations respectively different variations of building materials (e.g. new or repurposed containers and materials). More details are given in the respective sections of the different housing models.

[1] Full water footprint is a sum of the indicators above. Additionally, water use during operation and water reuse was estimated based on literature data and expert estimates. Details can be found in Deliverable D4.

1 Goal of the Study

The goal of the study is to estimate the global warming potential and net water consumption of urban pop-up housing environments in the following life cycle stages:

- Product stage
- Construction stage
- Operation
- End-of-life stage

2 Scope of the study

2.1 Functional Unit

The following functional unit is considered:

- **1 m^2 built utilisable area used for 1 year.**

Built utilisable area of the pop-up environments:

	popup 1	**popup 2**	**popup 3**	**popup 4**	**popup 5**	**popup 6**
Name	Pallet Shelter	Gapsolutely fitting	InFactory	BinnenBleiben	TinyTainer	Shop hopping box
m^2	960	1700	2300	2000	400	50

These numbers are derived or calculated from plans and drawings that can be found in the detailed description of the housing models in Deliverable D3. It has to be noted, that in some housing models, main parts of the interior are included in the modelling (e.g. kitchen appliances, wall partitioning, etc.), in case they are essential for the integral concept of the respective housing model. In cases where residents themselves can resp. have to choose and equip their living space with appliances and furniture of their choice, these items are not integrated into the LCA calculations.

Use phase lifetime years and relocation times included:

	popup 1			popup 2			popup 3			popup 4			popup 5		popup 6			
Name	Pallet Shelter			Gapsolutely fitting			InFactory			BinnenBleiben[2]			TinyTainer[3]		Shop hopping box			
Lifetime	5	10	20	2	5	10	15	30	60	15	30	60	10	20	0.5	1	2	10
Number of times relocated (incl. replacement)	3	8	18	0	0	1	2	5	9	4	9	19	4	9	-	-	1	8
Number of times decommissioned	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

2.2 System boundaries

Modules of the product life cycle included in the LCA (X = declared module; MND = module not declared)

[2] According to considerations in Deliverable D3, BinnenBleiben will moor for up to 3 years at one location, then the ship will move (or be moved) as a whole, replacement refers to maintenance of the interior and facilities but not the ship hull as such.

[3] Analogous to BinnenBleiben, TinyTainer is also conceived as a mobile solution in which the living container is not rebuilt each time, but can be moved "as a whole" from one location to the next.

Production			Installation		Use stage							End-of-Life				Next product system
Raw material supply (extraction, processing, recycled material)	Transport to manufacturer	Manufacturing	Transport to building site	Installation	Use / application	Relocation	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport to EoL	Waste processing for reuse, recovery or recycling	Disposal	Reuse, recovery or recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	X	MND	x	MND	x	MND	X	x	x	X	X	X	X

2.3 Selection of Life cycle Impact Assessment methodology and resource use indicators

Following impacts and resources were included in the assessment:

- Global warming potential, following the IPCC 5th assessment Report (2014) characterisation method for the fossil global warming potential over a time period of 100 years.
- Net fresh water use

It shall be noted that the above impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emitted molecules would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.4 Software and Database

The LCA model was created using the GaBi 10 software and GaBi and ecoinvent 3.7.1. LCI databases.

3 Life Cycle Inventory Analysis

3.1 Data collection

Primary data was provided by project team members and are based on architectural modelling and expert judgment.

3.1.1 Raw materials and processes – background data

Data for up- and downstream raw materials and unit processes were obtained from the GaBi 10 database and ecoinvent 3.7.1. The table below shows the most relevant LCI datasets used in modelling the product systems. A documentation for all datasets can be found at:

- https://gabi.sphera.com/databases/gabi-data-search/

- https://www.ecoinvent.org/database/older-versions/ecoinvent-version-2/how-to-use-ecoinvent-2-online/database-search/database-search.html

Geography	Dataset name as in DB	Source
GLO	market for door, inner, wood	ecoinvent 3.7.1
GLO	market for window frame, wood-metal, U=1.6 W/m²K	ecoinvent 3.7.1
GLO	market for cookstove	ecoinvent 3.7.1
RER	market for EUR-flat pallet	ecoinvent 3.7.1
GLO	market for door, outer, wood-glass	ecoinvent 3.7.1
GLO	market for refrigerator	ecoinvent 3.7.1
GLO	market for door, outer, wood-aluminium	ecoinvent 3.7.1
GLO	market for washing machine	ecoinvent 3.7.1
GLO	market for photovoltaic panel, single-Si wafer	ecoinvent 3.7.1
GLO	market for intermodal shipping container, 40-foot	ecoinvent 3.7.1
EU-28	Sanitary ware (EN15804 A1-A3)	Sphera
EU-28	Dimpled sheets polyethylene (PE) (A1-A3)	Sphera
EU-28	Lightweight concrete block	Sphera
EU-28	Bath- and shower tub acrylic (EN15804 A1-A3)	Sphera
AT	Thermal energy from biomass (solid)	Sphera
EU-28	Particle board	Sphera
DE	Wooden window (1.00x2.10)	Sphera
DE	Winter wheat straw, at field (12% H_2O content) (economic allocation)	Sphera
EU-28	Glued laminated timber (EN15804 A1-A3)	Sphera
EU-28	Bitumen sheets G 200 S4 (EN15804 A1-A3)	Sphera
EU-28	Steel sections (EN15804 A1-A3)	Sphera
EU-28	Direct pressure laminate (DPL) (1m²) (MeisterWerke Schulte GmbH) (EN15804 A1-A3)	Sphera-EPD
EU-28	Oriented Strand Board (OSB) (4,5% Humidity) - Kronoply (A1-A3)	Sphera-EPD

3.1.2 Transportation (A4 and C2)

For all in- and outputs an average transport distance of **100 km** was assumed.

3.1.3 Installation stage (A5)

The installation stage accounts for the first installation of the pop-up environment. It includes estimates for diesel and electricity use of a range of construction machines used to assemble the pop-up environment. Energy consumption by power tools is assumed to be marginal and has not been included.

3.1.4 Use stage

3.1.4.1 Relocation (B2)

Some of the pop-up environments are relocated during their lifetime. Relocation includes disassembly and reassembly at a different location. It is estimated that energy required to disassemble and assemble equals the amount of energy required for life cycle stages A5 (installation) and C5 (deconstruction).

3.1.4.2 Replacements (B4)

The use stage has been modelled for all pop-up housing environments in the same way. It was assumed that 10% of the materials have to be replaced when pop-up environments are disassembled, relocated and reassembled. Relocation has been considered for all pop-up housing environments in at least one scenario (see Table in section 2.1).

3.1.5 Operational energy use, energy produced and water use (B6 and B7)

National and regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 10 database 2021. The following table shows LCI datasets used to model operational energy production.

Energy	Dataset	Geography	Source
Electricity	Electricity grid mix	AT	Sphera
Thermal energy from biomass	Thermal energy from biomass (solid)	AT	Sphera
Thermal energy district heating renewable	Thermal energy from biomass (solid)	AT	Sphera
Electricity from photovoltaic produced	Electricity from photovoltaic	EU	Sphera

Electricity produced by photovoltaic panels on site was included with the dataset "EU-28 Electricity from photovoltaic" (Sphera 2021). Exported solar electricity was expected to substitute the Austrian electricity grid mix. The potentially achievable benefit is reported separately as credit in module B6.

Thermal energy provided by district heating systems is assumed to be renewable and generated with solid biomass.

The annual energy demand and production per pop-up environment is as follows:

	Pallet Shelter	Gapsolutely fitting	InFactory	BinnenBleiben	TinyTainer	Shop hopping box	
Electricity	90948	33170	191654	78820	73790	6552	[kWh]
Biomass			446772				[kWh]
District heating renewable						7065	[kWh]
Photovoltaic electricity exported				20208			[kWh]

Operational water use (B7):

	Pallet Shelter	Gapsolutely fitting	InFactory	BinnenBleiben	TinyTainer	Shop hopping box	
Water irrigation	1200	0	0	0	0	0	l
Water use other	1728	3534	8658	1280	4560	456	l
Waste water	1728	3534	8658	1280	4560	456	l

3.1.6 End of Life Phase and Benefits and Loads Beyond the Production Systems Boundary

3.1.6.1 Deconstruction (C1)

For the deconstruction stage it was assumed that the same amount of energy is used as for the installation phase.

3.1.6.2 Waste processing (C3) and disposal (C4)

The end-of-life phase as well as benefits and loads beyond the production system are modelled in the same way for all pop-up houses. A waste collection rate of 100% has been assumed.

All metals are recycled. Steel recycling is based on the World Steel methodology and data, see World Steel (2017). The World Steel methodology follows the end-of-life approach, same as EAA (Atherton, 2006). This approach accounts for the full life cycle of a product, from cradle to grave, the 'grave' being the furnace into which the steel scrap is fed for recycling.

Plastic and wood components are assumed to be incinerated in a municipal waste incineration plant with energy recovery. Is assumed that electricity is fed into the Austrian electricity grid mix and that thermal energy from waste incineration replaces thermal energy from natural gas.

It is assumed that inert construction waste is landfilled.

For the end of life of planting substrates and soils it was assumed that these are transported 100km and reused. No burdens or benefits have been included for reuse.

Plant material (turf) was assumed to be composted.

3.1.6.3 Benefits and loads beyond the product system (D)

Steel scrap at the end of life is assumed to replace primary steel. Wood incinerated with recovery in a municipal waste incineration plant producing electricity and thermal energy is assumed to replace electricity from the Austrian grid mix and thermal energy from natural gas.

Module D (Next product system, including reuse, recovery or recycling potential) is considered in the indicator GWP total.

3.2 Pallet Shelter

3.2.1 Production phase (A1-A3)

The pallet shelter is modelled in four variations:

1. Placed in a green area using new EUR pallets.
2. Placed in a green area using discarded EUR pallets (production and EoL of pallets are excluded)
3. Placed on a car park using new EUR pallets.
4. Placed on a car park using discarded EUR pallets (production and EoL of pallets are excluded)

Note: The scenario called *"car park"* includes the following: In case the pallet shelter is placed on a vacant lot, such as brownfields or parking areas, additionally to the materials necessary to construct Pallet shelters, additional inputs are required to convert these lots ("car parks") into a "green space" to increase living quality and the cooling effect for the residents. Detailed considerations can be found in Deliverable D3.

PALLET SHELTER		
Module 1 - Floor		**Description**
Number of modules	*13*	*1*[no] number of modules required*
timber flooring (indoor)	936.0	[kg] wooden laminate flooring
timber flooring (outdoor)	545.2	[kg] wooden laminate flooring
EUR-Pallet	2860	[kg] standardized EUR-pallet (800x1200mm), 22 kg/pcs
Polyethylene sheet	117.3	[kg] plastic foil, vapour barrier (2mm)
Module 2 - Walls		**Description**
Number of modules	*13*	*1*[no] number of modules required*
OSB (oriented strand board)	2454.8	[kg] OSB (oriented strand board)
EUR-Pallet	2706	[kg] standardized EUR-pallet (800x1200mm), 22 kg/pcs
straw	404.7	[kg] straw (density 120 kg/m³)
glued laminated timber (density: 740 kg/m³) (pillar)	1555.8	[kg] glued laminated timber (density: 740 kg/m³) (wall)
glued laminated timber (density: 740 kg/m³) (beam)	31.3	[kg] glued laminated timber (density: 740 kg/m³) (wall)
Module 3 – Wall openings		**Description**
Number of modules	*13*	*1*[no] number of modules required*
external door, wood	36.5	[kg] external door, size 90x210cm
room door, wood	47.0	[kg] room door, size 80x210cm
window, glass + frame	219.1	[kg] front window
Module 4 - Roof		**Description**
Number of modules	*13*	*1*[no] number of modules required*
bitumen asphalt fabric foil (vapour barrier)	46.2	[kg] "Teerpappe"
timber flooring	1636.4	[kg] wooden laminate flooring
OSB (oriented strand board)	82.5	[kg] OSB (oriented strand board)
EUR-Pallet	1430	[kg] standardized EUR-pallet (800x1200mm), 22 kg/pcs
glued laminated timber (density: 740 kg/m³) (beam)	136.4	[kg] glued laminated timber (density: 740 kg/m³) (wall)

Module 5 – Pavillion / shading		**Description**
Number of modules	*13*	*1*[no] number of modules required*
concrete footing	6600.0	[kg] light concrete
waterproof shade sail	43.2	[kg] Sunsail
glued laminated timber (density: 740 kg/m³) (pillar)	929.4	[kg] glued laminated timber (density: 740 kg/m³) (wall)
Module 6 – Pathway		**Description**
Number of modules	*1*	*1*[no] number of modules required*
EUR-Pallet	18040.0	[kg] standardized EUR-pallet (800x1200mm), 22 kg/pcs
Module 7 – interior of residential units		**Description**
Number of modules	*13*	*1*[no] number of modules required*
water heater	3.2	[no] Water heater
refridgerator	33.9	[no] refrigerators
bathoom sink	8.0	[kg] ceramic bathroom sink
kitchen sink	8.0	[kg] ceramic kitchen sink
stove with 2 hotplates	4.5	[kg] of electric stoves
bathtub	19.0	[kg] bath tubs
washing machine	66.0	[kg] washing machines
toilet bowl (dry toilet)	25.0	[kg] ceramic toilet
Electricity and water supply		
Electric cables	187.1	[kg]
Drinking water pipes	522.9	[kg]
Warm water pipes	94.2	[kg]
Waste water pipes	413.8	[kg]

As mentioned above, in the “car park” variation of the Pallet Shelter housing model, it is placed on a vacant lot, such as brownfields or parking areas. Therefore, additionally to the materials above following inputs are required to convert these lots into a “green space”:

Greening of car park	Amount	Unit
Drainage mats (Polypropylene)	278.0	kg
Vegetation substrate	278130.0	kg
Turf	36370.0	kg

Output		
(greened) Area	2139	m²

The drainage mats are placed on the existing surface in order to protect it from mechanical damage and to prevent the applied soil from being washed away in case of strong downpours. As reference product, Maccaferri MacDrain M mats have been chosen.

3.2.2 Operation Phase (B7)

As for the irrigation of the lawn, a water consumption of 4 l/m²/day is assumed, based on a source that mentions this amount as typical evaporation sum of 1 m² of turf on hot summer days (Rasenexperte 2021). This approximation corresponds to values derived from an empirical study by Itten (2020), assuming that approximately 70% of annual water demand for irrigation occurs during the use phase of this housing model. The resulting water demand for the use phase of 70 days is 280 l/m² or 599045l in total.

3.2.3 Construction Phase (A5)

Use of construction machinery		

2 Pallet jacks (battery powered)	Calculation based on OEM data regarding energy consumption under industry standard measurement procedure
	Assumptions:
	• Working time per housing unit: 4h
	• Share of pallet jack utilization: 0.5
	• Use of two pallet jacks:
	  o Jungheinrich EJC M13 ZT (with lifting capability)
	  o Jungheinrich EJE M15 (without lifting capability)
		7.02 kWh (for all 13 units)

1 Trailer-mounted trailer crane (diesel powered)	Calculation: estimated working time Assumptions: • Working time per unit: 4h • Share of crane utilization: 0.5 • Reference model: AHK 30 • Engine power: 15.5 kW • Assumed system efficiency: 0.4	1007.50 kWh (for all 13 units) 102.81 l (with 9.8 kWh/l diesel)
1 Skid-steer loader ("Bobcat", diesel powered) *(Skid-steer loader is only needed in car park scenario)*	Construction of soil structure for turf lawns. Soil distribution - assumptions: • Reference model: Bobcat S530 • Volume of soil: 216.095 m³ (Area of 2160.95 m² with 0.1m soil thickness) • Loading capacity Bobcat: 0.4 m³ • Average trip length: 62.55 m² (calculated from corner to center of plot) • Average speed: 0.75x of maximum speed = 8.85 km/h • Added time factor for unaccounted working steps: 0.5 • Resulting time for distributing soil: 11.45 h • Average work load (based on carrying capacity): 0.571 • Fuel consumption at 0.5 work load (OEM data) = 7.60 l/h Soil compaction – assumptions: • Reference model: 122cm compaction roll for Bobcat skid-steer loaders • Resulting driving distance: 1771.27 m • Mass of compaction roll: 811.0 kg (OEM data) • Average speed: 5.00 km/h • Added time factor for unaccounted working steps: 0.25 • Resulting working time: 0.44 h	Soil distribution: 87.05 l Soil compaction: 4.69 l

	• Average work load (based on carrying capacity): 0.89 • Fuel consumption at 1.0 work load (OEM data): 10.60 l/h	

3.3 Gapsolutely Fitting

3.3.1 Production Phase (A1-A3)

Material list production. Two scenarios are included for Module 1:

1. The staircase (Module 1) is constructed using reinforced concrete. In case Gapsolutely Fitting is relocated, the staircase cannot be reused.
2. The staircase module (Module1) is constructed with steel. In case Gapsolutely Fitting is relocated, the staircase can be reused.

GAPSOLUTELY FITTING		
Module 1 – option 1: 'single use concrete staircase'	**staircase**	**Description**
Number of modules	*1*	*1*[no] number of modules required*
reinforced concrete (density: 2400 kg/m³) - slabs, steps	12216.0	[kg] reinforced concrete (density 2400 kg/m³)
reinforced concrete (density: 2400 kg/m³) - wall	249840.0	[kg] reinforced concrete (density 2400 kg/m³)
Module 1 - option 2: 'reusable steel staircase'		
hot dipped galvanized steel *(Stahl, feuerverzinkt)*	4100.0	[kg]

The remaining material composition stays the same:

:GAPSOLUTELY FITTING		
Module 2 - building envelope		**Description**
Number of modules	*1*	*1*[no] number of modules required*
glued laminated timber (density: 740 kg/m³) (pillar)	908.9	[kg] glued laminated timber (density: 740 kg/m³) (wall)
glued laminated timber (density: 740kg/m³) (slab internal)	542124.0	[kg] glued laminated timber (density: 740 kg/m³) (wall)
glued laminated timber (density: 740kg/m³) (slab external)	64135.8	[kg] glued laminated timber (density: 740 kg/m³) (wall)
Module 3 - building openings		**Description**
Number of modules	*1*	*1*[no] number of modules required*
external door, wood	1934.5	[kg] external door, size 90x210cm
window, glass + frame	1753.0	[kg] front window
Module 4 - roof		**Description**
Number of modules	*1*	*1*[no] number of modules required*
timber flooring	44792.2	[kg] wooden laminate flooring
vapour barrier (plastic foil)	94.8	[kg] vapour barrier plastic foil
Module 5 - foundation		**Description**
Number of modules	*1*	*1*[no] number of modules required*
reinforced concrete (density: 2400 kg/m³) - plinths	6480.0	[kg] reinforced concrete (density 2400 kg/m³)
glued laminated timber (density: 740 kg/m³) (pillar)	251.6	[kg] glued laminated timber (density: 740 kg/m³) (wall)
Module 6 – terraces		**Description**

Number of modules	*1*	*1*[no] number of modules required*
timber flooring (outdoor)	39782.4	[kg] wooden laminate flooring
Module 7 – open areas		**Description**
Number of modules	*1*	*1*[no] number of modules required*
light concrete (density: 2100 kg/m³)	224196.0	[kg] light concrete
Module 8 – garbage / bike room		**Description**
Number of modules	*1*	*1*[no] number of modules required*
glued laminated timber (density: 740 kg/m³) (slab)	10767.0	*Kg*
glued laminated timber (density: 740 kg/m³) (roof)	10767.0	*Kg*
glued laminated timber (density: 740 kg/m³) (wall)	14896.2	*Kg*
Electricity and water supply		
Number of modules	*1*	*1*[no] number of modules required*
Electric cables	222.5	kg
Drinking water pipes	363.9	kg
Warm water pipes	336.6	kg
Waste water pipes	346.0	kg

3.3.2 Construction Phase (A5)

Use of construction machinery		
1 Construction crane (AC powered)	Calculation: $W = m * g * \Delta h$ Assumptions: • Sum of building mass (excl. foundation modules) is lifted on average to half of 1.25x the final building height. • Assumed lifting system efficiency: 0.8 • Correction factor for share of unaccounted mass: 0.25	44.47 kWh
1 Scissor lift (battery powered)	Assumptions: • Construction time: 2.5 months • Workdays per month: 27.74 • Working hours per day: 8.0 h • Reference model: PB S101-12E • Engine power: 8.0 kWh • Share of scissor lift utilization: 0.05 • Average engine load: 0.5 • Assumed lifting system efficiency: 0.8	108.71 kWh
1 Crawler Excavator (diesel)	Levelling and preparation of construction site. Assumptions: • Required time: 8h Consumption data, based on the average of data recorded by Winkler, C. (2017) for excavators with operating weight of 20-25t: • Engine power: 110 kW • Average fuel consumption: 0,14 l/kWh	123.20 l

	Excavation work for foundation plinths. Data from Winkler, C. (2017) apply here, too. Assumptions: • Required time: 2 working days = 16h	246.40 l
1 Concrete pump (diesel)	Pumping of wet concrete for foundations, walls, stairs and slabs of the staircase. Assumptions: • Due to a lack of technical data of mobile concrete mixers with pumps, use of a stationary concrete pump is assumed • Reference model: BSA 1407 D5 • Engine power: 105 kW • Max. volume: 73.0 m³/h • Full load conditions are assumed • Resulting time under full load: 1.79h • Assumed diesel engine efficiency: 0.4 • Assumed energy content of diesel: 9.8 kWh/l	470.24 kWh 47.98 l diesel

As for the scenario with reusable staircase components, diesel demand for concrete pumping decreases to 6.79 l, whilst electricity consumption for lifting tasks increases to 68,322 kWh.

3.4 InFactory

3.4.1 Production Phase (A1-A3)

Two scenarios were modelled:

1. Including the production and end of life of the hall
2. Excluding the hall (use of pre-existing, vacant hall)

INFACTORY		
Module 1 – living unit for 2 people		**Description**
Number of modules	*4*	*1*[no] number of modules required*
room door, wood	23.5	[kg] room door, size 80x210cm
shower	19.0	[kg] shower (0,75x0,75m)
bathroom sink	8.0	[kg] ceramic bathroom sink
steel frame (structural) (density: 7500 kg/m³)	2850.0	[kg] structural steel (density 7500 kg/m³)
straw (insulation)	304.8	[kg] straw (density 120 kg/m³)
glued laminated timber (density: 740 kg/m³) (wall)	3196.8	[kg] glued laminated timber (density: 740 kg/m³) (wall)
water toilet bowl	25.0	[kg] ceramic toilet
window, glass + frame	36.5	[kg]front window
Module 2 – living unit for 3 people		**Description**
Number of modules	*8*	*1*[no] number of modules required*
room door, wood	23.5	[kg]room door, size 80x210cm
shower	19.0	[kg] shower (0,75x0,75m)
bathroom sink	8.0	[kg] ceramic bathroom sink
steel frame (structural) (density: 7500 kg/m³)	3750.0	[kg] structural steel (density 7500 kg/m³)
water toilet bowl	25.0	[kg] ceramic toilet
window, glass + frame	36.5	[kg] front window
Module 3 – living unit for 4 people		**Description**
Number of modules	*4*	*1*[no] number of modules required*
shower	19.0	[kg] shower (0,75x0,75m)
bathroom sink	8.0	[kg] ceramic bathroom sink
steel frame (structural) (density: 7500 kg/m³)	4650.0	[kg] structural steel (density 7500 kg/m³)
straw (insulation)	1283.8	[kg] straw (density 120 kg/m³)
glued laminated timber (density: 740 kg/m³) (wall)	4824.8	[kg] glued laminated timber (density: 740 kg/m³) (wall)
water toilet bowl	25.0	[kg] ceramic toilet
window, glass + frame	36.5	[kg] front window
Electricity and water supply		
Electric cables	198.7	kg
Drinking water pipes	530.1	kg
Warm water pipes	504.9	kg
Waste water pipes	460.9	kg
Module 4 – Floor		**Description**
Number of modules	*1*	*1*[no] number of modules required*

steel foot, galvanised steel	6407.5	[kg] galvanised steel, steel foot
EPS insulation	153.6	[kg] EPS boards for insulation, 4mm thickness
aluminium foil, insulation	2601.6	[kg] aluminium foil layer, 0,5mm thickness
linoleom floor panel	4416.0	[kg] linoleom floor panel, 2mm, 60x60cm
Module 5 – Common areas with kitchens		**Description**
Number of modules	*1*	*1*[no] number of modules required*
stove	590.4	kg electric stove
kitchen sink	78.2	kg stainless steel kitchen sink
Suction hood	142.4	kg] stainless steel suction hood
furniture wood, kitchen cabinet	640.0	[kg] furniture wood (Ikea-Quality)
refrigerator	516.5	[kg refrigerator
Module 6 – Green walls		**Description**
Number of modules	*4*	*1*[no] number of modules required*
wooden plant wall type 1	2047.5	[kg] glued laminated timber (density: 740 kg/m³) (wall)
wooden plant wall type 2	1023.75	[kg] glued laminated timber (density: 740 kg/m³) (wall)

3.4.2 Construction Phase (A5)

Use of construction machinery		

2 Pallet jacks (battery powered)	Calculation based on OEM data regarding energy consumption under industry standard measurement procedure
	Assumptions:
	• Working time: 1 month
	• Working days per month: 21.74
	• Working hours per day: 8 h
	• Share of pallet jack utilization: 0.2
	• Resulting machine utilization time: 34.79 h
	• Use of two pallet jacks:
	  o Jungheinrich EJE M15
	  o Jungheinrich EJE M13 (with lifting capability)
		33.74 kWh

1 Construction elevator (AC powered)	Calculation: $W = m * g * \Delta h$ Assumptions: • Total of accounted mass is lifted to the first floor of a factory building with 5m storey height and 0.5m ceiling thickness = 5.5 m • Assumed lifting system efficiency: 0.8 • Correction factor for share of unaccounted mass: 0.5 • Assumed max. payload: 1000 kg • Resulting number of liftings: 225 • Assumed elevator cabin weight: 500 kg • For downward movements, breaking is assumed to be performed by hydraulic cylinders. The resulting heat is dissipated to the environment.	6.33 kWh

3.5 BinnenBleiben

3.5.1 Production Phase (A1-A3)

Two scenarios were modelled:

1. Production using new containers
2. Production using discarded containers (excluding production and end of life of containers)

Note: The weight of the ship itself was not included in the calculations due to lack of LCA data regarding the ship hull.

BinnenBleiben		
Module 1 – platform		**Description**
Number of modules	*1*	*1*[no] number of modules required*
steel frame (structural) (density: 7500 kg/m³)	180000.0	[kg] structural steel (density 7500 kg/m³)
Module 2 – staircase		**Description**
Number of modules	*1*	*1*[no] number of modules required*
steel frame (structural) (density: 7500 kg/m³)	65700.0	[kg] structural steel (density 7500 kg/m³)
Module 3 – openings		**Description**
Number of modules	*1*	*1*[no] number of modules required*
external door, wood	328.5	[kg] external door, size 90x210cm
room door, wood	141.1	[kg] room door, size 80x210cm
Module 4 – common areas		**Description**
Number of Modules	*1*	*1*[no] number of modules required*
Furniture wood	771.2	[kg] furniture wood
Shower	53.0	[kg] shower (0,75x0,75m)
bathroom sink	60.3	[kg] ceramic bathroom sink
Steel	579450.0	[kg] structural steel (density 7500 kg/m³)
Straw	8652.0	[kg] straw (density 120 kg/m³)
washing machine	396.0	[kg] washing machines
Toilet bowl	122.1	[kg] ceramic toilet
plaster board (Gipskartonplatten)	2599.2	[kg] Gipskartonplatten, wall finish
gypsum Plaster (Putz), wall finish	12650.0	[kg] Putz, wall finish
Module 5 – greening, open areas		**Description**
Number of modules	*1*	*1*[no] number of modules required*
potting soil	43740.5	[kg] potted soil, for high raised beds on terrace,
Furniture wood	6177.6	[kg] furniture wood
Module 6 – Living unit (type 1, consisting of 2 containers)		**Description**
Number of modules	*4*	*1*[no] number of modules required*
20ft standard shipping container	4400.0	[kg] ISO Shipping container20ft (unit weight: 2200kg)

wool insulation	391.3	[kg] wool insulation
gypsum Plaster (Putz), wall finish	1925.6	[kg] Putz, wall finish
Door	36.5	[kg] external door, size 90x210cm
Door	73.0	[kg] external door, size 90x210cm
Furniture wood	300.7	[kg] furniture wood
Laminated flooring	491.4	[kg] wooden laminate flooring
Refrigerator	33.9	[kg]
Shower	53.0	[kg] shower (0,75x0,75m)
Sink	15.1	[kg] ceramic bathroom sink
Sink	3.6	[kg] Kitchen sink
Steel	1050.0	[kg] structural steel (density 7500 kg/m³)
Stove	36.9	[kg] of electric stoves
Ceramic toilet	30.5	[kg] ceramic toilet
window	73.0	[kg] front window
Module 7 – living unit (type 2, consisting of 3 containers)		**Description**
No of modules	*4*	*no of units*
20ft standard shipping container	6600.0	[kg] ISO Shipping container20ft (unit weight: 2200kg)
wool insulation	576.1	[kg] wool insulation
gypsum Plaster (Putz), wall finish	2946.4	[kg] Putz, wall finish
Door	109.5	[no] external door, size 90x210cm
Furniture wood	313.9	[kg] furniture wood
Laminated flooring	729.3	[kg] wooden laminate flooring
refridgerator	33.9	[no] refrigerators
Shower	53.0	[kg] shower (0,75x0,75m)
kitchen sink	3.6	[kg] ceramic kitchen sink
Steel	1050.0	[kg] structural steel (density 7500 kg/m³)
stove with 2 hotplates	4.5	[kg] of electric stoves
toilet bowl (dry toilet)	30.5	[kg] ceramic toilet
Window	109.6	[kg] front window
Electricity and water supply		**Description**
Electric cables	348.7	kg
Drinking water pipes	438.9	kg
Warm water pipes	113.6	kg
Grey water pipes	236.7	kg
Waste water pipes	426.9	kg

3.5.2 Construction Phase (A5)

Use of construction machinery		
1 Mobile crane (diesel)	Calculation: estimated working time Assumptions: • Total construction time: 2 months	1817.55 kWh 185.46 l (with 9.8 kWh/l diesel)

	• Working days per month: 21.74 • Working hours per day: 8 h • Share of mobile crane utilization: 0.1 • Reference model: Liebherr LTM 1030-2.1 • Engine power: 209 kW • Assumed system efficiency: 0.4 • Assumed engine load for lifting: 0.1	
1 Forklift (diesel)	Calculation based on OEM data regarding energy consumption under industry standard measurement procedure Assumptions • Total construction time: 2 months • Working days per month: 21.74 • Working hours per day: 8 h • Share of mobile crane utilization: 0.1 • Reference model: Jungheinrich DFG 435s • Fuel consumption (OEM data according to EN 16796): 3,10l/h	107.84 l

3.6 TinyTainer

3.6.1 Production Phase (A1-A3)

Two scenarios were modelled:

1. Production using new containers
2. Production using discarded containers (excluding production and end of life of containers)

TINYTAINER		
Module 1 – container hull		**Description**
Number of modules	*10*	*1*[no] number of modules required*
40ft standard shipping container	3800.0	[kg] ISO Shipping container 40ft
plaster board (Gipskartonplatten)	1079.2	[kg] Gipskartonplatten, wall finish
timber flooring (indoor)	202.8	[kg] wooden laminate flooring
straw (insulation)	727.2	[kg] straw (density 120 kg/m³)
Module 2 – platform terrace		**Description**
Number of modules	*10*	*1*[no] number of modules required*
Laminated flooring	464.1	[kg] wooden laminate flooring
steel frame (structural) (density: 7500 kg/m³)	4800.0	[kg] structural steel (density 7500 kg/m³)
glued laminated timber (density: 740 kg/m³) (pillar)	2316.2	[kg] glued laminated timber (density: 740 kg/m³) (wall)
washing machine	66.0	[kg] washing machines
Module 3 – container openings		**Description**
Number of modules	*10*	*1*[no] number of modules required*
external door, wood	109.5	kg external door, size 90x210cm
room door, wood	23.5	kg room door, size 80x210cm
Module 4 – living module		**Description**
Number of modules	*10*	*1*[no] number of modules required*
Furniture wood	487.2	[kg] furniture wood
Shower	53.4	[kg] shower (0,75x0,75m)
bathroom sink	15.9	[kg] ceramic bathroom sink
Kitchen Sink	4.0	[kg] Kitchen sink
Stove	4.5	[kg] of electric stoves
Toilet bowl	28.7	[kg] ceramic toilet
Electricity and water supply		
Electric cables	108.8	[kg]
Drinking water pipes	244.8	[kg]
Warm water pipes	33.5	[kg]
Waste water pipes	271.6	[kg]

3.6.2 Construction Phase (A5)

Use of construction machinery		
1 Mobile crane (diesel)	Use: Lifting containers from trucks onto flatbed freight cars	418,00 kWh

	Calculation: estimated working time Assumptions: • Estimated construction time: 8 h • Reference model: Liebherr LTM 1030-2.1 • Engine power: 209 kW • Assumed system efficiency: 0.4 • Assumed engine load for lifting: 0.1	42,65 l (with 9.8 kWh/l diesel)
1 Forklift (diesel)	Use: final assembly (e.g. terraces) and lifting of residual interior components. Calculation based on OEM data regarding energy consumption under industry standard measurement procedure Assumptions • Total construction time: 0.5 months • Working days per month: 21.74 • Working hours per day: 8 h • Share of mobile crane utilization: 0.25 • Reference model: Jungheinrich DFG 435s • Fuel consumption (OEM data according to EN 16796): 3,10l/h	67,40 l

3.7 Shop hopping box

3.7.1 Production Phase (A1-A3)

SHOP HOPPING BOX		
Module 1 – single bed module		**Description**
Number of modules	*1*	*1*[no] number of modules required*
furniture wood (bed, table)	795.6	[kg] furniture wood
glued laminated timber (density: 740 kg/m³) (wall)	806.6	[kg] glued laminated timber (density: 740 kg/m³) (wall)
Module 2 – bathroom module		**Description**
Number of modules	*1*	*1*[no] number of modules required*
Door	36.5	[kg] external door, size 90x210cm
shower	12.0	[kg] shower (0,75x0,75m)
bathroom sink	15.9	[kg] ceramic bathroom sink
glued laminated timber (density: 740 kg/m³) (pillar)	577.2	[kg] glued laminated timber (density: 740 kg/m³) (wall)
Module 3 – double bed module		**Description**
Number of modules	*1*	*1*[no] number of modules required*
furniture wood (bed, table)	1060.8	[kg] furniture wood
glued laminated timber (density: 740 kg/m³) (wall)	873.2	[kg] glued laminated timber (density: 740 kg/m³) (wall)
Module 4 – kitchen module		**Description**
Number of modules	*1.0*	*1*[no] number of modules required*
Refrigerator	33.9	[kg] refrigerators
Kitchen Sink	4.0	[kg] Kitchen sink
Stove	4.5	[kg] of electric stoves
glued laminated timber (density: 740 kg/m³) (beam)	310.8	[kg] glued laminated timber (density: 740 kg/m³) (wall)
Electricity and water supply		
Drinking water pipes	15.0	kg
Warm water pipes	11.6	kg
Waste water pipes	12.0	kg

3.7.2 Construction Phase (A5)

Use of construction machinery		
1 Pallet jack (battery powered)	Calculation based on OEM data regarding energy consumption under industry standard measurement procedure Assumptions: • Working time per unit: 8 • Share of pallet jack utilization: 0.2 • Reference model: Jungheinrich EJC M13 ZT (with lifting capability) • Energy consumption (OEM data according to “EN cycle”): 0.91 kWh/h	1.46 kWh

4 Life Cycle Impact Assessment

4.1 Global warming potential

Global Warming Potential kg CO_2e per m² and year (IPCC AR5 GWP100, excl. biogenic carbon)

Lifetime, scenario name[4]	A1-A3	A4	A5	B2	B4	B6	B6 credit	B7	C1	C2	C3	C4	D	Net impact
5 Pallet shelter	32	0.33	0.019	0.12	0.82	30	0	0.0016	0.019	0.44	2.7	0.27	-22	45
10 Pallet shelter	16	0.17	0.0097	0.15	0.55	30	0	0.0016	0.0097	0.22	1.3	0.13	-11	38
20 Pallet shelter	8.1	0.083	0.0048	0.17	0.32	30	0	0.0016	0.0048	0.11	0.67	0.067	-5.5	34
5 Pallet shelter (discarded pallets)	25	0.32	0.019	0.12	0.85	30	0	0.0016	0.019	0.32	2.3	0.27	-14	45
10 Pallet shelter (discarded pallets)	13	0.16	0.0097	0.15	0.61	30	0	0.0016	0.0097	0.16	1.2	0.13	-7	38
20 Pallet shelter (discarded pallets)	6.3	0.08	0.0048	0.17	0.32	30	0	0.0016	0.0048	0.08	0.58	0.067	-3.5	34
5 Pallet shelter, car park	64	0.33	0.02	0.12	2.94	30	0	0.092	0.019	0.44	5.9	0.27	-22	82
10 Pallet shelter, car park	48	0.17	0.0098	0.15	3.37	30	0	0.092	0.0097	0.22	4.6	0.13	-11	76
20 Pallet shelter, car park	40	0.083	0.005	0.17	3.45	30	0	0.092	0.0048	0.11	3.9	0.067	-5.8	72
5 Pallet shelter, car park (discarded pallets)	57	0.32	0.02	0.12	2.96	30	0	0.092	0.019	0.32	5.5	0.27	-14	83
10 Pallet shelter, car park (discarded pallets)	44	0.16	0.0098	0.15	3.32	30	0	0.092	0.0097	0.16	4.4	0.13	-7.3	75
20 Pallet shelter, car park (discarded pallets)	38	0.08	0.005	0.17	3.44	30	0	0.092	0.0048	0.08	3.8	0.067	-3.8	72
2 Gapsolutely fitting, single use concrete stairs	120	2.7	0.016	0	0	6.1	0	0.0016	0.016	2.7	6.1	2.2	-120	20
5 Gapsolutely fitting, single use concrete stairs	50	1.1	0.0063	0	0	6.1	0	0.0016	0.0063	1.1	2.4	0.87	-48	14
10 Gapsolutely fitting, single use concrete stairs	27	0.67	0.0031	0.0063	0.06	6.1	0	0.0016	0.0031	0.67	1.2	0.67	-24	12
2 Gapsolutely fitting, steel stairs	120	2.2	0.016	0	0	6.1	0	0.0016	0.016	2.2	6.1	1	-120	18
5 Gapsolutely fitting, steel stairs	47	0.87	0.0063	0	0	6.1	0	0.0016	0.0063	0.87	2.4	0.41	-48	10
10 Gapsolutely fitting, steel stairs	24	0.44	0.0031	0.0063	0.02	6.1	0	0.0016	0.0031	0.44	1.2	0.2	-24	8
15 InFactory without hall	2.4	0.024	0.00011	0.00042	0.02	29	0	0.003	0.00011	0.024	0.11	0	-0.92	31
30 InFactory without hall	1.2	0.012	0.000053	0.00053	0.01	29	0	0.003	0.000053	0.012	0.056	0	-0.46	30
60 InFactory without hall	0.61	0.0061	0.000026	0.00048	0.01	29	0	0.003	0.000026	0.006	0.028	0	-0.23	29
15 InFactory with hall	10	0.024	0.00011	0.00042	0.13	29	0	0.003	0.00011	0.024	0.56	0	-0.92	39
30 InFactory with hall	8.9	0.012	0.000053	0.00053	0.15	29	0	0.003	0.000053	0.012	0.5	0	-0.46	38

[4] C:\Users\abfuser\Filr\Netzwerkordner\DATAH81000\H813\PROJEKTE\Pop-up housing\WP3\0 ARCH. MODELLING (Gaetano)\0_material lists_revised_LCA Documentation\LCIA 20211012.xlsx

60 InFactory with hall	8.3	0.0061	0.000026	0.00048	0.13	29	0	0.003	0.000026	0.006	0.47	0	-0.23	38
15 BinnenBleiben with new containers	15	0.096	0.0056	0	0.323013	12	-0.87	0.00051	0.0056	0.095	0.11	0.012	-3.2	24
30 BinnenBleiben with new containers	7.6	0.048	0.0028	0	0.184767	12	-0.87	0.00051	0.0028	0.048	0.057	0.0059	-1.6	17
60 BinnenBleiben with new containers	4.1	0.024	0.0014	0	0.10703	12	-0.87	0.00051	0.0014	0.024	0.029	0.0029	-0.8	15
15 BinnenBleiben with discarded containers	9.2	0.085	0.0056	0	0.22112	12	-0.87	0.00051	0.0056	0.085	0.11	0.012	-1.2	20
30 BinnenBleiben with discarded containers	4.9	0.042	0.0028	0	0.133737	12	-0.87	0.00051	0.0028	0.043	0.057	0.0059	-0.59	16
60 BinnenBleiben with discarded containers	2.7	0.021	0.0014	0	0.078657	12	-0.87	0.00051	0.0014	0.021	0.029	0.0029	-0.29	14
10 TinyTainer with new containers	54	0.27	0.0097	0	1.41964	57	0	0.009	0.0097	0.26	0.92	0.041	-20	94
20 TinyTainer with new containers	27	0.13	0.0048	0	0.7983	57	0	0.009	0.0048	0.13	0.46	0.02	-10	76
10 TinyTainer with discarded containers	19	0.19	0.0097	0	0.51764	57	0	0.009	0.0097	0.19	0.92	0.041	-7.4	70
20 TinyTainer with discarded containers	9.4	0.097	0.0048	0	0.28683	57	0	0.009	0.0048	0.097	0.46	0.02	-3.7	64
0.5 Shop hopping box	110	1.4	0.0053	0	0	43	0	0.0072	0.0053	1.4	9.2	0	-100	65
1 Shop hopping box	56	0.68	0.0027	0	0	43	0	0.0072	0.0027	0.68	4.6	0	-50	55
2 Shop hopping box	28	0.34	0.0013	0.0027	0.30	43	0	0.0072	0.0013	0.34	2.3	0	-25	49
10 Shop hopping box	5.6	0.068	0.00027	0.0042	0.10	43	0	0.0072	0.00027	0.068	0.46	0	-5	44

4.2 Net use of fresh water

Net use of fresh water in m³ per m² and year

Lifetime, scenario name[5]	A1-A3	A4	A5	B2	B4	B6	B6 credit	B7	C1	C2	C3	C4	D	Net impact
5 Pallet shelter	0.26	0.00029	0.000016	0.000096	0.021	0.28	0	0.0013	0.000016	0.00039	0.17	0.00089	-0.085	0.65
10 Pallet shelter	0.13	0.00015	0.000008	0.00013	0.014	0.28	0	0.0013	0.000008	0.00019	0.085	0.00044	-0.042	0.47
20 Pallet shelter	0.064	0.000073	0.000004	0.00014	0.008	0.28	0	0.0013	0.000004	0.000096	0.043	0.00022	-0.021	0.38
5 Pallet shelter (discarded pallets)	0.13	0.00028	0.000016	0.000096	0.011	0.28	0	0.0013	0.000016	0.00028	0.11	0.00089	-0.054	0.48
10 Pallet shelter (discarded pallets)	0.064	0.00014	0.000008	0.00013	0.007	0.28	0	0.0013	0.000008	0.00014	0.054	0.00044	-0.027	0.38
20 Pallet shelter (discarded pallets)	0.032	0.000071	0.000004	0.00014	0.004	0.28	0	0.0013	0.000004	0.000071	0.027	0.00022	-0.013	0.33
5 Pallet shelter, car park	1.2	0.00029	0.000016	0.000096	0.077	0.28	0	0.63	0.000016	0.00039	0.17	0.00089	-0.086	2.27
10 Pallet shelter, car park	1.1	0.00015	8.1E-06	0.00013	0.092	0.28	0	0.63	0.000008	0.00019	0.089	0.00044	-0.044	2.15
20 Pallet shelter, car park	1	0.000073	4.1E-06	0.00014	0.092	0.28	0	0.63	0.000004	0.000096	0.047	0.00022	-0.022	2.03
5 Pallet shelter, car park (discarded pallets)	1.1	0.00028	0.000016	0.000096	0.069	0.28	0	0.63	0.000016	0.00028	0.11	0.00089	-0.055	2.14
10 Pallet shelter, car park (discarded pallets)	1	0.00014	8.1E-06	0.00013	0.082	0.28	0	0.63	0.000008	0.00014	0.058	0.00044	-0.028	2.02
20 Pallet shelter, car park (discarded pallets)	1	0.000071	4.1E-06	0.00014	0.091	0.28	0	0.63	0.000004	0.000071	0.031	0.00022	-0.015	2.02
2 Gapsolutely fitting, single use concrete stairs	0.52	0.0024	0.000018	0	0	0.057	0	9.9E-06	0.000018	0.0024	0.94	0.0072	-0.46	1.07
5 Gapsolutely fitting, single use concrete stairs	0.21	0.00096	7.3E-06	0	0	0.057	0	9.9E-06	7.3E-06	0.00096	0.38	0.0029	-0.18	0.47
10 Gapsolutely fitting, single use concrete stairs	0.11	0.00059	3.7E-06	7.3E-06	0.002	0.057	0	9.9E-06	3.7E-06	0.00059	0.19	0.0022	-0.092	0.27
2 Gapsolutely fitting, steel stairs	0.51	0.0019	0.000018	0	0	0.057	0	9.9E-06	0.000018	0.0019	0.94	0.0034	-0.46	1.05
5 Gapsolutely fitting, steel stairs	0.2	0.00076	7.3E-06	0	0	0.057	0	9.9E-06	7.3E-06	0.00076	0.38	0.0013	-0.18	0.46
10 Gapsolutely fitting, steel stairs	0.1	0.00038	3.7E-06	7.3E-06	0.002	0.057	0	9.9E-06	3.7E-06	0.00038	0.19	0.00067	-0.092	0.26
15 InFactory without hall	0.012	0.000021	8.1E-08	3.2E-07	0.000	0.41	0	0.000018	8.1E-08	0.000021	0.0056	0	-0.0033	0.42
30 InFactory without hall	0.0059	0.000011	4.1E-08	4.1E-07	0.000	0.41	0	0.000018	4.1E-08	0.000011	0.0028	0	-0.0016	0.42
60 InFactory without hall	0.0029	5.3E-06	2E-08	3.7E-07	0.000	0.41	0	0.000018	2E-08	5.3E-06	0.0014	0	-0.00082	0.41
15 InFactory with hall	0.073	0.000021	8.1E-08	3.2E-07	0.001	0.41	0	0.000018	8.1E-08	0.000021	0.0067	0	-0.0033	0.49

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30 InFactory with hall	0.067	0.000011	4.1E-08	4.1E-07	0.001	0.41	0	0.000018	4.1E-08	0.000011	0.0039	0	-0.0016	0.48
60 InFactory with hall	0.064	5.3E-06	2E-08	3.7E-07	0.001	0.41	0	0.000018	2E-08	5.3E-06	0.0025	0	-0.00082	0.48
15 BinnenBleiben with new containers	0.11	0.000084	4.8E-06	0	0.002811	0.12	-0.0082	0.000003	4.8E-06	0.000084	0.0022	0.000039	-0.007	0.22
30 BinnenBleiben with new containers	0.057	0.000042	2.4E-06	0	0.001641	0.12	-0.0082	0.000003	2.4E-06	0.000042	0.0011	0.000019	-0.0035	0.17
60 BinnenBleiben with new containers	0.03	0.000021	1.2E-06	0	0.000916	0.12	-0.0082	0.000003	1.2E-06	0.000021	0.00056	0.000009 6	-0.0017	0.14
15 BinnenBleiben with discarded containers	0.034	0.000074	4.8E-06	0	0.000877	0.12	-0.0082	0.000003	4.8E-06	0.000075	0.0022	0.000039	-0.0035	0.15
30 BinnenBleiben with discarded containers	0.019	0.000037	2.4E-06	0	0.000555	0.12	-0.0082	0.000003	2.4E-06	0.000038	0.0011	0.000019	-0.0017	0.13
60 BinnenBleiben with discarded containers	0.012	0.000019	1.2E-06	0	0.000372	0.12	-0.0082	0.000003	1.2E-06	0.000019	0.00056	0.000009 6	-0.00086	0.12
10 TinyTainer with new containers	0.6	0.00023	8.8E-06	0	0.023944	0.54	0	0.000054	8.8E-06	0.00023	0.048	0.00013	-0.05	1.16
20 TinyTainer with new containers	0.3	0.00012	4.4E-06	0	0.013468	0.54	0	0.000054	4.4E-06	0.00011	0.024	0.000067	-0.025	0.85
10 TinyTainer with discarded containers	0.12	0.00017	8.8E-06	0	0.005659	0.54	0	0.000054	8.8E-06	0.00017	0.048	0.00013	-0.027	0.69
20 TinyTainer with discarded containers	0.058	0.000085	4.4E-06	0	0.003116	0.54	0	0.000054	4.4E-06	0.000085	0.024	0.000067	-0.013	0.61
0.5 Shop hopping box	1	0.0012	4.1E-06	0	0	0.5	0	0.000043	4.1E-06	0.0012	0.79	0	-0.39	1.90
1 Shop hopping box	0.5	0.0006	0.000002	0	0	0.5	0	0.000043	0.000002	0.0006	0.39	0	-0.19	1.20
2 Shop hopping box	0.25	0.0003	0.000001	0.000002	0.018	0.5	0	0.000043	0.000001	0.0003	0.2	0	-0.097	0.87
10 Shop hopping box	0.05	0.00006	2E-07	3.3E-06	0.006	0.5	0	0.000043	2E-07	0.00006	0.039	0	-0.019	0.58

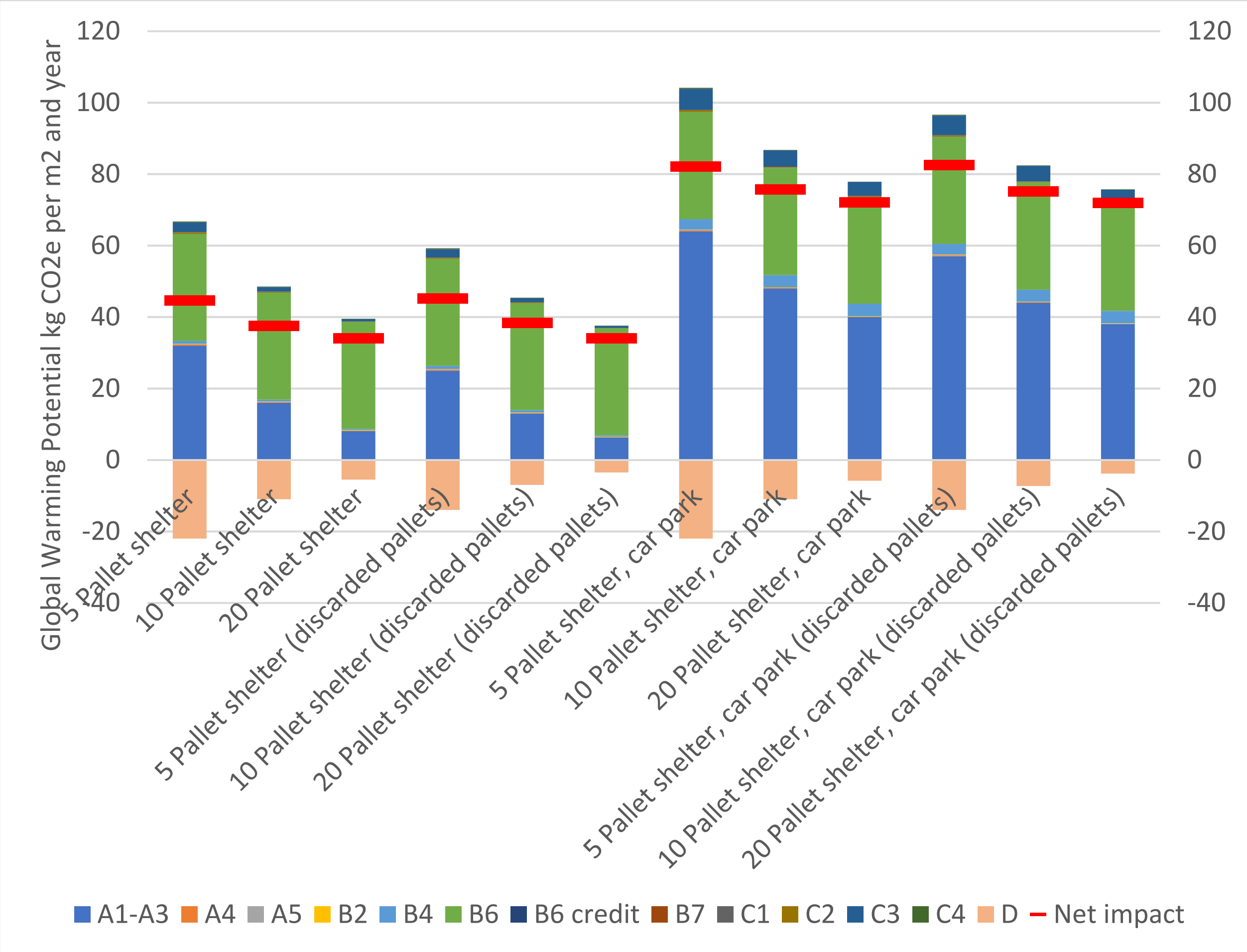
5 Results

The following results presented in column charts provide the basis for a scientific paper, which is in progress and expected to be submitted in 2022. Further adaptations, a sensitivity analysis and specific modelling aspects will be considered in this paper, alongside the final interpretation of the results.

5.1 Pallet shelter

5.1.1 Global warming potential

Global Warming Potential kg CO_2e per m² and year (IPCC AR5 GWP100, excl. biogenic carbon)



Processes with major contributions in phases A1-A3 (percentages shown for processes with a major contribution):

	10 Pallet shelter	10 Pallet shelter (discarded pallets)	5 Pallet shelter, car park
EU-28: Direct pressure laminate (DPL) ($1m^2$) (MeisterWerke Schulte GmbH) (EN15804 A1-A3) Sphera-EPD	12%	15%	6%
RER: market for EUR-flat pallet ecoinvent 3.7.1	7%	0%	3%
EU-28: Glued laminated timber (EN15804 A1-A3) Sphera	5%	6%	2%
EU-28: Oriented Strand Board (OSB) (4,5% Humidity) - Kronoply (A1-A3) Sphera-EPD	10%	13%	5%
DE: Wooden window (1.00x2.10) Sphera	5%	6%	2%
EU-28: Direct pressure laminate (DPL) ($1m^2$) (MeisterWerke Schulte GmbH) (EN15804 A1-A3) Sphera-EPD	13%	17%	7%
EU-28: Lightweight concrete block Sphera	16%	21%	8%
DE: Vegetation substrate Sphera	0%	0%	41%

Processes with major contributions in phases C3-C4 (percentages shown for processes with a major contribution):

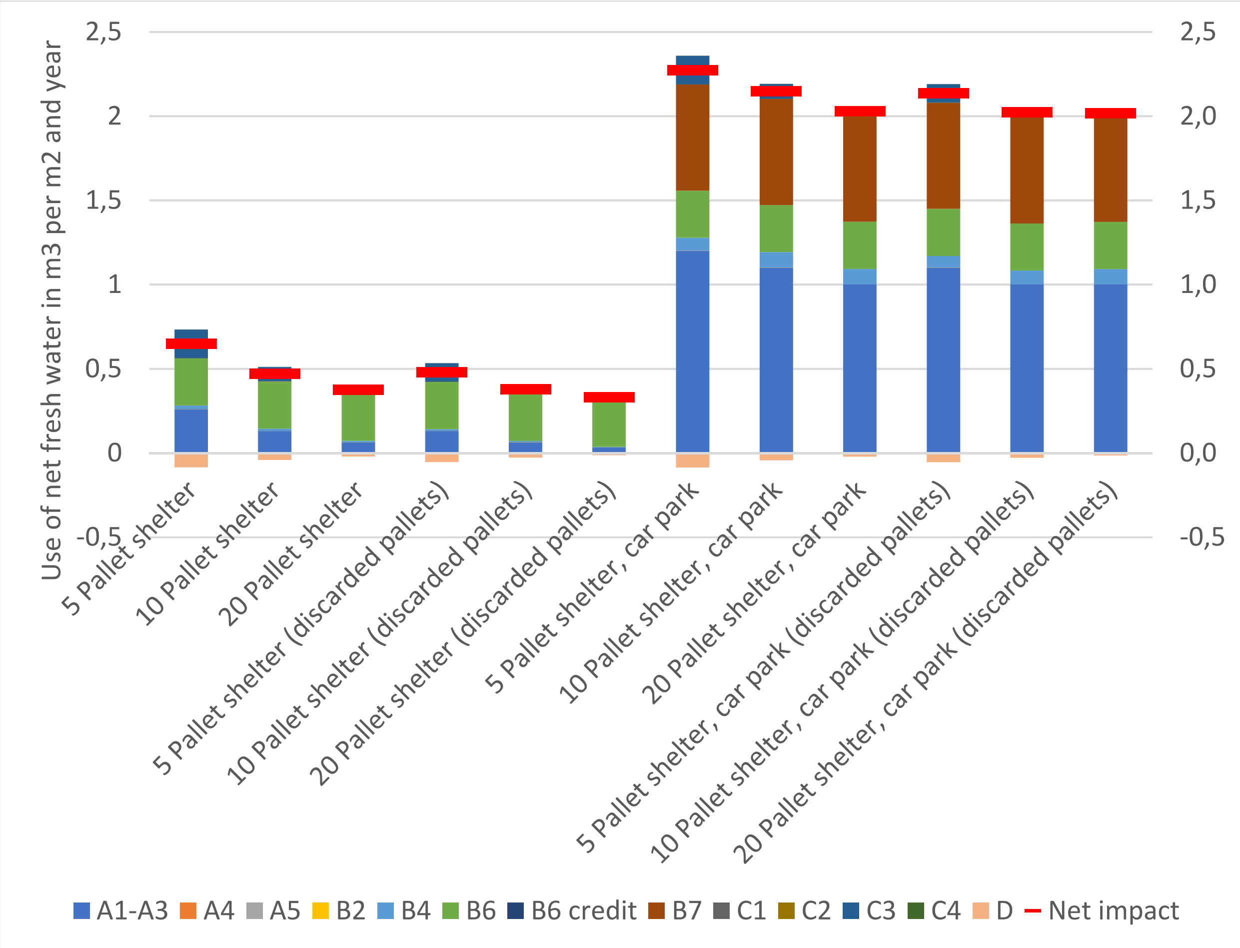
Installations	Incineration plastics	EU-28: Plastic packaging in municipal waste incineration plant Sphera <p-agg>	11%
Modul 1	Incineration plastics	EU-28: Plastic packaging in municipal waste incineration plant Sphera <p-agg>	27%
Modul 2	Incineration wood	EU-28: Wood (natural) in municipal waste incineration plant Sphera <p-agg>	15%
Modul 4	Incineration plastics	EU-28: Plastic packaging in municipal waste incineration plant Sphera <p-agg>	11%

Processes with major contributions in phase D (percentages shown for processes with a major contribution):

Energy credit municipal waste incineration with recovery wood 80%

5.1.2 Net use of fresh water

Net use of fresh water in m³ per m² and year



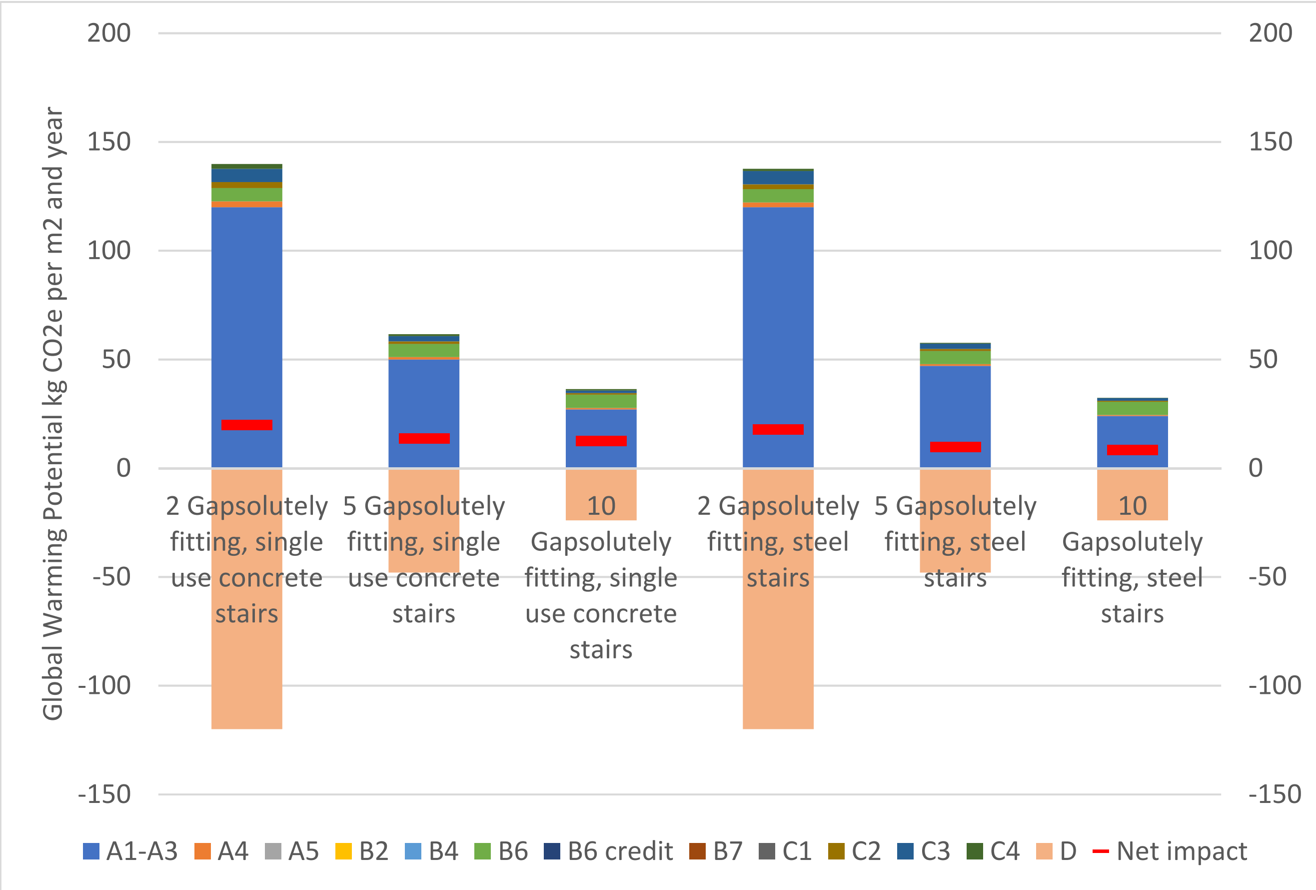
Processes with major contributions (percentages shown for processes with a major contribution):

Module NFW (net fresh water)	Process	10 Pallet shelter	10 Pallet shelter (discarded pallets)	5 Pallet shelter, car park
Module 1	EU-28: Direct pressure laminate (DPL) (1m²) (MeisterWerke Schulte GmbH) (EN15804 A1-A3) Sphera-EPD	7%	15%	2%
Module 1	RER: market for EUR-flat pallet ecoinvent 3.7.1	17%	0%	3%
Module 2	RER: market for EUR-flat pallet ecoinvent 3.7.1	16%	0%	3%
Module 4	EU-28: Direct pressure laminate (DPL) (1m²) (MeisterWerke Schulte GmbH) (EN15804 A1-A3) Sphera-EPD	8%	16%	2%
Module 4	RER: market for EUR-flat pallet ecoinvent 3.7.1	8%	0%	2%
Module 5	EU-28: Lightweight concrete block Sphera	4%	7%	1%
Module 7	EU-28: Bath- and shower tub acrylic (EN15804 A1-A3) Sphera	6%	12%	1%
Module 7	GLO: market for refrigerator ecoinvent 3.7.1	3%	7%	1%
Module 7	GLO: market for washing machine ecoinvent 3.7.1	4%	8%	1%
Turf incl. substrate, sheet, irrigation pipes 7854 sqm pellet shelter	DE: Vegetation substrate Sphera	0%	0%	29%
Turf incl substrate, sheet, irrigation pipes 7854 sqm pellet shelter <LC>	RoW: market for irrigation ecoinvent 3.7.1	0%	0%	49%

5.2 Gapsolutely Fitting

5.2.1 Global warming potential

Global Warming Potential kg CO_2e per m² and year (IPCC AR5 GWP100, excl. biogenic carbon)

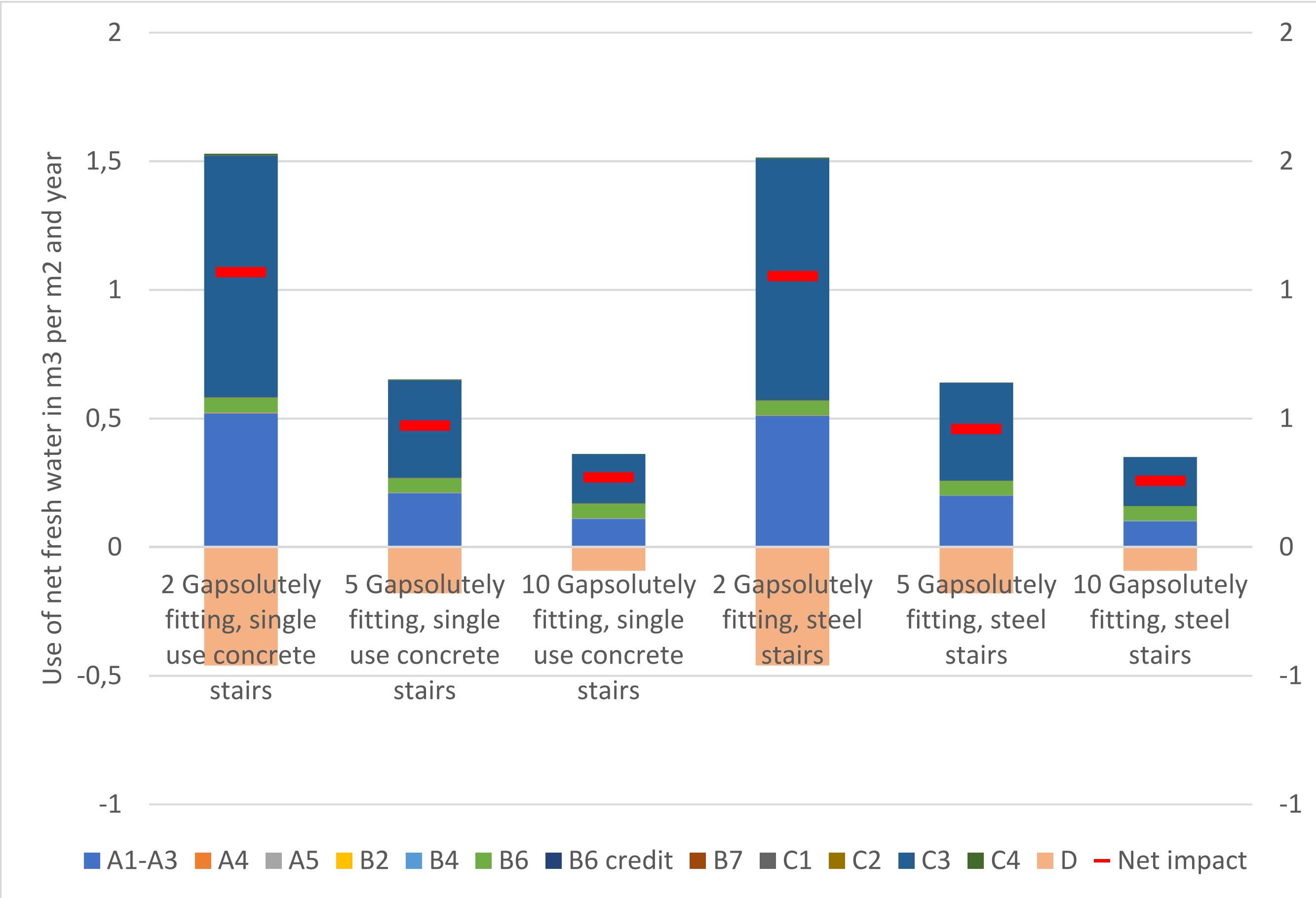


Processes with major contributions (percentages shown for processes with a major contribution):

Module	Process	5 Gapsolutely fitting, single use concrete stairs	5 Gapsolutely fitting, steel stairs
Modul 2	EU-28: Glued laminated timber (EN15804 A1-A3) Sphera	51%	54%
Modul 4	EU-28: Direct pressure laminate (DPL) (1m²) (MeisterWerke Schulte GmbH) (EN15804 A1-A3) Sphera-EPD	10%	11%
Modul 6	EU-28: Direct pressure laminate (DPL) (1m²) (MeisterWerke Schulte GmbH) (EN15804 A1-A3) Sphera-EPD	9%	10%
Modul 7	EU-28: Lightweight concrete block Sphera	15%	16%

5.2.2 Net use of fresh water

Net use of fresh water in m³ per m² and year



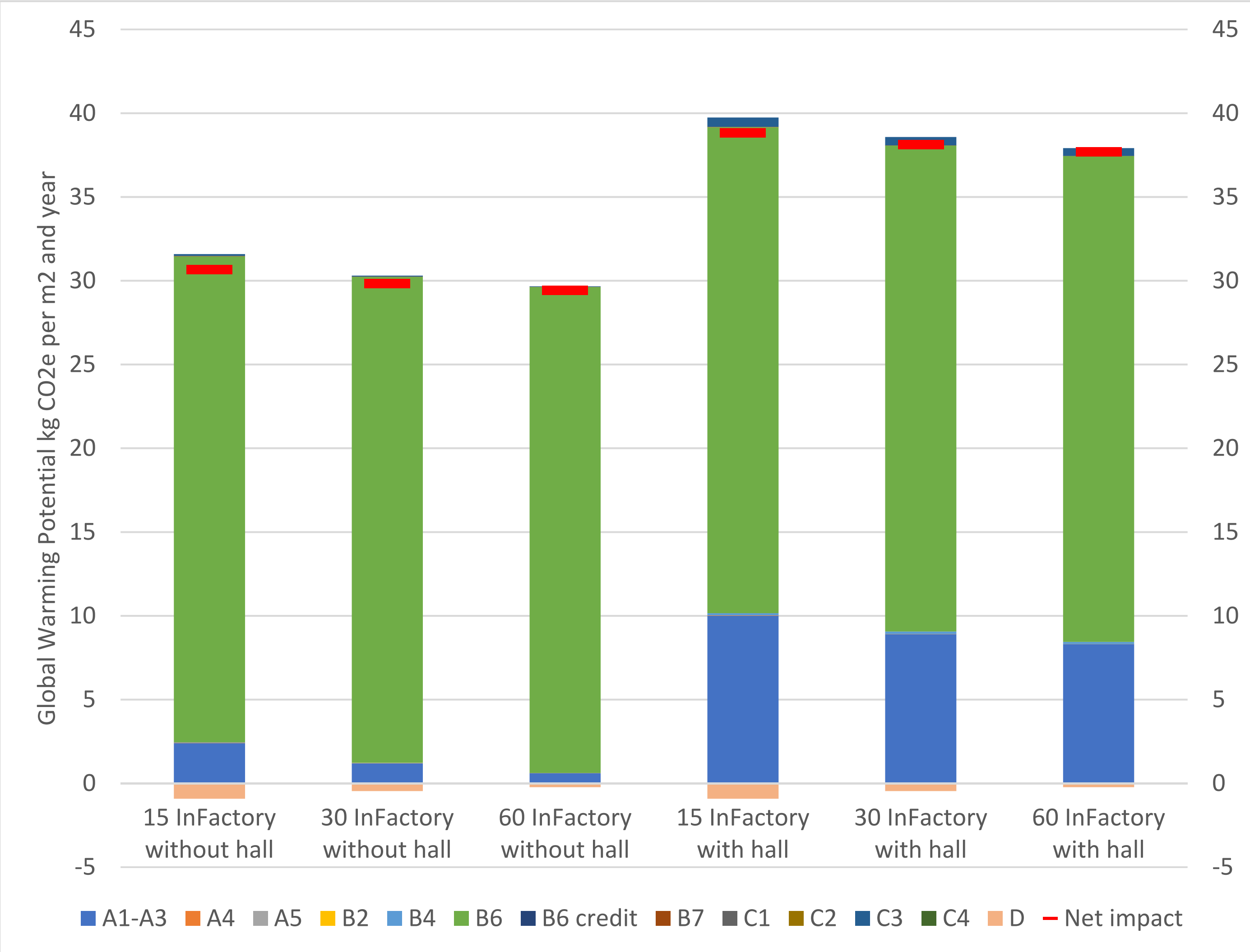
Processes with major contributions (percentages shown for processes with a major contribution):

Module	Process	5 Gapsolutely fitting, single use concrete stairs	5 Gapsolutely fitting, steel stairs
Modul 4	EU-28: Direct pressure laminate (DPL) (1m²) (MeisterWerke Schulte GmbH) (EN15804 A1-A3) Sphera-EPD	12%	12%
Modul 6	EU-28: Direct pressure laminate (DPL) (1m²) (MeisterWerke Schulte GmbH) (EN15804 A1-A3) Sphera-EPD	11%	11%
Modul 7	EU-28: Lightweight concrete block Sphera	7%	7%

5.3 InFactory

5.3.1 Global warming potential

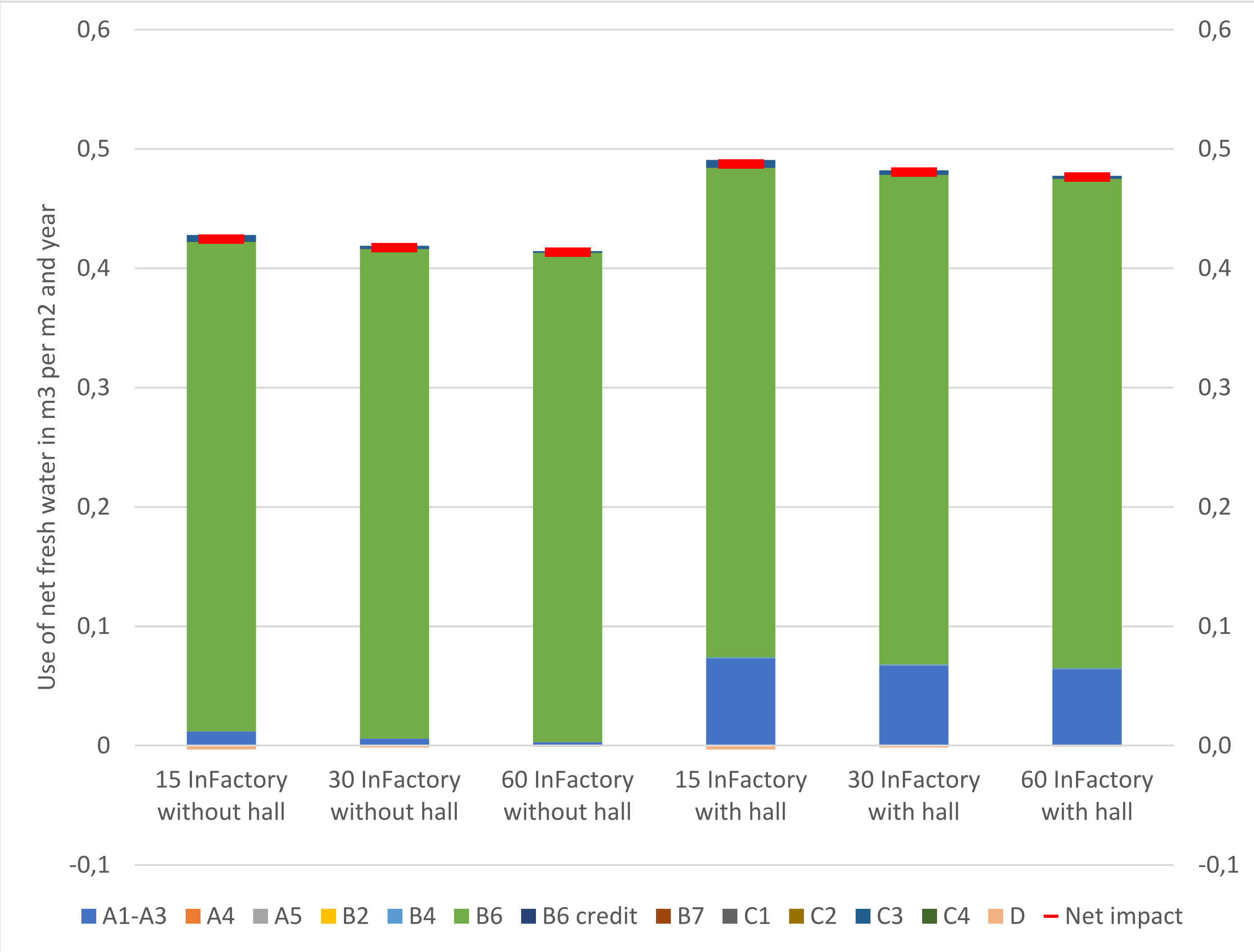
Global Warming Potential kg CO_2e per m² and year (IPCC AR5 GWP100, excl. biogenic carbon)



Processes with major contributions (percentages shown for processes with a major contribution):

Module	Process	30 InFactory without hall	30 InFactory with hall
Building hall	GLO: market for building, hall, steel construction ecoinvent 3.7.1	0%	88%
Modul 1	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	14%	2%
Modul 2	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	38%	4%
Modul 3	EU-28: Glued laminated timber (EN15804 A1-A3) Sphera	10%	1%
Modul 3	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	23%	3%

5.3.2 Net use of fresh water



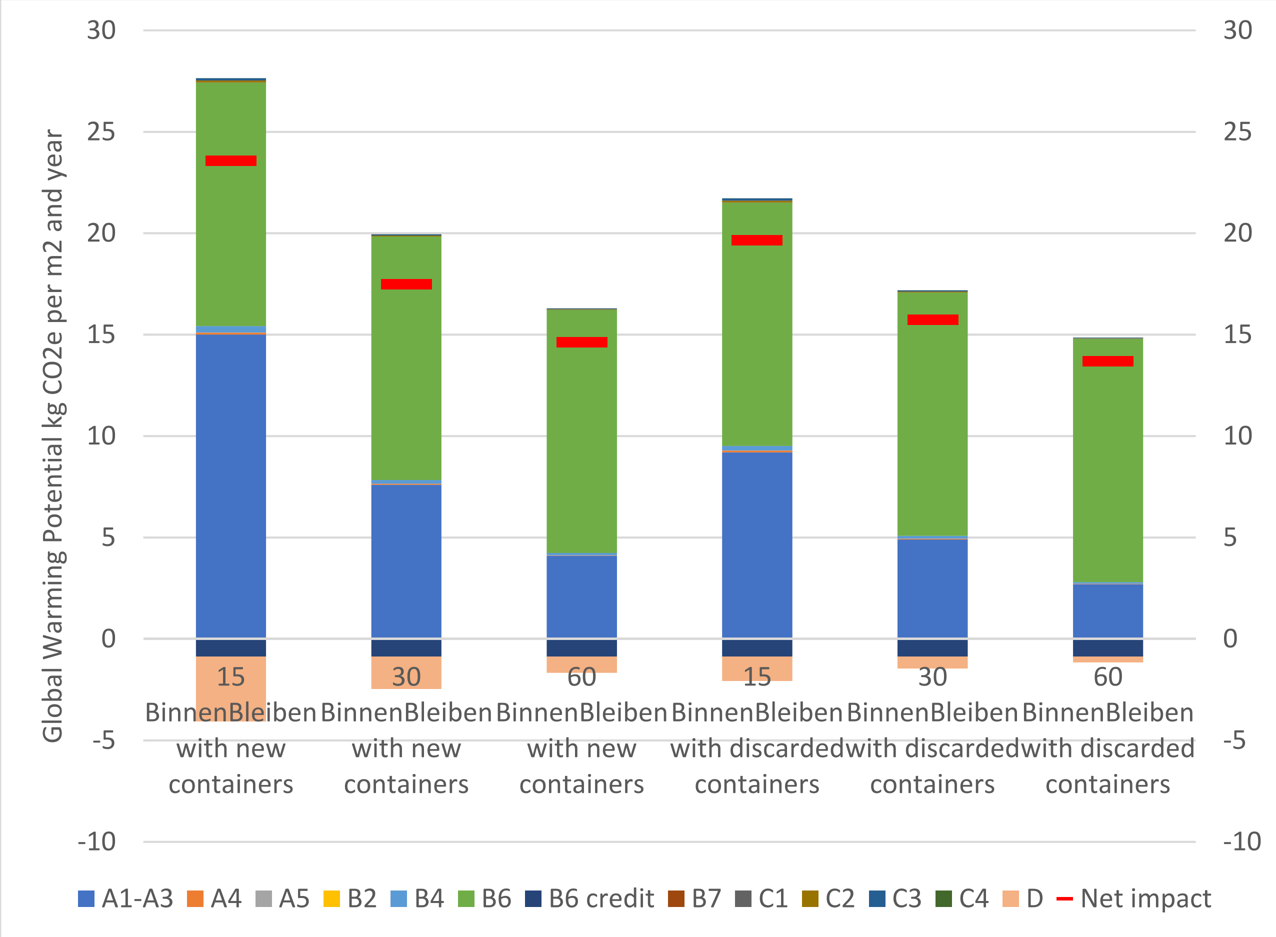
Processes with major contributions (percentages shown for processes with a major contribution):

Module	Process	30 InFactory without hall	30 InFactory with hall
Building hall	GLO: market for building, hall, steel construction ecoinvent 3.7.1	0%	88%
Modul 1	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	14%	2%
Modul 2	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	38%	4%
Modul 3	EU-28: Glued laminated timber (EN15804 A1-A3) Sphera	10%	1%
Modul 3	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	23%	3%

5.4 BinnenBleiben

5.4.1 Global warming potential

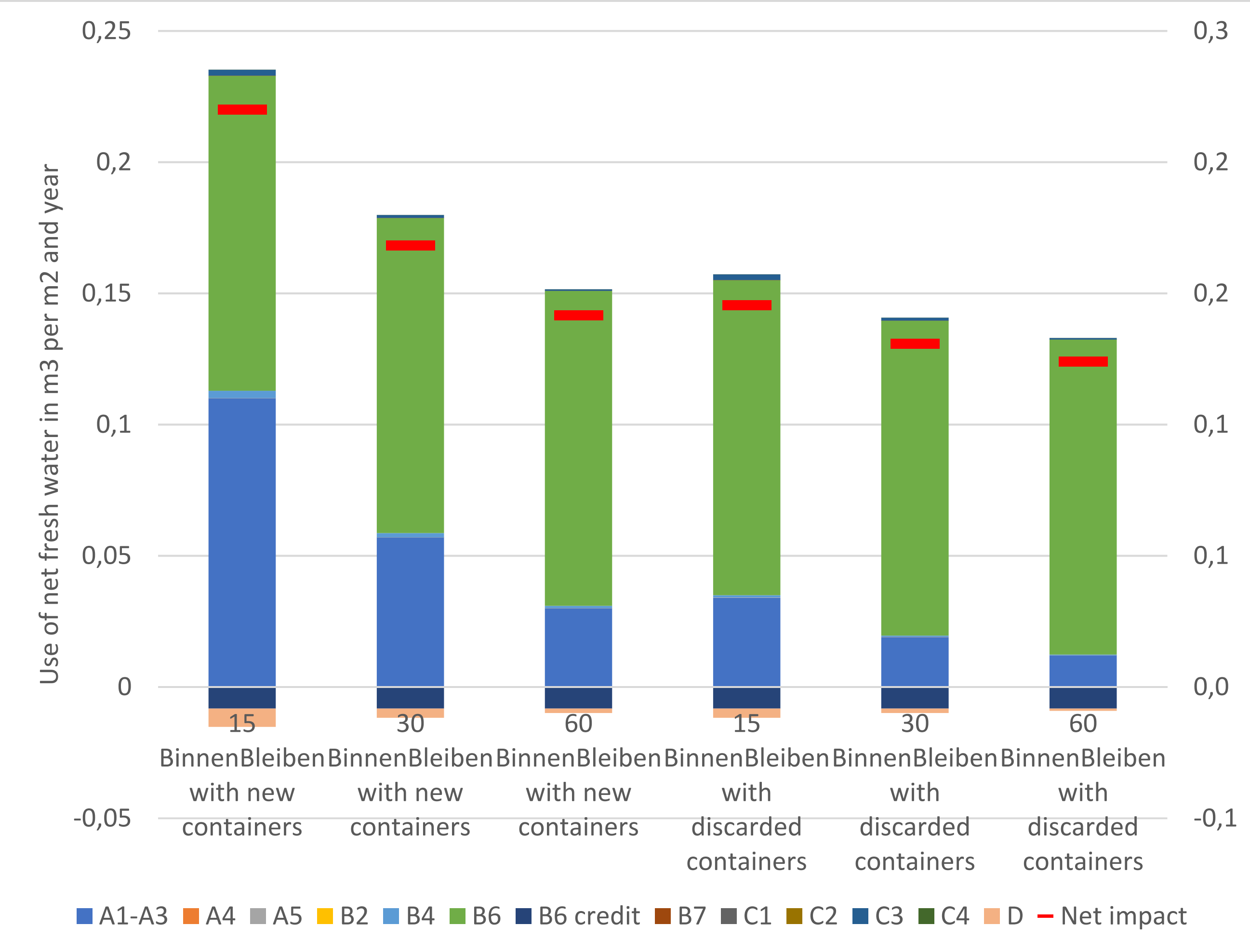
Global Warming Potential kg CO_2e per m² and year (IPCC AR5 GWP100, excl. biogenic carbon)



Processes with major contributions (percentages shown for processes with a major contribution):

Module	Process	30 BinnenBleiben with new containers	30 BinnenBleiben with discarded containers
Module 1	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	33%	51%
Module 2	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	12%	19%
Module 6	Shipping container <LC>	14%	0%
Module 6	Shipping container <LC>	14%	0%
Module 6	GLO: market for cookstove ecoinvent 3.7.1	4%	7%
Module 7	Shipping container <LC>	20%	0%
Module 7	Shipping container <LC>	20%	0%
Operation	EU-28: Electricity from photovoltaic Sphera	7%	11%

5.4.2 Net use of fresh water



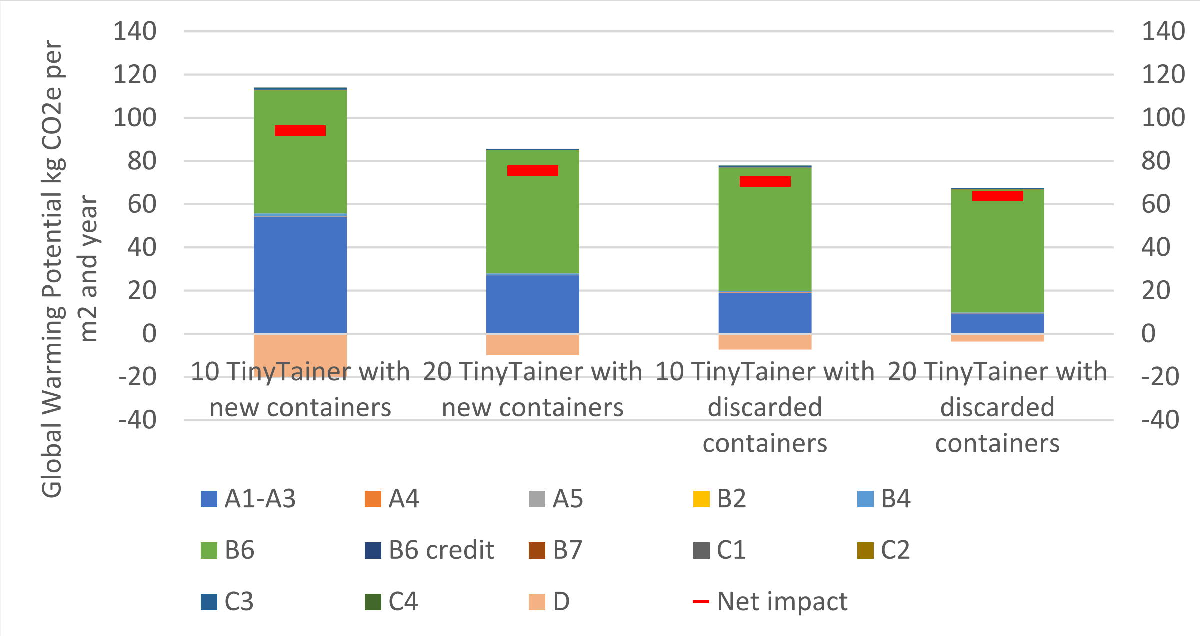
Processes with major contributions (percentages shown for processes with a major contribution):

Module NFW	Process	30 BinnenBleiben with new containers	30 BinnenBleiben with discarded containers
Module 1	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	11%	30%
Module 2	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	4%	11%
Module 6	Shipping container <LC>	25%	0%
Module 6	GLO: market for cookstove ecoinvent 3.7.1	7%	17%
Module 7	Shipping container <LC>	37%	0%
Operation	EU-28: Electricity from photovoltaic Sphera	7%	18%

5.5 TinyTailer

5.5.1 Global warming potential

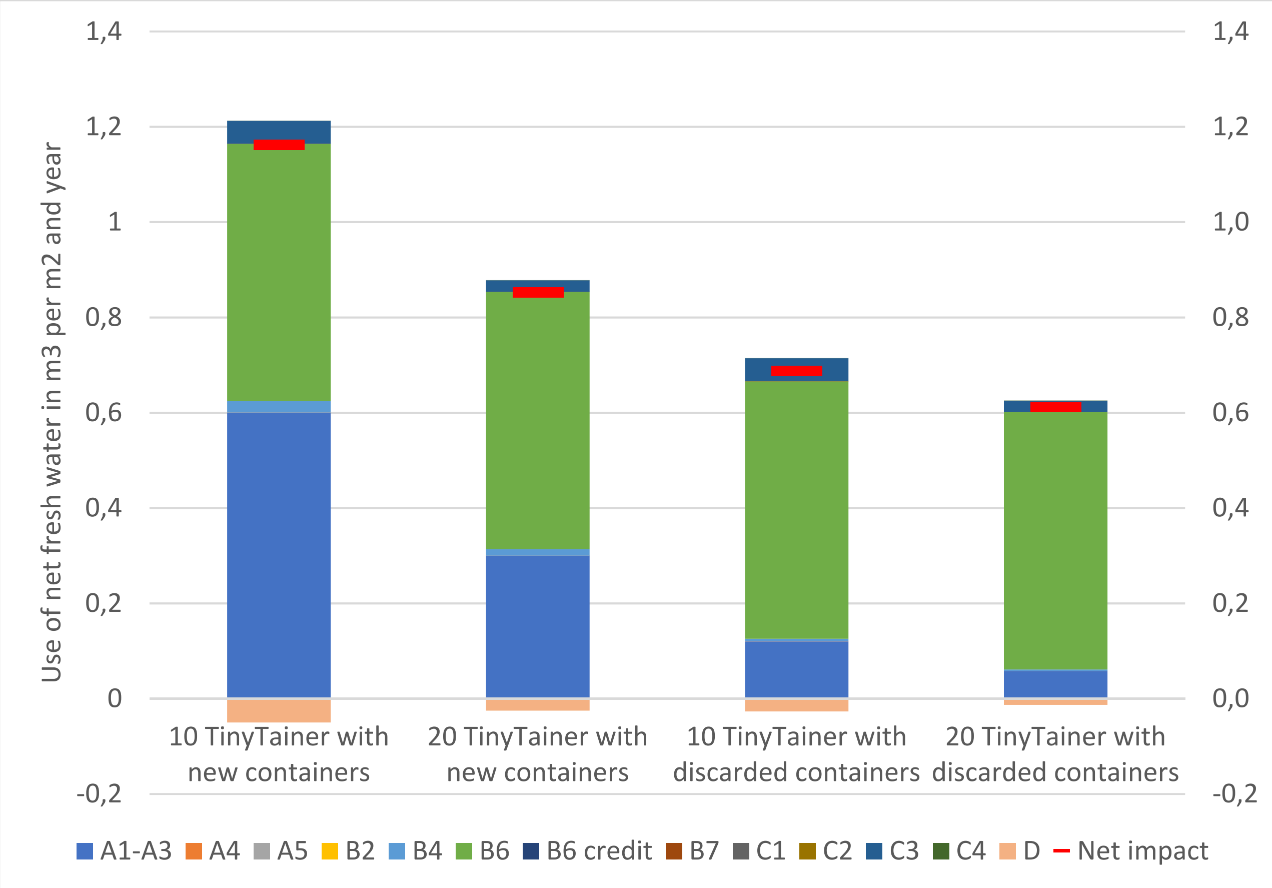
Global Warming Potential kg CO_2e per m² and year (IPCC AR5 GWP100, excl. biogenic carbon)



Processes with major contributions (percentages shown for processes with a major contribution):

Module	Process	20 TinyTainer with new containers	20 TinyTainer with discarded containers
Module 1	Shipping container <LC>	65%	0%
Module 2	EU-28: Glued laminated timber (EN15804 A1-A3) Sphera	4%	11%
Module 2	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	20%	56%
Module 3	GLO: market for door, outer, wood-aluminium ecoinvent 3.7.1	3%	8%

5.5.2 Net use of fresh water



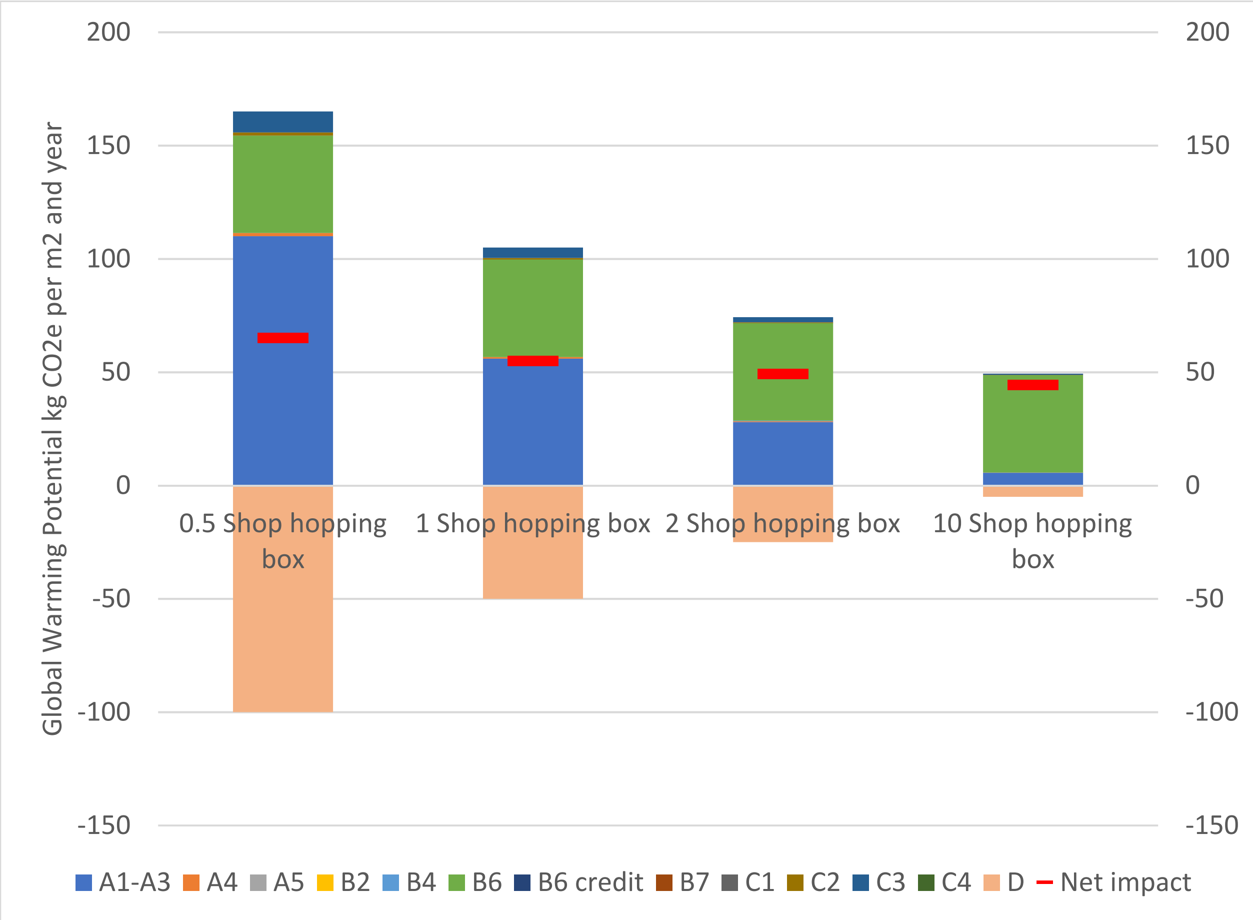
Processes with major contributions (percentages shown for processes with a major contribution):

Module NFW	Process	20 TinyTainer with new containers	20 TinyTainer with discarded containers
Module 1	Shipping container <LC>	81%	0%
Module 2	EU-28: Glued laminated timber (EN15804 A1-A3) Sphera	2%	9%
Module 2	EU-28: Steel sections (EN15804 A1-A3) Sphera <p-agg>	5%	24%
Module 2	GLO: market for washing machine ecoinvent 3.7.1	2%	9%
Module 3	GLO: market for door, outer, wood-aluminium ecoinvent 3.7.1	2%	12%
Module 4	EU-28: Bath- and shower tub acrylic (EN15804 A1-A3) Sphera	5%	26%

5.6 Shop hopping box

5.6.1 Global warming potential

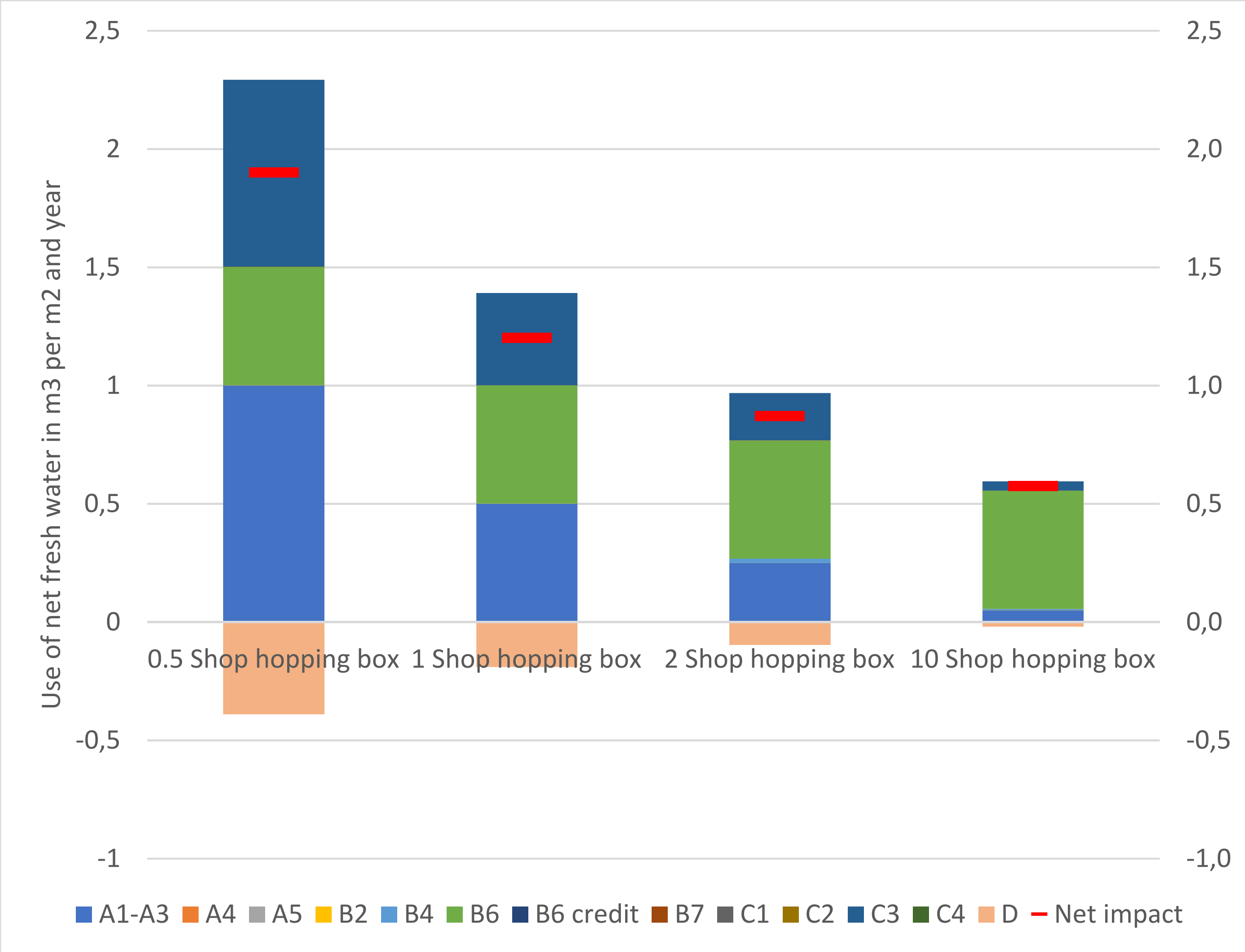
Global Warming Potential kg CO_2e per m² and year (IPCC AR5 GWP100, excl. biogenic carbon)



Processes with major contributions (percentages shown for processes with a major contribution):

Module	Process	2 Shop hopping box
Modul 1	EU-28: Glued laminated timber (EN15804 A1-A3) Sphera	10%
Modul 2	DE: Wooden window (1.00x2.10) Sphera	17%
Modul 3	EU-28: Glued laminated timber (EN15804 A1-A3) Sphera	11%

5.6.2 Net use of fresh water



Processes with major contributions (percentages shown for processes with a major contribution):

Module NFW	Process	2 Shop hopping box
Module 2	EU-28: Bath- and shower tub acrylic (EN15804 A1-A3) Sphera	19%
Module 3	EU-28: Particle board Sphera	12%
Module 4	GLO: market for refrigerator ecoinvent 3.7.1	13%

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Universität für Bodenkultur Wien

alchemia nova
institute for innovative phytochemistry & closed loop processes

Urban pop-up housing environments and their potential as local innovation systems

Indicator Set

Part of Deliverable D4

December 2021

This project is funded under the framework of the Environmental Systems Research 2017 Urban Environments funding programme of the Vienna Science and Technology Fund. Project ID: ESR17-010

VIENNA SCIENCE AND TECHNOLOGY FUND

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Lead Partner / Institute	ÖAW-ITA (Michael Ornetzeder)
Work Package No.:	4
Issue Date:	Dec. 2021

Principal Investigators:

Marion Huber-Humer, Michael Ornetzeder, Doris Österreicher

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PREFACE

As part of the interdisciplinary research project "Urban pop-up housing environments and their potential as local innovation systems", six deliverables (D1 – D6) were generated in accordance with the project proposal, which reflect in detail the working process and outputs of the diverse tasks in the working packages. An overview of all deliverables and their key messages is provided in the Executive Summary (Deliverable D0). The individual deliverables were developed chronologically according to the project schedule and progress, and thus, completed at different time points in the project, reflecting the state of knowledge at the respective project status at that time.

In this document you will find the detailed description of the indicators which were developed within the project (as part of Deliverable D4) to evaluate temporary housing solutions in terms of ecological, social/residential, technical and site quality in order to assess the sustainability of temporary housing environments. This indicator set was developed based on an interdisciplinary, iterative process within the project team (specific methodological approach see main document of D4, or Executive Summary). The indicator set was pre-tested and applied to the six developed temporary housing models (see e.g. fact sheets) and adapted in diverse feed-back loops.

CONTENT

LIST OF SYMBOLS

Ecological Indicators

Abbreviation	Indicator
GWP_MEPP	GWP Material extraction and production phase.
GWP_EC	GWP construction phase
GWP_OMP	GWP operational phase and maintenance.
GWP_DP	GWP deconstruction phase.
GWP_EOL	GWP End of Life phase.
GWP_T	GWP emissions Total.
W_Ru	Water reuse.
PED_O	Primary energy demand – operation.
W_Fp	Full water footprint.
WP_FP	Product water footprint of materials used in building
WU_DO	Water use during operation.
WU_CD	Water use during construction and disassembly.
S_UF	Stock usage factor

Technical indicators

Abbreviation	Indicator
C_{ED}	Energy demand- cooling
$C_{renewe,E}$	Coverage energy, electrical.
DLQ	Daylight quality.
SEP_{renewe}	Share Energy Production Renewable.
HED	Energy demand- heating.
L_{ass}	Level of ease of assemble.
B_A	Level of building control.
MB	Maintenance building.
MB_{ES}	Maintenance building eng. Services.
R_P	Recycling potential.
D_{reuse}	Reuse Potential (End Of Life).
L_{disass}	Level of ease of disassembly.
SM_U	Secondary material utilization
MCI	Material circularity indicator
R_R	Realizable recycling factor

Site indicators

Abbreviation	Indicator
CT_P	Connection to public transport.
AM_P	Active mobility on the plot.
AM_Q	Active mobility in the quarter.
P_{OF}	Proximity to use-specific objects and facilities.
POS_{QC}	Access to public open spaces in the quarter and city.
GI_P	Green Infrastructure on the Plot.
A_{ADO}	Accessibility for assembly, dismantling and operating phase.
SR_{AN}	Suitability for residential use depending on ambient noise.
L_{UE}	Land use efficiency.
S_{Site}	Suitability of site
C_{ES}	Consumption of ecologically sensitive areas.

Indicators social and residential quality

Abbreviation	Indicator
Ea_{P_P}	Effective area per person.
F_C	Facility category.
Ea_{P_C}	Effective area per person (Community).
S_{CC}	Spaces conducive to communication.
BF_{AR}	Barrier-free accessible rooms.
C_{SL}	Changeability of the room size and layout.
GD_A	Gender+ and diversity aspects of built and open space structures on the plot.
P_R	Empowerment & type of participation.
OS_P	Private open spaces.
OS_C	Communal open spaces.
AMU_P	Open spaces of areas with mixed use.
RQ_d	High residential quality in the district.

1 ECOLOGICAL QUALITY

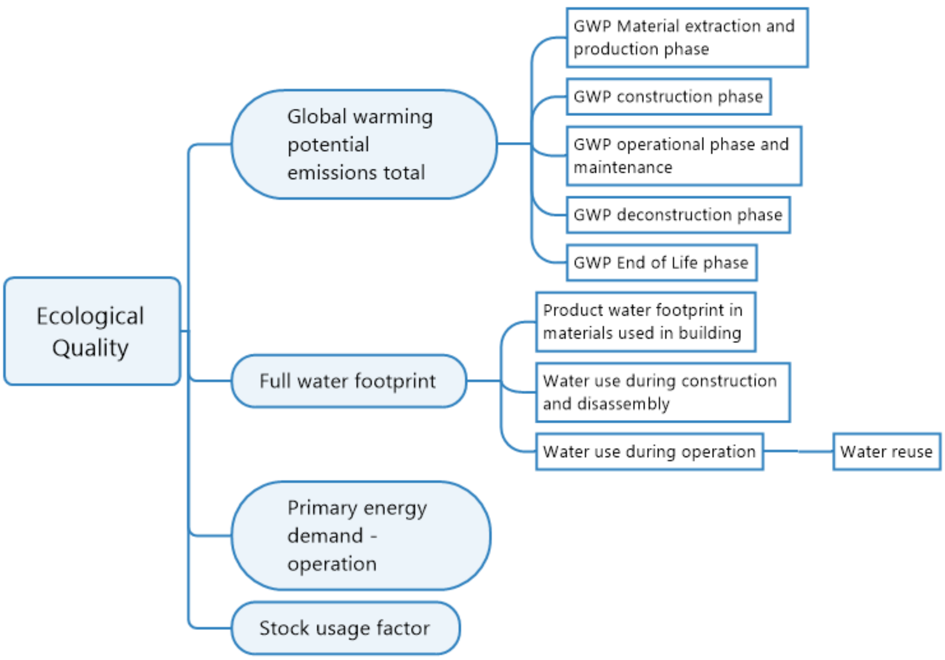
The ecological quality of buildings can be described as buildings, that are developed, used and reused without unnecessary resource depletion, environmental pollution and ecosystem degradation[1].

The main focus in selecting or developing of indicators were three main categories, namely materials, energy and water as well as the consideration of various processes related to a building:

- Construction of the building (including material extraction)
- Use phase of a building
- End-of life phase of a building
- Development of the area which surrounds a building

The indicators chosen to describe the ecological quality of buildings are in most cases not developed from scratch, but are similar to existing indicators in building assessment systems (e.g ÖGNI[2], BREEAM) and help understanding the total and relative impact of the different life cycle stages of buildings[3].

The figure below provides an overview of the indicators that were used to describe ecological quality.



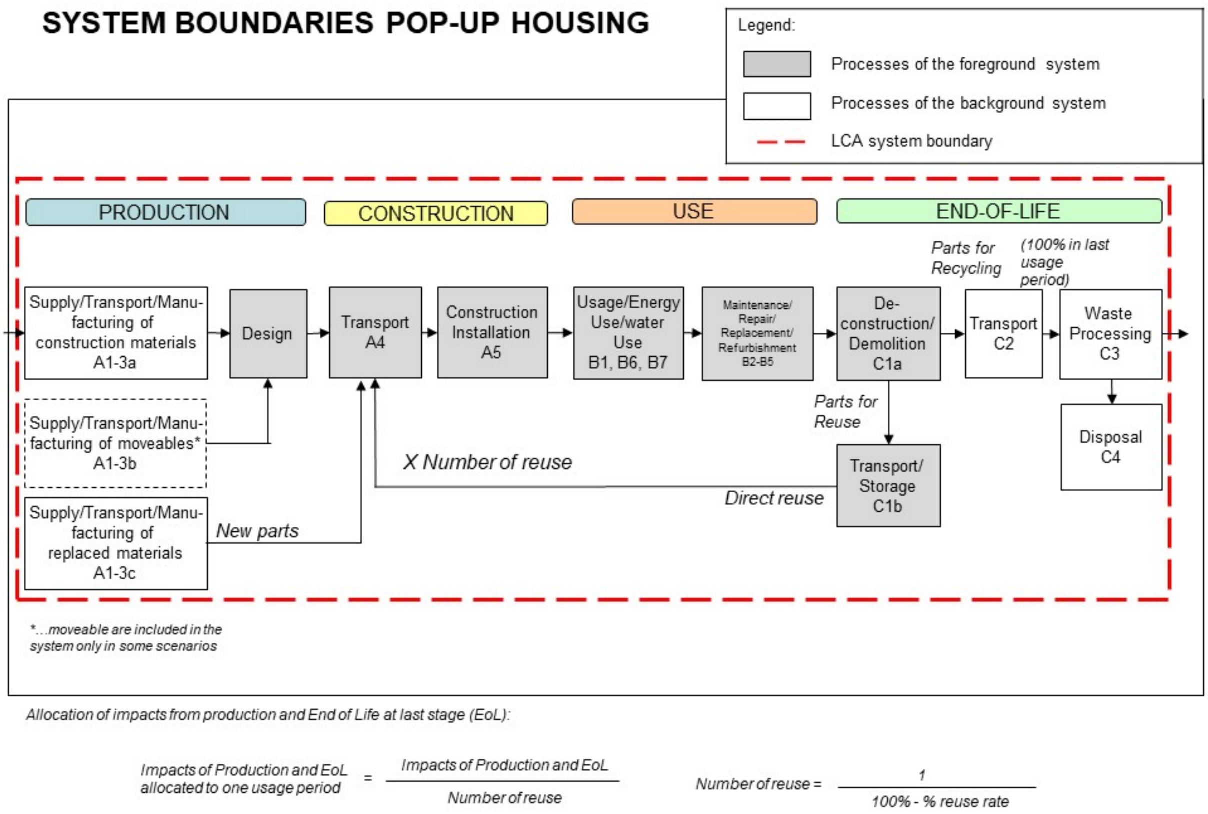
[1] Circle Economy (2018): A framework for circular buildings. Indicators for possible inclusion in BREEAM.
[2] ÖGNI (2013). Ausgezeichnet. Nachhaltig bauen mit System.
[3] König, Kohler, Kreißig, Lützkendorf (2009): Lebenszyklusanalyse in der Gebäudeplanung. Grundlagen, Berechnungen, Planungswerkzeuge.

1.1 GWP MATERIAL EXTRACTION AND PRODUCTION PHASE

General considerations

This indicator expresses the environmental impact of the production phase of the structure/components. Raw material extraction, transport and production of components are considered here (see standard 15804, A1-A3: Production Phase[4]). The indicator addresses the question of which emissions are associated with the building materials used.

This indicator is part of the indicator "GWP emissions total", so the units must always be the same (or have to be converted) to allow summation.



Measurements

- On the basis of the material list of a building to be assessed, Gabi software is used to put a virtual housing model of PUE (Pop-up environment) in place (following the Flowchart given above, here: phase A1-3). The LCA model was created using the GaBi 10 software and GaBi and ecoinvent 3.7.1. LCI databases.
- GWP values are calculated in software and can be extracted

Unit used in LCA software (and in ISO Norm 15804): **kg CO2-equ**. The conversion factors of other greenhouse gases (e.g. methane, …) are taken from current table of IPCC.

[4] DIN EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products (includes Amendment :2019)

- For better comparability the results should be expressed in $\frac{\text{kg CO2-euq.}}{m^2\text{of PUE}}$ (or if needed also in $\frac{\text{kg CO2-euq.}}{\text{Persons in PUE}}$).

Description

The (relative) global warming potential (GWP) or CO_2-equivalent of a chemical compound is a measure of its relative contribution to the greenhouse effect, i.e. its average warming effect on the earth's atmosphere over a certain period of time (usually 100 years). It thus indicates how much a certain mass of a greenhouse gas contributes to global warming compared to the same mass of CO_2.

For the assessment of environmental impacts, the Global warming potential is a widely used indicator. In this indicator, Global warming potential of the production phase (including upstream processes of material extraction and transport) is considered (= “Cradle to gate”).

Sub-processes

Most of the simulation and assessment process is embedded in Gabi-Software. The different materials are simulated as aggregated flows, which already include resource extraction, transport and material production (Cradle to gate). Therefore, those steps are summarized in this indicator.

Acceptance measure (0-1)

Building components are assessed by their environmental impact. There are materials, that lead to high emissions and other that contribute on a lesser level to greenhouse effect.

As a rule of thumb

- The smaller the value for GWP, the better → 1
- The higher the value for GWP, the worse → 0

It was not easy to find a suitable reference model, but an interesting approach is given in BMVIT publication 2017[5], where benchmark values for GWP and target values for GWP in new buildings are listed.

So, if the benchmark is assumed to be 7,1 kg CO2-equ/m²*a for grey energy building, everything that is even above this value is not acceptable (→ 0), as it is aspired to build new buildings that are already worse than the benchmark value of 2017.

If the target value for grey energy building of 1,7 kg CO2-equ./m²*a is met, it can be considered optimal (→1).

Definition GWP_{MEPP} (GWP material extraction and production phase)

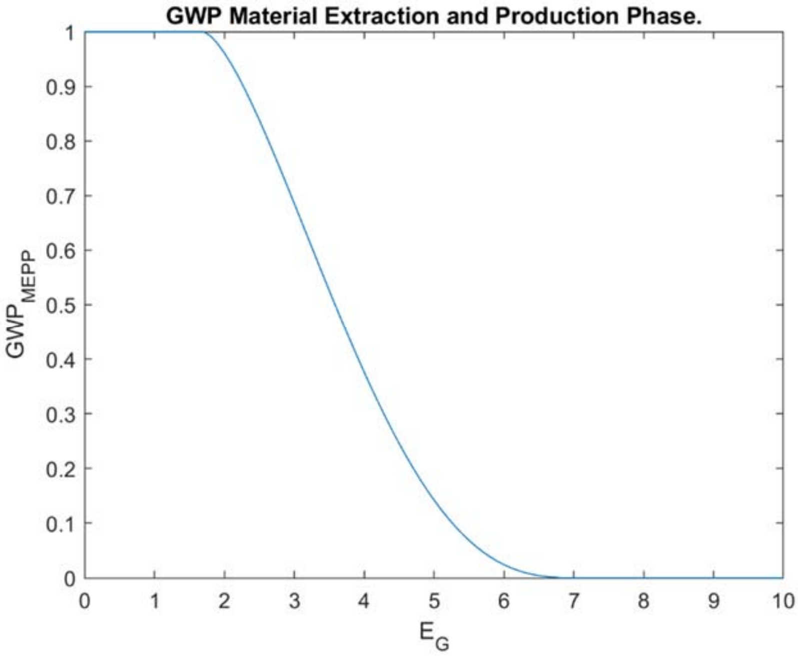
[5] BMVIT (2017): Richt- und Zielwerte für Siedlungen zur integralen Bewertung der Klimaverträglichkeit von Gebäuden und Mobilitätsinfrastruktur in Neubausiedlungen. Berichte aus Energie- und Umweltforschung 39/2017.

$E_{Gmin} := 1.7 \frac{\text{kg CO}_2\text{-equ.}}{m^2}$ … Lower limit of accepted CO2 emissions for grey energy in buildings.

$E_{Gmax} := 7.1 \frac{\text{kg CO}_2\text{-equ.}}{m^2}$ … Upper limit of accepted CO2 emissions for grey energy in buildings.

E_G … CO2 emissions for gray energy of the building.

$$GWP_{MEPP} := \left(1 - \min\left(\max\left(\frac{E_G - E_{Gmin}}{E_{Gmax} - E_{Gmin}}, 0\right), 1\right)^k\right)^l$$



1.2 GWP CONSTRUCTION PHASE

General considerations

This indicator expresses the environmental impact of the construction phase. Transport (from factory to construction site) and construction phase are taken into account (see standard 15804, A4-A5). The indicator addresses the question of which emissions are associated with the construction of the temporary residential building.

This indicator should also be part of the total indicator "GWP emissions total", so the unit must always be the same to allow summation.

Measurements

- On the basis of the material list, Gabi software is used to put a virtual housing model of PUE in place (following the Flowchart given above, here: phase A4-5).
- GWP values are calculated in Gabi software and can be extracted

Unit used in LCA software (and in ISO Norm 15804): **kg CO2-equ**. The conversion factors of other greenhouse gases (e.g. methane, …) are taken from current table of IPCC.

Exhaust emissions, transport km, energy sources and energy requirements for machine use, machine hours, etc. are taken into account. Water consumption is calculated in a separate indicator and is not considered here.

- For better comparability the results should be expressed in $\frac{\text{kg CO2-euq.}}{m^2\text{of PUE}}$ (or $\frac{\text{kg CO2-euq.}}{\text{Persons in PUE}}$)

Descripton

In this indicator, Global warming potential of the construction phase (transport from factory and construction on-site) is considered.

Acceptance measure (0-1):

1: construction phase and transport can be carried out without fossil energy input.

0: efforts for a temporary housing construction site (Exhaust emissions, transport km, energy sources and energy requirements for machine use, machine hours), should not be higher than in conventional housing construction.

Subprocesses

- Transportation of building materials / compounds from factory to construction site: Measurements (or assumptions) regarding distance / route are made and taken into account in LCA.
- Transport vehicle + fuel: Information on truck type and fuel consumption is collected (or assumptions are made) and considered in LCA.
- Construction site operation: Information regarding machines used (forklift, trucks, drilling machines, manual assembly, etc.) and energy requirements is collected (or assumptions are made) and considered in LCA.

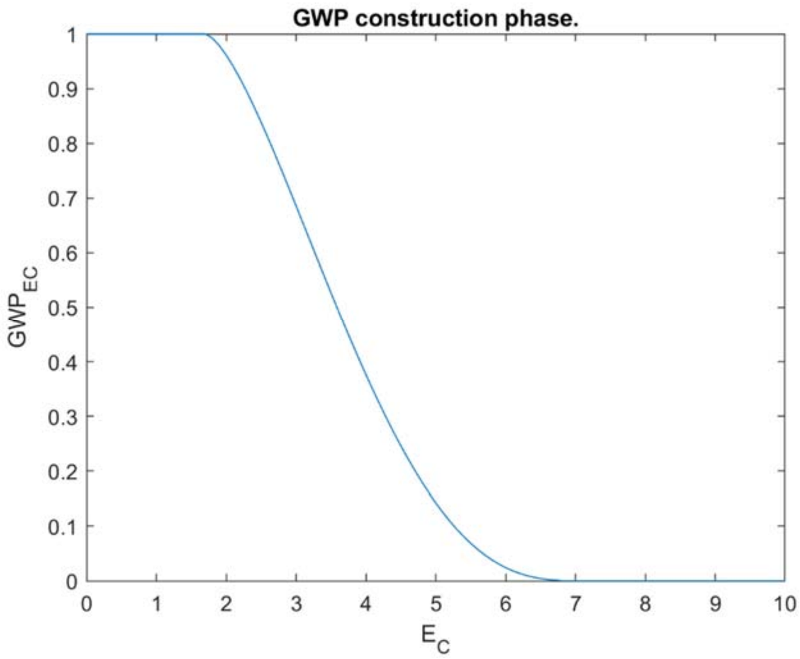
Definition GWP_{CP} (GWP construction phase)

$E_{Cmin} := 1.7 \frac{\text{kg CO}_2\text{-equ.}}{m^2}$ …Lower limit of accepted CO_2 emissions for grey energy in construction phase

$E_{Cmax} := 7.1 \frac{\text{kg CO}_2\text{-equ.}}{m^2}$ …Upper limit of accepted CO_2 emissions for grey energy in construction phase.

E_C … CO_2 emissions for gray energy of the construction phase.

$$GWP_{CP} := \left(1 - \min\left(\max\left(\frac{E_C - E_{Cmin}}{E_{Cmax} - E_{Cmin}}, 0\right), 1\right)^k\right)^l$$



1.3 GWP OPERATIONAL PHASE AND MAINTENANCE

General considerations

This indicator expresses the environmental impact of the operation phase of the structure and components. Raw material extraction, transport and production of components are taken into account here (see standard 15804, B1-B6: Operation Phase). The indicator addresses the question of which emissions are associated with the operation of the temporary building.

This indicator should also be part of the total indicator "GWP emissions total", so the unit must always be the same to allow summation.

For an approximation, the various "large" household devices used in the operating phase and which are an essential part of the building concept (refrigerator, stove, boiler, etc.) are used here. The indicator addresses the question of which emissions are associated with the use phase of the temporary residential building. It must be clearly delimited (system boundary) which devices are taken into account. (Furniture is not included here!)

Measurements

Kg CO2-equ., related to use phase.

- List of relevant household items
- List of operating resources (duration of use, energy demand) for cooling, heating, light

(should be taken from calculations of respective energy indicators)

- Listing of operating resources (energy source, operating time) for expenses for repair, overhaul, maintenance, modernization (if necessary)
- For better comparability the results should be expressed in $\frac{\text{kg CO2-euq.}}{m^2\text{of PUE}}$ (or $\frac{\text{kg CO2-euq.}}{\text{Persons in PUE}}$)

Sum of emissions resulting from production of household appliances, operation of household appliances and maintenance of household appliances equated to the total emissions of operational phase.

Note: water consumption is considered in an individual indicator.

Acceptance measure (0-1)

1: the lower the emissions, the better.

0: the higher the emissions, the worse.

Description

Kg CO2-equ., op., environmental emissions from operational phase.

Definition GWP_{OMP} (GWP emissions operational phase and maintenance)

As a reference model, again, the approach resp. calculations given in BMVIT 2017[6] are used, where benchmark values for GWP and target values for GWP in new buildings are listed:

Tabelle 4: Top-Down abgeleitete Ist-Werte (Berechnung: SIR, 2017; grau hinterlegt: Aus der Schweiz übernommen):

		IST-Werte 2014		
		PEB ges. [MJ/m²a]	**PEB n.ern. [MJ/m²a]**	**THG-E [kg CO2-eq./m²a]**
Wohngebäude	Graue Energie G.	128	90	7,1
	Betriebsenergie G.	844	505	36,1
	Graue Energie M.	80	78	2,8
	Betriebsenergie M.	280	260	18,2
	Summe pro m²	**1.332**	**932**	**64,1**
		PEB ges. [MJ/m²a]	**PEB n.ern. [MJ/m²a]**	**THG-E [kg CO2-eq./m²a]**
Bürogebäude	Graue Energie G.	169	145	11,0
	Betriebsenergie G.	1.758	1.460	75,9
	Graue Energie M.	200	194	7
	Betriebsenergie M.	274	254	17,8
	Summe pro m²	**2.400**	**2.053**	**111,5**

Upper limit value for CO_2 are derived from Table 4 values for operating energy in the BMVIT publication.

$$E_{OMmin} := 0 \frac{\text{kg CO}_2\text{-equ.}}{m^2}$$

Lower limit of accepted CO2 emissions for operational and maintenance phase

$$E_{OMmax} := 36.1 + 18.2 = 54.3 \frac{\text{kg CO}_2\text{-equ.}}{m^2}$$

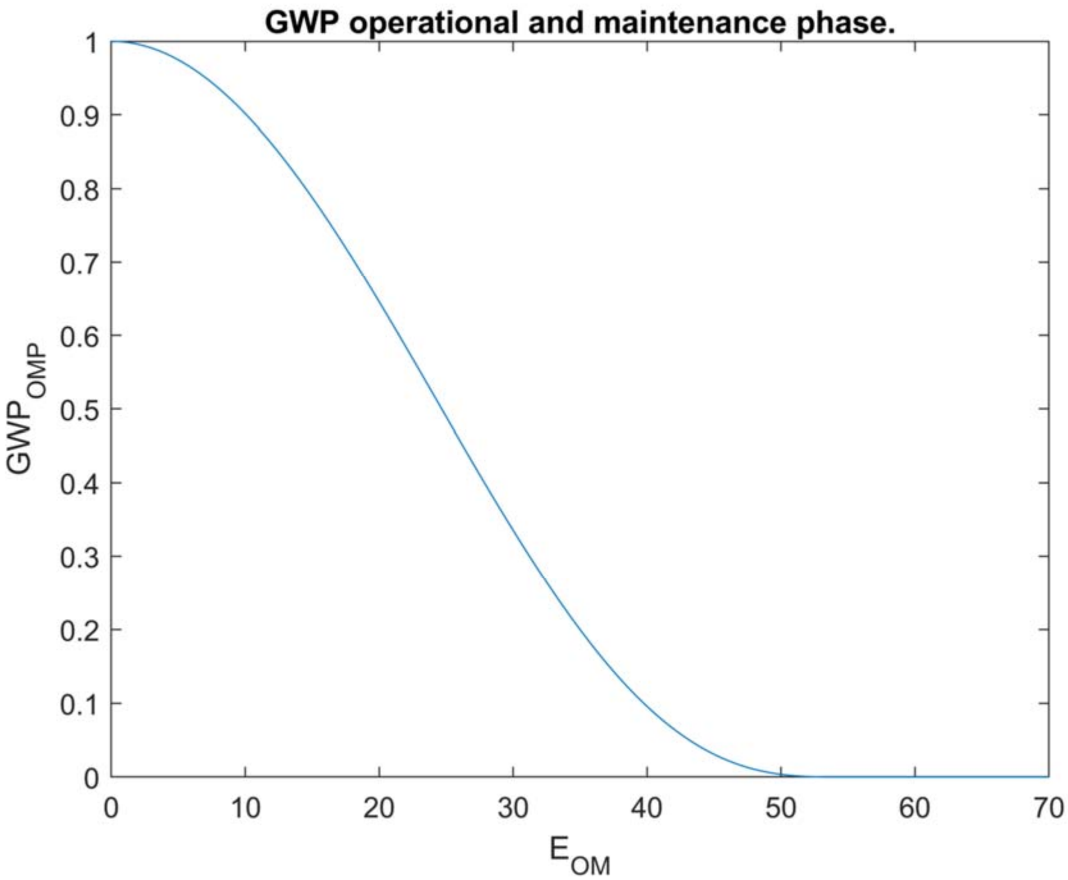
Upper limit of accepted CO2 emissions for operational and maintenance phase.

$$E_{OM}$$

CO2 emissions for operational and maintenance phase.

$$GWP_{OMP} := \left(1 - \min\left(\max\left(\frac{E_{OM} - E_{OMmin}}{E_{OMmax} - E_{OMmin}}, 0\right), 1\right)^{k}\right)^{l}$$

[6] BMVIT (2017): Richt- und Zielwerte für Siedlungen zur integralen Bewertung der Klimaverträglichkeit von Gebäuden und Mobilitätsinfrastruktur in Neubausiedlungen. Berichte aus Energie- und Umweltforschung 39/2017.

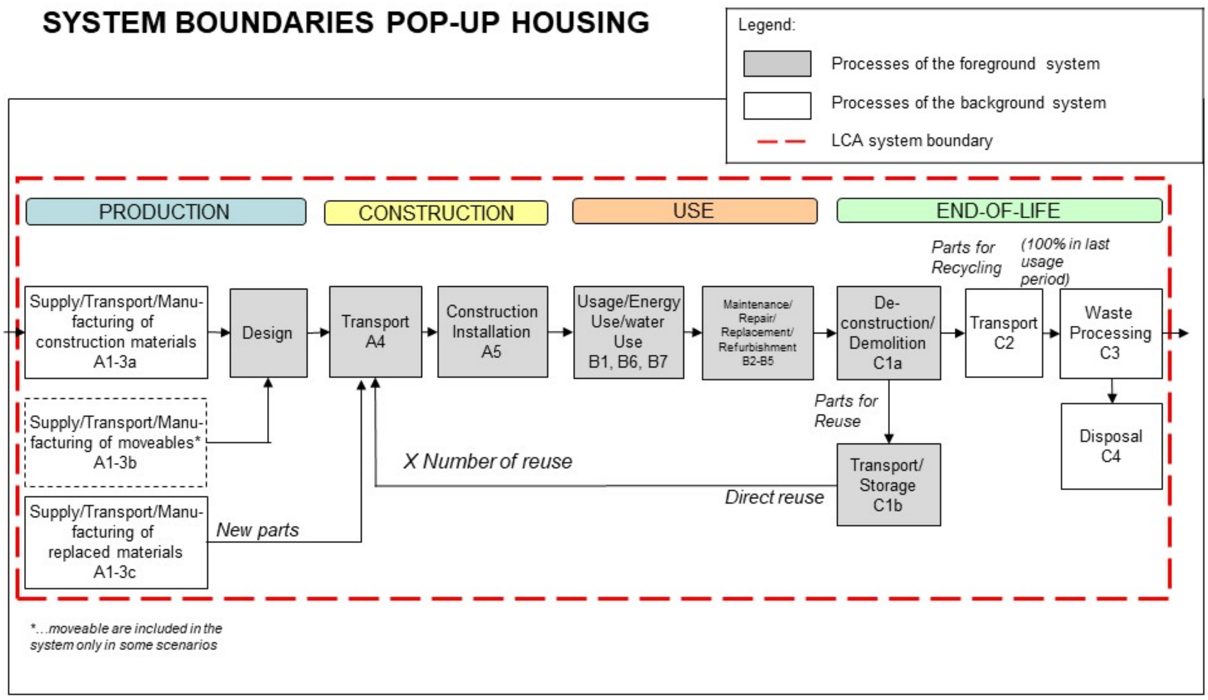

GWP operational and maintenance phase.
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
GWP_OMP
0
10
20
30
40
50
60
70
E_OM

1.4 GWP DECONSTRUCTION PHASE

General considerations

This indicator expresses the environmental impact of the deconstruction phase for temporary residential buildings (see ISO norm 15804, C1a-b). Comparable to the construction phase, the question here is which emissions are caused purely by the dismantling of the temporary building. Transportation from the construction site to a storage facility or the next construction site (if no storage phase is planned) are also taken into account here.

This indicator should also be part of the total indicator "GWP emissions total", therefore the unit must always be chosen the same so that a summation is possible.



Allocation of impacts from production and End of Life at last stage (EoL):

$$\text{Impacts of Production and EoL allocated to one usage period} = \frac{\text{Impacts of Production and EoL}}{\text{Number of reuse}} \qquad \text{Number of reuse} = \frac{1}{100\% - \%\ \text{reuse rate}}$$

Measurements

- On the basis of the material list and well documented assumptions, Gabi software is used to put a virtual housing model of PUE in place (following the Flowchart given above, here: phase C1a-b).
- GWP values are calculated in software and can be extracted

Unit used in LCA software (and in ISO Norm 15804): **kg CO2-equ**. The conversion factors of other greenhouse gases (e.g. methane, …) are taken from current table of IPCC.

Exhaust emissions, transport km, energy sources and energy requirements for machine use, machine hours, etc. are taken into account. Water consumption is calculated in a separate indicator and is not considered here.

- For better comparability the results should be expressed in $\frac{\text{kg CO2-euq.}}{m^2\text{of PUE}}$ or $\frac{\text{kg CO2-euq.}}{\text{Persons in PUE}}$.

Description

In this indicator, Global warming potential of the deconstruction phase is considered.

Acceptance measure (0-1):

1: deconstruction phase and transport can be carried out without fossil energy input.

0: efforts for a temporary housing deconstruction site (Exhaust emissions, transport km, energy sources and energy requirements for machine use, machine hours), should not be higher than in conventional housing construction.

Subprocesses

- Transportation of building materials / compounds from initial site to next factory to new destination (new construction site, storage facility): information regarding distance / route is collected (or assumptions are made) and taken into account in LCA.
- If applicable, activities related to preparation for reuse (e.g. cleaning, …) are considered: assumptions are made and taken into account.
- Transport vehicle + fuel: Information on vehicle type and fuel consumption is collected or assumptions are made and considered in LCA.
- deconstruction site operation: Information regarding machines used (forklift, trucks, drilling machines, manual assembly, etc.) and energy requirements is collected or assumptions are made and considered in LCA.

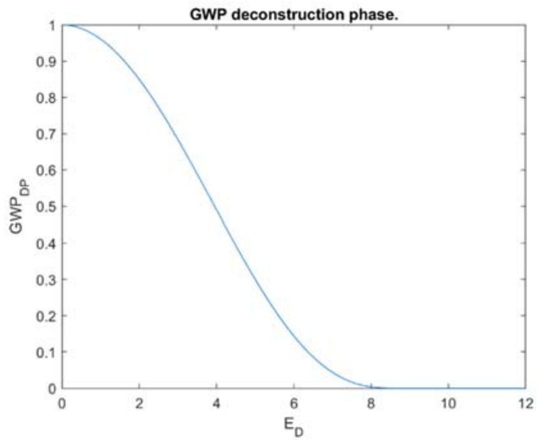
Definition GWP_{DP} (GWP deconstruction phase)

$E_{Dmin} := 0\frac{\text{kg CO}_2\text{-equ.}}{\text{per use}}\ldots$ Lower limit of accepted CO2 emissions for deconstruction phase.

$E_{Dmax} := 8.7\frac{\text{kg CO}_2\text{-equ.}}{\text{per use}}\ldots$ Upper limit of accepted CO2 emissions for deconstruction phase.

$E_D \ldots$ CO2 emissions for deconstruction phase.

$$GWP_{DP} := \left(1 - \min\left(\max\left(\frac{E_D - E_{Dmin}}{E_{Dmax} - E_{Dmin}}, 0\right), 1\right)^k\right)^l$$

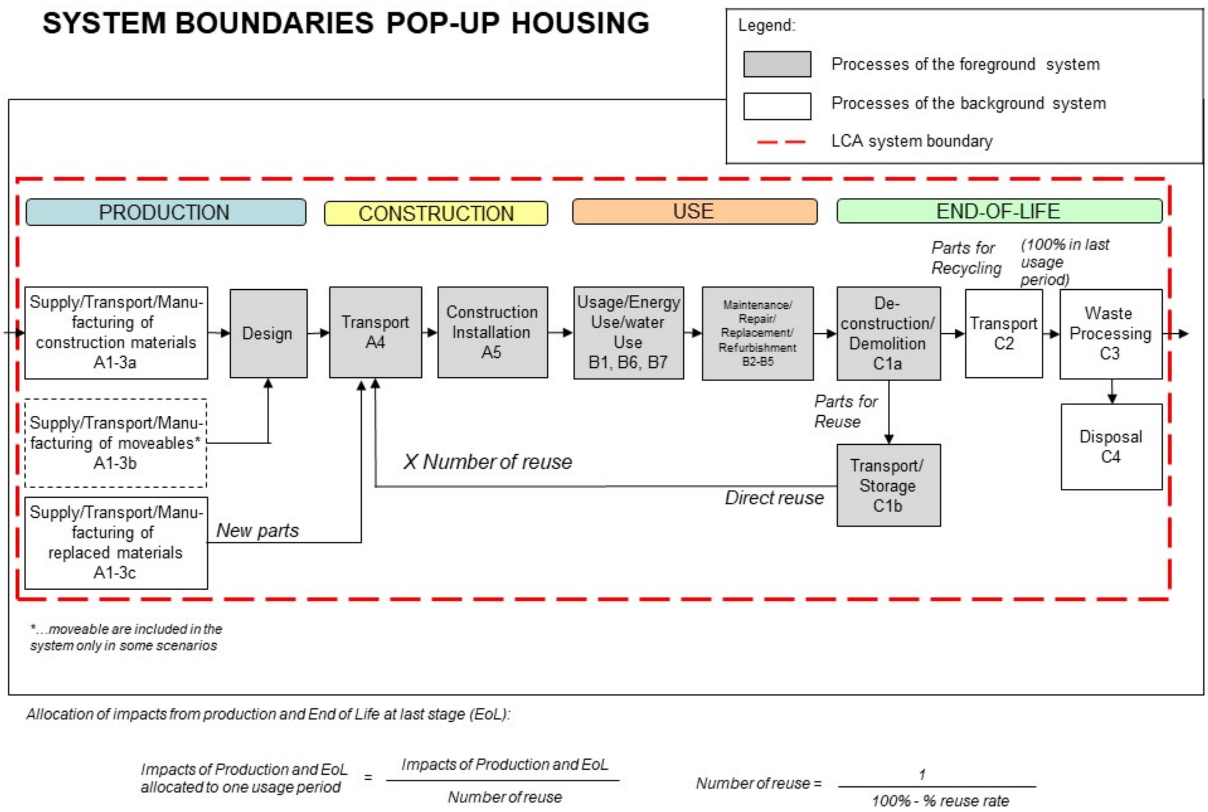


1.5 GWP END OF LIFE PHASE (19)

General considerations

This indicator expresses the environmental impact of the end of life phase of a temporary residential building (see norm 15804, C2-C4). This concerns emissions associated with transport, material/thermal recycling or recovery or landfilling of the remaining quantities.

This indicator should also be part of the total indicator "GWP emissions total", so the unit must always be the same to allow summation.



Measurements

- On the basis of the material list and well documented assumptions, Gabi software is used to put a virtual housing model of PUE in place (following the Flowchart given above, here: phase C2-4).
- GWP values are calculated in software and can be extracted

Unit used in LCA software (and in ISO Norm 15804): **kg CO2-equ**. The conversion factors of other greenhouse gases (e.g. methane, …) are taken from current table of IPCC.

Exhaust emissions, transport km, energy sources and energy requirements for machine use, machine hours, etc. are taken into account (based on assumptions)

- For better comparability the results should be expressed in $\frac{\text{kg CO2-euq.}}{m^2\text{of PUE}}$ (or converted into $\frac{\text{kg CO2-euq.}}{\text{Persons in PUE}}$)

Description

CO_2,eq.,EoF

Subprocesses

- Transportation of building materials / compounds from initial site to waste processing facility: assumptions regarding vehicle type, fuel, distance / route are made (or information is collected) and taken into account in LCA. (=C2)
- Waste processing (C3): incl. machine use, fuel, operating hours, based on assumptions.

(further steps regarding material and thermal recycling are excluded, as they are outside the system boundaries).

- Disposal (C4): incl. machine use, fuel, operating hours, based on assumptions.

Acceptance measure (0-1)

1: End of life phase and transport can be carried out without fossil energy input.

0: efforts for a temporary housing deconstruction site (Exhaust emissions, transport km, energy sources and energy requirements for machine use, machine hours), should not be higher than in conventional housing construction.

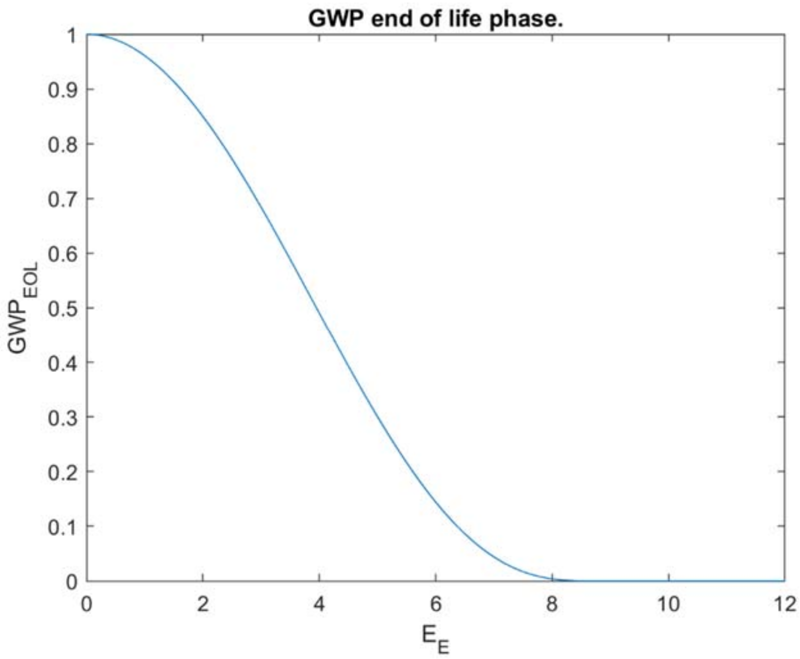
Definition GWP_{EOL} (GWP end of life phase).

$E_{Emin} := 0\frac{\text{kg CO}_2\text{-equ.}}{\text{per use}}$ … Lower limit of accepted CO_2 emissions for end of life phase.

$E_{Emax} := 8.7\frac{\text{kg CO}_2\text{-equ.}}{\text{per use}}$ … Upper limit of accepted CO_2 emissions for end of life phase.

E_E … CO_2 emissions for end of life phase.

$$GWP_{EOL} := \left(1 - \min\left(\max\left(\frac{E_E - E_{Emin}}{E_{Emax} - E_{Emin}}, 0\right), 1\right)^k\right)^l$$


GWP end of life phase.
GWP_EOL
E_E
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
12

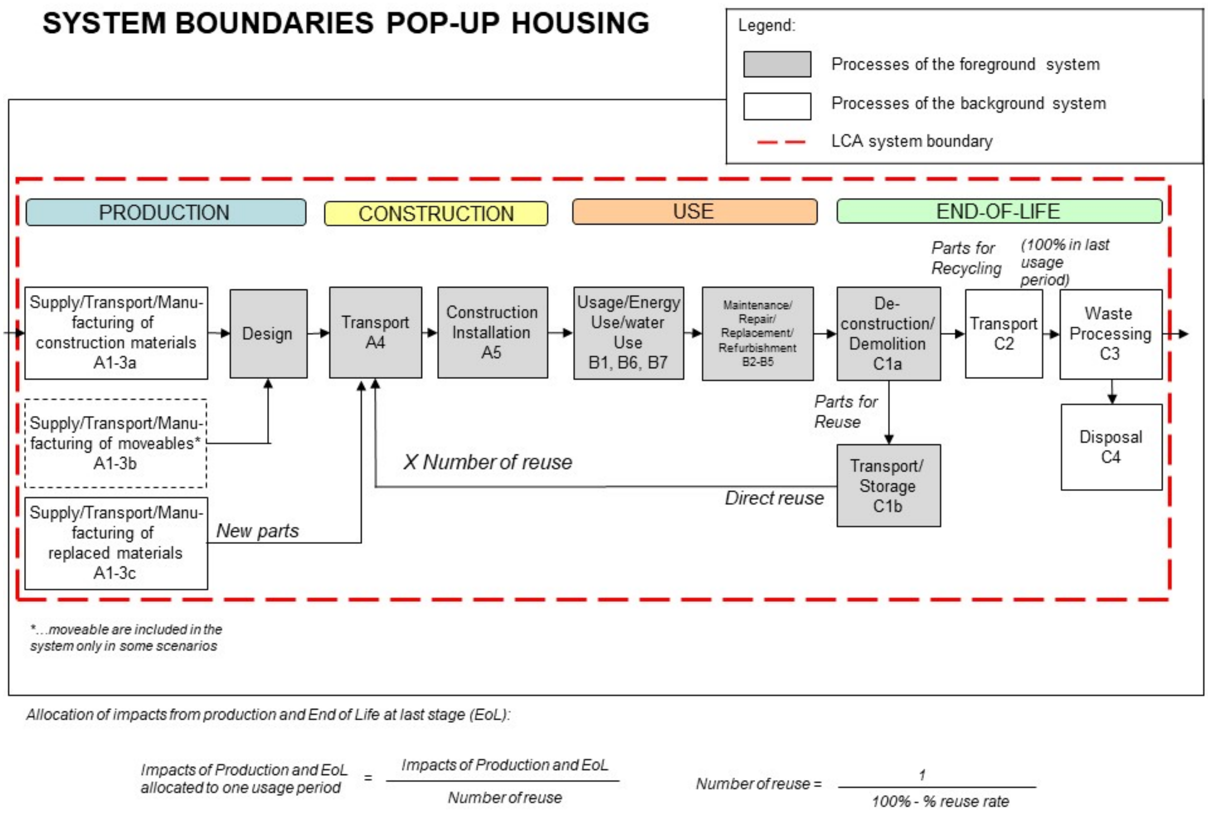
1.6 GWP EMISSIONS TOTAL

General considerations

This indicator shows the environmental impact expressed in CO_2-equivalents. It considers the whole life cycle of pop-up environment, from cradle to the grave. No new data is collected for this indicator, however benefits and loads beyond the product system (phase D – next product system including reuse, recovery and recycling potential) is considered in this indicator and have to be included.

It is a composite indicator of indicators

- GWP Material extraction and production phase
- GWP construction phase
- GWP operational phase and maintenance
- GWP deconstruction phase
- GWP end of life phase



Measurements

- The values of each phase A1-C4 are extracted from the LCA-software, as well as possible benefits and loads beyond the product system (phase D), once the virtual housing model and subprocesses are defined.

- The values (all expressed in kg CO_2-equ. /m²) are added for a total result.

Gabi Software allows a breakdown in GWP fossil and GWP biogenic (as recommended in 15804).

- To gain a deeper insight, it is then possible to divide each phase by the total sum of GWP emissions. This allows identification of the phases that contribute most to the GWP.

Acceptance measure (0-1)

Again, for the reference model for 0-1, the approach given in BMVIT 2017[7] was chosen. Benchmark values for GWP and target values for GWP in new buildings are listed in one of their tables.

Benchmark values for GWP and target values for GWP in new buildings

		IST-Werte 2014		
		PEB ges. [MJ/m²a]	PEB n.ern. [MJ/m²a]	THG-E [kg CO2-eq./m²a]
Wohngebäude	Graue Energie G.	128	90	7,1
	Betriebsenergie G.	844	505	36,1
	Graue Energie M.	80	78	2,8
	Betriebsenergie M.	280	260	18,2
	Summe pro m²	**1.332**	**932**	**64,1**
		PEB ges. [MJ/m²a]	**PEB n.ern. [MJ/m²a]**	**THG-E [kg CO2-eq./m²a]**
Bürogebäude	Graue Energie G.	169	145	11,0
	Betriebsenergie G.	1.758	1.460	75,9
	Graue Energie M.	200	194	7
	Betriebsenergie M.	274	254	17,8
	Summe pro m²	**2.400**	**2.053**	**111,5**

		Richtwerte - Top Down		
		PEB ges. [MJ/m²a]	PEB n.ern. [MJ/m²a]	THG-E [kg CO2-eq./m²a]
Wohngebäude	Graue Energie G.	71	7	1,7
	Betriebsenergie G.	469	39	8,7
	Graue Energie M.	44	6	0,7
	Betriebsenergie M.	156	20	4,4
	Summe pro m²	**740**	**72**	**15,4**
		PEB ges. [MJ/m²a]	**PEB n.ern. [MJ/m²a]**	**THG-E [kg CO2-eq./m²a]**
Bürogebäude	Graue Energie G.	94	11	2,6
	Betriebsenergie G.	977	112	18,3
	Graue Energie M.	111	15	1,7
	Betriebsenergie M.	152	20	4,3
	Summe pro m²	**1.334**	**158**	**26,8**

[7] BMVIT (2017): Richt- und Zielwerte für Siedlungen zur integralen Bewertung der Klimaverträglichkeit von Gebäuden und Mobilitätsinfrastruktur in Neubausiedlungen. Berichte aus Energie- und Umweltforschung 39/2017.

So, if the benchmark is assumed to be 43,2 kg CO2-equ/m²*a (sum of for grey energy building and operational energy building *(Betriebsenergie Gebäude)*. Note: Values for mobility considerations *(Mobilitätswerte (Graue Energie M / Betriebsenergie M.)* are excluded here, as they are not relevant for these considerations), everything that is even above this value is not acceptable (→ 0), as it is not aspirational to build new buildings that are already worse than the benchmark value of 2017.

If the target value for grey energy building is 10,1 kg CO2-equ./m²*a is met (sum of for grey energy building and operational energy *(Betriebsenergie Gebäude),* it can be considered optimal (à 1).

Description

Environmental impacts over the entire life cycle of the temporary home, starting with material extraction, manufacture, construction phase, use phase, deconstruction phase and end-of-life phase. GWP is expressed in kg CO_2-equ.

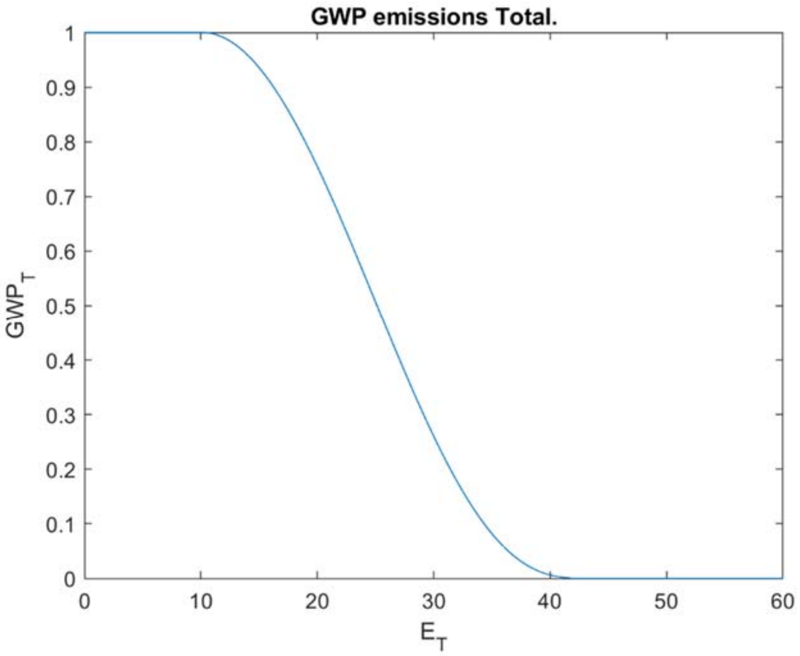
Definition GWP_{total} (GWP emissions total)

$E_{Tmin} := 10.1 \frac{\text{kg CO}_2\text{-equ.}}{m^2 \cdot a}$ … Lower limit of accepted CO2 emissions total.

$E_{Tmax} := 43.2 \frac{\text{kg CO}_2\text{-equ.}}{m^2 \cdot a}$ … Upper limit of accepted CO2 emissions total.

E_T … CO2 emissions total.

$$GWP_T := \left(1 - \min\left(\max\left(\frac{E_T - E_{Tmin}}{E_{Tmax} - E_{Tmin}}, 0\right), 1\right)^k\right)^l$$



1.7 PRIMARY ENERGY DEMAND OPERATION

Definition PED_O

Includes HWB; WWB; HTEB etc.

Electricity and hot water is calculated over gross floor area. The calculation is based on the energy pass and is performed with ArchiPhysik.

Definition of efficiency classes A++, A+, A, B, C, D, E, F, G:

A++ --> 1

B --> ca. 0.5

G --> 0

tend to stay lower in the bad area

Table 1: EU-energy efficiency classification

Klasse	**$HWB_{Ref,SK}$ [kWh/m^2a]**	**PEB_{SK} [kWh/m^2a]**	**$CO_{2eq,SK}$ [kWh/m^2a]**	**$f_{GEE,SK}$ [-]**
A++	10	60	8	0,55
A+	15	70	10	0,70
A	25	80	15	0,85
B	50	160	30	1,00
C	100	220	40	1,75
D	150	280	50	2,50
E	200	340	60	3,25
F	250	400	70	4,00
G	>250	>400	>70	>4,00

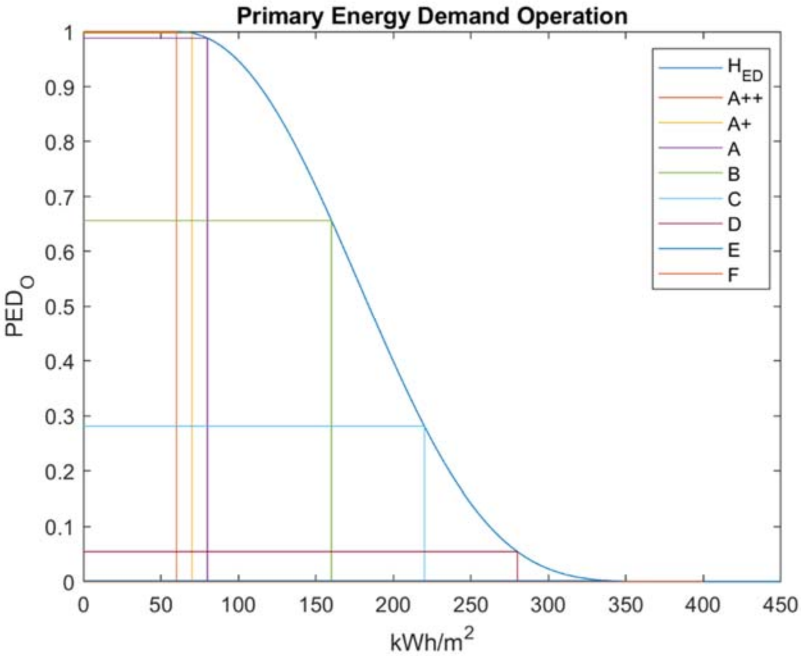
Definition PED_O (Primary energy demand)

Shown here for DoU of one year.

$$E_{min} := 60$$

$$E_{max} := 400$$

$$PED_O := \left(1 - \min\left(\max\left(\frac{E_D - E_{min}}{E_{max} - E_{min}}, 0\right), 1\right)^{2.2}\right)^{6}$$



tab = 2×8 table

	AAA	AA	A	B	C	D	E	...
1 kWh	60	70.0000	80.0000	160.0000	220.0000	280.0000	340.0000	
2 CED	1	0.9974	0.9883	0.6565	0.2815	0.0548	0.0018	

1.8 PRODUCT WATER FOOTPRINT OF MATERIALS USED IN BUILDING

General considerations

Each material needs a certain amount of fresh water resources necessary for extraction and production. The greater this water consumption, the worse it is for the environment.

Measurements

Fresh water consumption of materials is available in software Gabi (software for life cycle assessments) and data can be extracted (unit: Use of net fresh water in **m3 per m2 and year**)

- Values can be taken from LCA databases for the materials
- Values are approximations (uncertainty factor and fluctuations possible)
- comparative value can only be approximated with specific factors (location of the construction site, real origin of the materials, actual extraction, etc.)
- included in this step is the water embedded in the material itself, but also the water necessary for extraction and production of materials ("cradle to gate")
    - o if reuse material is used, water consumption from the first use phase must be allocated fairly
- results should then be expressed in **m³/m² of a pop-up housing environment per year.**

Definition

$$W_{material} = \frac{\sum_{i=1}^{n}(water\ footprint\ of\ \text{virgin}\ materials\ [\text{m}^3])_i + \frac{water\ footprint\ of\ reused\ materials\ [m^3]}{number\ of\ use\ phases}}{\left(\frac{days\ of\ use\ [d]}{year}\right) \times (total\ area\ of\ PUE\ [m^2])}$$

Acceptance value:

Materials with marginal embedded water consumption (W_material = **0 m³/m²*y**) → 1

Embodied water[8] **>20m³/m²*y** → 0

---

[8] McCormack, Treloar, Palmowski and Crawford (2007): Modelling direct and indirect water requirements of construction. Building Research & Information. 35(2), 156-162: Note: *It was found that there is a considerable amount of water embodied in construction. The highest value was 20.1 kilolitres (kL)/m2 gross floor area (GFA), representing many times the enclosed volume of the building, and many years worth of operational water. The water required by the main construction process is minimal. However, the water embodied in building materials is considerable. These findings suggest that the selection of elements and materials has a great impact on a building's embodied water.*

1.9 WATER USE DURING OPERATION

General considerations

Water use in the operating phase of the building is assessed. It is necessary that safe drinking water is available in sufficient quantity for the residents. Although it is common practice in Austria, it is not necessary that all water consumption of daily needs is covered by high quality drinking water (e.g. toilet flush).

Measurements

1. Measurement of water consumption is necessary during the whole operation (in real cases: water meter installed for monitoring of water consumption, whilst in theoretical cases this is done by estimating the consumption in households).
2. List of water consuming appliances (kitchen sink, shower, WC, dishwasher, washing machine, garden hose etc.)
3. Estimation of an average number of uses and reference values for water consumption per use
4. An approximate value can be determined by these factors. Here, projections for Austria are used (see Neunteufel et al. 2012[9]), respectively an adapted framework for different sites has to be implemented.
5. Assessment of whether safe drinking water must be used for this
6. Indicator is evaluated per m² of PUE **or** related to inhabitants per day [Ed]
7. (Other sources than drinking water: water cascading and reuse is estimated and influence the balance positively, if less drinking water has to be used in areas where it is not absolutely necessary (e.g. toilet flushing) → this is covered in a separate indicator → Water reuse)
8. Water measurement (in theoretical cases estimation of water quantities) necessary for use of water from other sources than drinking water (e.g. Grey water system, rainwater collection system, resource / nutrient recovery, ...) during the whole operation
    - is evaluated per m² of usable floor space or related to inhabitants
    - types of water cascading:
        - rainwater collection
        - water quantity, that is treated on site (e.g. plant based purification plant)
        - other water cascading applications

Reference values for average per capita water consumption in Austria in [l/Ed] are based on this publication: Neunteufel et al., 2012. The values for the acceptance measure are derived from this publication also.

Definition WU_{DO} (water use during operation)

$W_D \ldots$ Water demand in l/Ed

[9] Neunteufel, Richard, Perfler, Tuschel, Böhm, Haas (2012). Wasserverbrauch und Wasserbedarf. Zusammenfassung der Ergebnisse. Available at: https://docplayer.org/17374611-Wasserverbrauch-und-wasserbedarf-zusammenfassung-der-ergebnisse.html

$W_R \ldots$ Water reuse in l/Ed

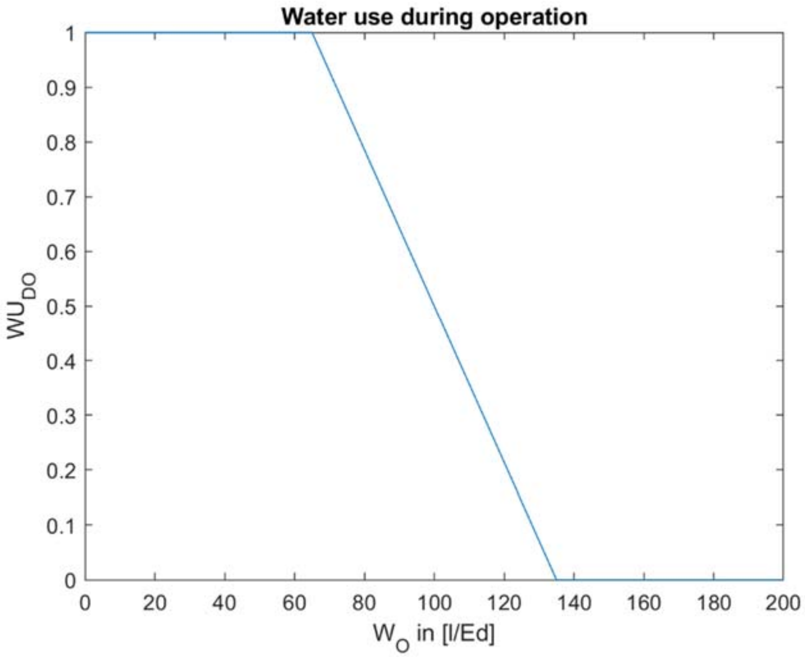
$W_O = W_D - W_R \ldots$ Water during operration.

$W_{min} = 65l/Ed$

$W_{max} = 135l/Ed$

$WU_{DO} := \left(1 - \min\left(\max\left(\frac{W_O - W_{min}}{W_{max} - W_{min}}, 0\right), 1\right)^l\right)^k \ldots$ Water use during operation.

$k = 1$



$l = 1$

1.10 WATER REUSE

General considerations

Regarding essential circular building design strategies, careful water use is an important topic and refers often to minimization of water consumption and water cascading[10]. Considerate fresh water use should therefore also be presented in a separate indicator within this indicator set. This indicator is however not "on the same level as the other water indicators" (It will not be directly integrated in the sum parameter Full water footprint in the end as it is already calculated in Water use during operation). However, it provides information on closed loop design, which would not be so easily visible if this indicator were only a partial aspect of water use during operation.

Measurements

1. Measurement of other sources than drinking water: water cascading and reuse is estimated and influences the water balance positively, if less drinking water has to be used in areas where it is not absolutely necessary (e.g. toilet flushing) during the whole operation
2. Water measurement (in our case estimation of water quantities) necessary for use of water from other sources than drinking water (e.g. Grey water system, rainwater collection system, resource / nutrient recovery, ...) during the whole operation
3. -is evaluated per m^2 of usable floor space or related to inhabitants

Subprocesses

Water quantify of types of water cascading:

- Rainwater collection
- Water quantity, that is treated on site (e.g. plant-based water purification)
- other water cascading applications

Acceptance measure (0-1)

Replacement rate of drinking water:

There is no water cascading and reuse → 0

All suitable water sources are reused or cascaded (excluding water necessary for drinking water) → 1

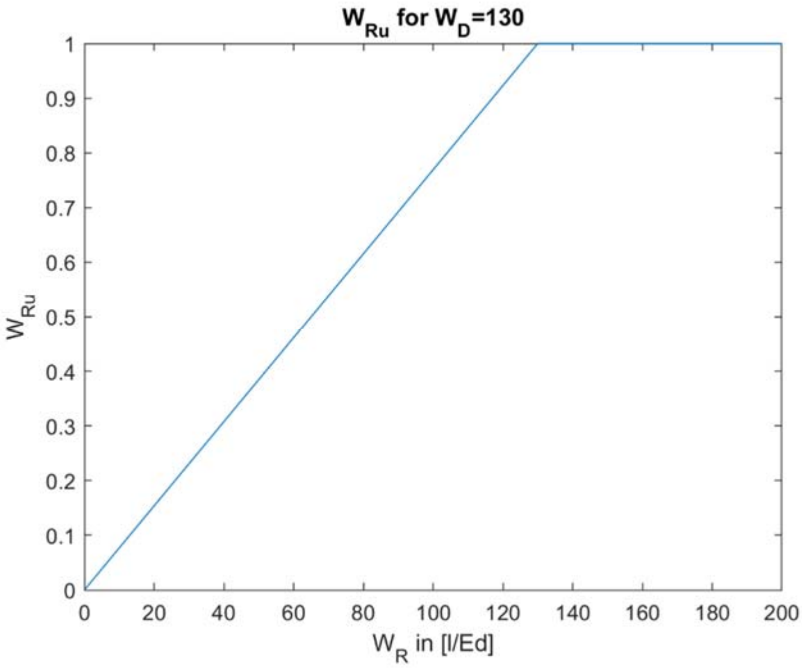
Definition W_{Ru} (water reuse)

W_D…Water demand in l/Ed

W_R…Water reuse in l/Ed

[10] Circle Economy (2018): A framework for circular buildings. Indicators for possible inclusion in BREEAM.

$W_{Ru} = \frac{W_R}{W_D} \ldots$ Water reuse



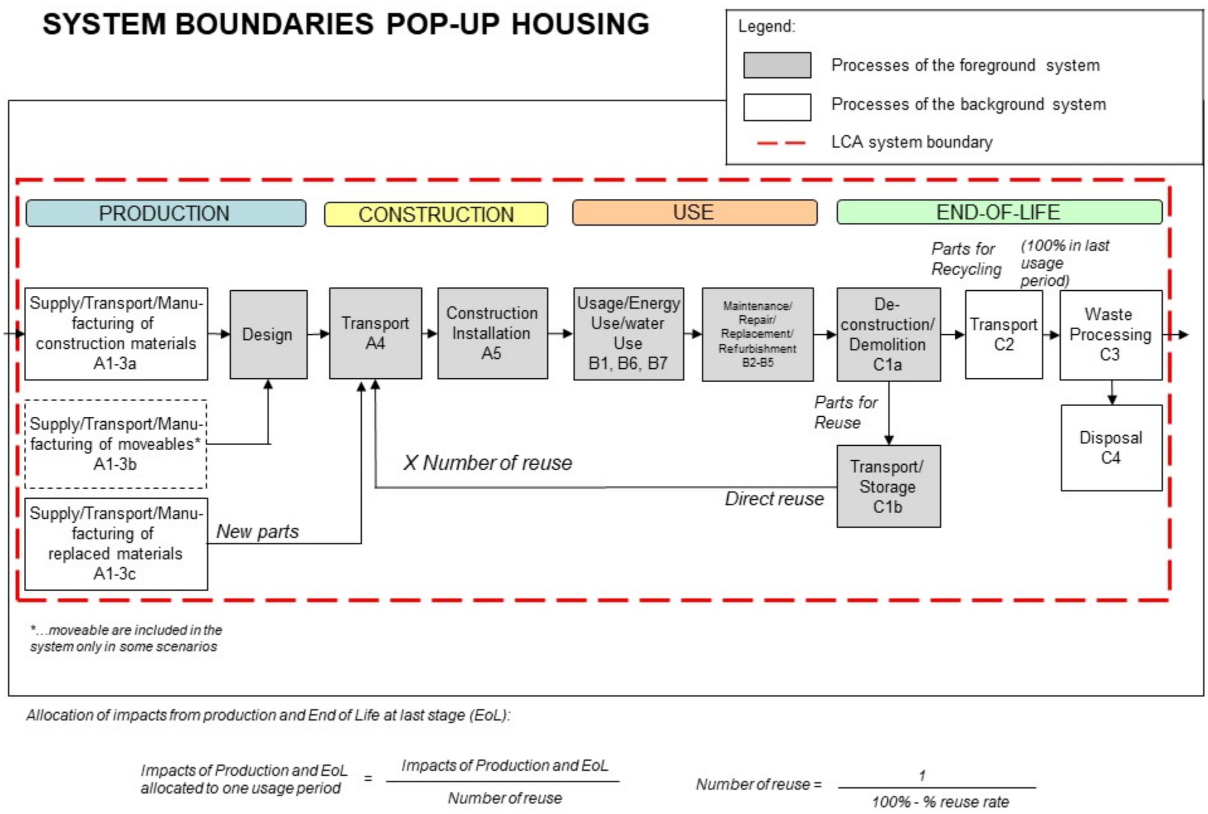
1.11 WATER USE DURING CONSTRUCTION, DISASSEMBLY AND END OF LIFE PHASE

General considerations

The guiding question is “How much fresh water is required for construction, disassembly and end of life phase for a pop-up environment?”

For the calculation of these values, a life cycle assessment following ISO Norm 15804 is undertaken, with the system boundaries as shown below.

The relevant life cycle phases for this indicator are A5, as well as C1-C4.



Results for this indicator are given in **m³ / m² of pop-up housing environment.**

Measurements

An assessment of fresh water demand during construction, disassembly and end of life phase is undertaken.

There is limited literature regarding the water demand during these specific phases in conventional buildings, let alone temporary housing. Literature should be regularly screened for updated or more specific values regarding the lower acceptance measure.

As temporary housing environments are usually constructed using prefabricated modules the water demand during construction, disassembly and EoL (end of life) are assumed to not be very high.

Acceptance measure (0-1)

No water is needed for construction / deconstruction / disassembly/end of life **(0m³/m²)** → 1

Fresh water demand for construction / deconstruction / disassembly **>0.2m³/m²** → 0

Description

Definition GWP_{total} (GWP emissions total)

W_constr,diss,EoL

$$W_{constr,diss,EoL} = \frac{(\sum water\ demand\ during\ construction\ phase\ [m^3]\ +\ \sum water\ demand\ during\ disassembly\ phase\ [m^3] + \sum water\ demand\ during\ EoL\ phase\ [m^3}{m^2}$$

- Water demand for construction phase
- Water demand for disassembly
- Water demand for EoL phase

References

Macieira, M. and Mendonca, P. (2016): Building rehabilitation with dry and wet systems – embodied water comparison. MATEC Web of Conferences, 68, 13009. DOI: 10.1051/matecconf/20166813009

1.12 FULL WATER FOOTPRINT

General considerations

This indicator is a sum of indicators 58-60:

- Fresh water use for material extraction and production phase
- Water use during operation
- Water use during construction, disassembly and End of Life

It has to be ensured that the same unit (m^3/m^2) is used for all sub-indicators.

As indicator water use during operation already includes calculations regarding water reuse, the water reuse indicator is already integrated in the calculation of this indicator.

Measurements

- Indicators 58-60 have to be calculated
- Indicators 58-60 are added for calculating indicator 57).

Unit: m^3/m^2 of pop-up housing environment

Acceptance measure (0-1)

The acceptance measure is also a sum of the individual acceptance measures of the sub-indicators .

Water footprint > $25.2 m^3/m^2$ → 0

Water footprint ≤$0.2 m^3/m^2$ → 1

The optimum can be close to 0 m^3/m^2, as water reuse is included in the water demand during operation. If high volumes of water are reused, the quanity for fresh water is reduced. This is not related to water scarcity[11].

Description

W_total = W_material + W_constr,diss,EoL + W_operation

Sum of all previous water quantities for materials, construction and disassembly, use.
(water reuse is already considered / credited in respective indicators)

---

[11] *Das Optimum kann sehr nahe bei 0 liegen, da reuse-Wasserverwendung mitgerechnet wird und hier dargestellt wird, wie viel „neues“ Frischwasser benötigt wird. Wenn viel Wasser im Kreislauf geführt wird ist dies positiv zu bewerten und ist kein Ausdruck von Wassermangel.*

1.13 STOCK USAGE FACTOR

General considerations

This indicator is intended to assess the efforts needed in terms of material use to realize a temporary use. Key question: How much material, infrastructure and effort must be added to existing "facilities" in order to realize / implement a desired temporary use.

The aim is to focus on the following consideration: Before something new is built, is there a possibility to appropriate or adapt some existing structures. (This is desirable from a resource perspective and is a guiding principle of circular construction.)

Fundamental considerations start from the question of how and whether existing structures should and can be attributed to a PUE.

The indicator should assess already existing structures (e.g. vacant commercial space, factories, offices, railway tracks, trains) and structures yet to be added for an intended temporary housing environment (e.g. extended sanitary facilities, kitchen modules, or even entire housing units).

Measurements

1. Description of planned pop-up environment: What type of PUE is intended? (sources: architectural model, floor plans including technical facilities)
2. Site assessment: List of available facilities and materials at intended site. (what is already available)
3. Assessment and estimations of existing material, facilities, rebuilds that are necessary to achieve the intended PUE and estimation via table (see below)
4. Weighing of all 5 aspects
5. Result describes stock usage (how much of an intended PUE can be achieved/implemented with existing infrastructure).

Taking inspiration from the project AbBau[12] but leaving 2 elements out (social, as it is covered in more differentiated indicators, and stuff, as it is not in the focus of this project) the following aspects will be assessed:

- **Space Plan** ("room layout") Doors, interior walls, floors, etc.
- **Services** ("Building Services") Pipes, ventilation, elevator, shafts, etc.
- **Structure** All load-bearing elements that define the basic shape of the building.
- **Skin** ("outer shell") Facade, windows, insulation, etc.
- **Site** ("Location") Immediate surroundings of the building (Access to water supply and energy on plot)

Calculations: estimation (percentage) of aspects and weighting in all 5 categories

[12] http://www.ecodesign.at/forschungsprojekte/abbau/

Fulfillment level	Site* (25% - *weighing factor*))	Skin (25%)	Structure (25%)	Service (20%)	Space plan (5%)
100%	Availability of: (weighing factor in brackets) electricity, energy (20) water supply (35) sewage (35) waste management system (10)	Exterior skin (roof, facade, exterior windows/doors) are functional, incl. insulation	Supporting structure and structural walls available, statics given	Building services (power lines, water pipes, sewage pipes, ventilation, etc.) completely available	The room layout is ideally suited for intended use
high	One component is missing	outer skin is intact (wind/water resistant), but no adequate insulation effect			
middle	Two components are missing	Windows/ façade/ roof are not wind / water resistant, need for renovation.	parts of supporting structures are missing, but can be retrofitted, statics restorable	The building services are partially suitable for intended use, Estimation (and gradation) in percent.	The space allocation is partially suitable for intended use. Estimation (and gradation) in percent.
low	Three components are missing	need for extensive renovation.			
0 %	Nothing present	Nothing present	Statics is not sufficient	No building services available or in unusable condition	Room layout not available and not suitable for intended use.

Definition S_{UF} (stock usage factor)

$d := (d_1, \ldots, d_5) \ldots$ degree of possible usage. $d_i \in [0,1]$ mit $i \in \{1,2,3,4,5\}$

$\omega := (\omega_1, \ldots, \omega_5) \ldots$ weighting of the individual structural elements.

$\omega_1 = 0.25 \ldots$ weighting for the first substructure, site.

$\omega_2 = 0.25 \ldots$ weighting for the second substructure, skin.

$\omega_3 = 0.25 \ldots$ weighting for the third substructure, structure.

$\omega_4 = 0.2 \ldots$ weighting for the fourth substructure, service.

$\omega_5 = 0.05 \ldots$ weighting for the fifth substructure, space plan.

$S_{UF} = d \times \omega$

w = 5×1

0.2500

0.2500

0.2500

0.2000

0.0500

d = 1×5

1 1 1 1 1

SUF = 1

d = 1×5

0 0 0 0 0

SUF = 0

d = 1×5

1 0 0 0 0

SUF = 0.2500

d = 1×5

0.5000 0.5000 0.5000 0.5000 0.5000

SUF = 0.5000

2 TECHNICAL QUALITY

2.1 LEVEL OF EASE OF DISASSEMBLY

Brief summary

The level of ease of disassembly describes the level of intensity of tools and knowledge in order to dismantle the building on site. Thus, the lower the need of specialized tools and equipment and the lower the specific skills and knowledge required by people involved in the dismantling of the building, the easier the disassembly.

Definition L_{disass}.

The identified sub-processes are tools and knowledge.

Tools T_i $i \in \{1, \ldots, 5\}$

No special tools required.

Small devices required.

Electrical equipment with power supply required.

Electrical equipment with power current supply required.

Special equipment required.

Knowledge K_i $i \in \{1, \ldots, 5\}$

1.No special expertise required.

Craftsmanship required.

Experienced helpers required.

Trained staff required.

Specialist staff required.

Claim: Tools are easier to obtain and cheaper than skilled personnel. Based on this claim, knowledge is weighted higher.

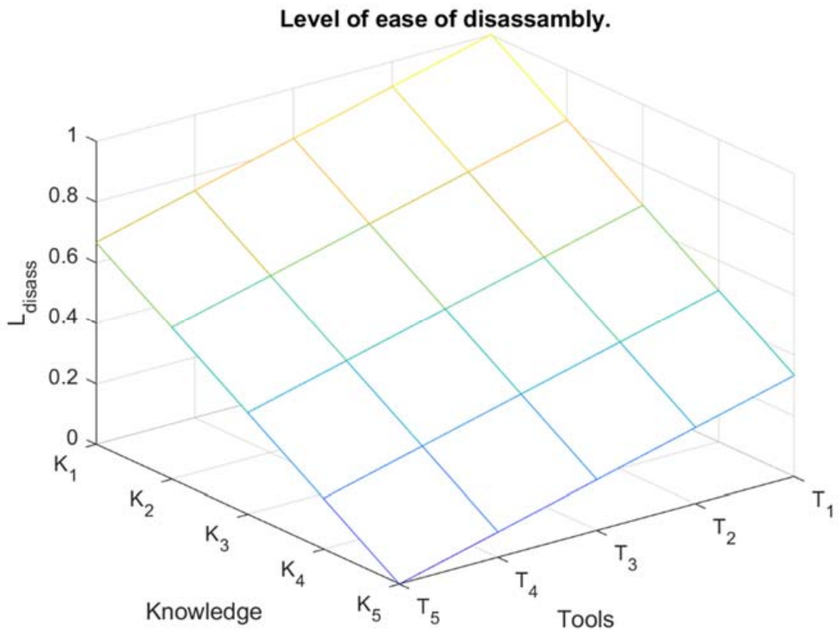
$\omega_K = \frac{2}{3}$ und $\omega_T = \frac{1}{3}$ different weighting.

Mappings

$L_{disass} \coloneqq T_i \cdot \omega_T + K_i \cdot \omega_K$

$T_i \coloneqq 1 - \frac{i-1}{i_{max}-1}$ $i \in \{1, \ldots, 5\}$ ... T_i means i-th category in Tools is fulfilled.

$K_i \coloneqq 1 - \frac{i-1}{i_{max}-1}$ $i \in \{1, \ldots, 5\}$ ... K_i means i-th category in Knowledge is fulfilled.


Level of ease of disassambly.
1
0.8
0.6
0.4
0.2
0
L_disass
K_1
K_2
K_3
K_4
K_5
Knowledge
T_1
T_2
T_3
T_4
T_5
Tools

2.2 COOLING ENERGY DEMAND

Brief summary

The Cooling Energy Demand (CED) describes the total amount of energy in kWh/m2a that is needed to cool the building to a defined internal temperature. The CED is dependent on the quality of the external building shell (e.g. quality of insulation, building form and orientation, area and quality and shading of transparent elements, shading of volume to floor area ratio).

Definition CED

Defined by means of

$10\frac{kWh}{m^2 DoU} \rightarrow 1$

$107.7\frac{kWh}{m^2 DoU} \rightarrow 0$

For DoU greater than one year, DoU equals one year. For DoU less than one year, DoU is equal to the fraction of the year.

Definition via re-scaling of the heating energy demand with regard to temperature difference.

Fixed point: Interior temperature $\vartheta_{\mathrm{In}} \coloneqq 20°C$.

Reference point heating: Outdoor temperature $\vartheta_{Out_H} \coloneqq -15°C$.

Reference point cooling: Outdoor temperature $\vartheta_{Out_C} \coloneqq 35°C$.

Scaling factor: $\alpha \coloneqq \frac{|\vartheta_{In} - \vartheta_{Out_C}|}{|\vartheta_{In} - \vartheta_{Out_H}|} = \frac{15}{35} = 0.43.$

Let E_{C_H} be the efficiency classes heating and let E_{C_C} be the efficiency classes cooling. Thus the efficiency class boundaries result from $E_{C_C} \coloneqq \alpha \cdot E_{C_H}$.

Used energy efficiency classes.

$A++ \leq 10\frac{kWh}{m^2} \cdot \alpha \approx 4.3\frac{kWh}{m^2}$

$A+ \leq 15\frac{kWh}{m^2} \cdot \alpha \approx 6.5\frac{kWh}{m^2}$

$A \leq 25\frac{kWh}{m^2} \cdot \alpha \approx 11\frac{kWh}{m^2}$

$B \leq 50\frac{kWh}{m^2} \cdot \alpha \approx 21.5\frac{kWh}{m^2}$

$C \leq 100\frac{kWh}{m^2} \cdot \alpha \approx 43\frac{kWh}{m^2}$

$D \leq 150\frac{kWh}{m^2} \cdot \alpha \approx 65\frac{kWh}{m^2}$

$E \leq 200\frac{kWh}{m^2} \cdot \alpha \approx 86\frac{kWh}{m^2}$

$F \leq 250\frac{kWh}{m^2} \cdot \alpha \approx 107\frac{kWh}{m^2}$

$G > 250\frac{kWh}{m^2} \cdot \alpha \approx 107\frac{kWH}{m^2}$

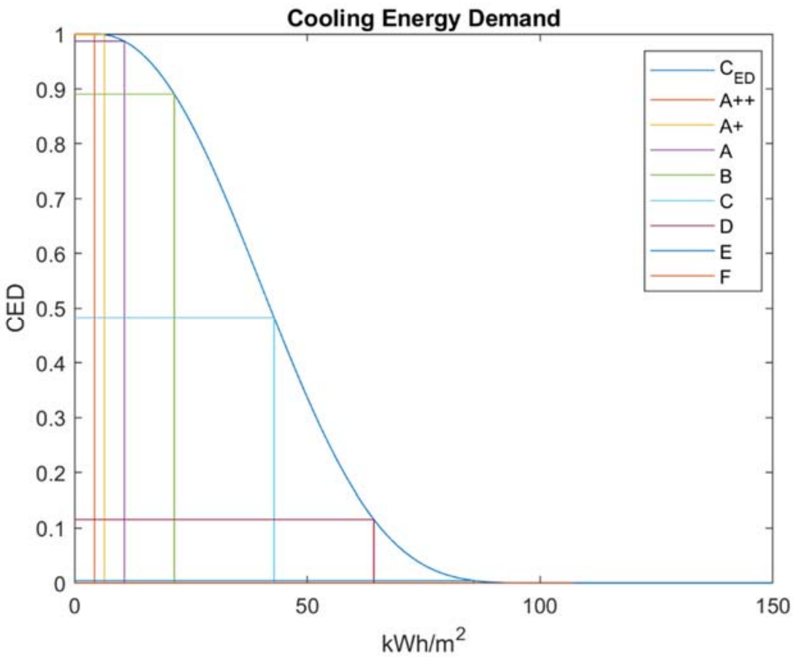
Definition $\boldsymbol{CED}$ (Cooling Energy Demand)

Shown here for DoU of one year.

$E_{min} \coloneqq 4.3$

$E_{max} \coloneqq 107.7$

$CED \coloneqq \left(1 - \min\left(\max\left(\frac{E_D - E_{min}}{E_{max} - E_{min}}, 0\right), 1\right)^{2.2}\right)^6$



tab = 2×8 table

	AAA	AA	A	B	C	D	E	...
1 kWh	4.2857	6.4286	10.7143	21.4286	42.8571	64.2857	85.7143	
2 CED	1.0000	0.9988	0.9868	0.8904	0.4832	0.1158	0.0047	

2.3 COVERAGE ENERGY, ELECTRICAL

Brief summary

The Coverage Energy Electrical indicator describes the percentage of electrical energy that the building can generate by renewable energy systems (RES) in relation to its total electrical energy demand. It thus defines the electrical self-coverage ratio of the building.

Balance sheet analysis of the self-coverage ratio according to OIB calculated with ArchiPhysik!

Definition $C_{renew.E}$

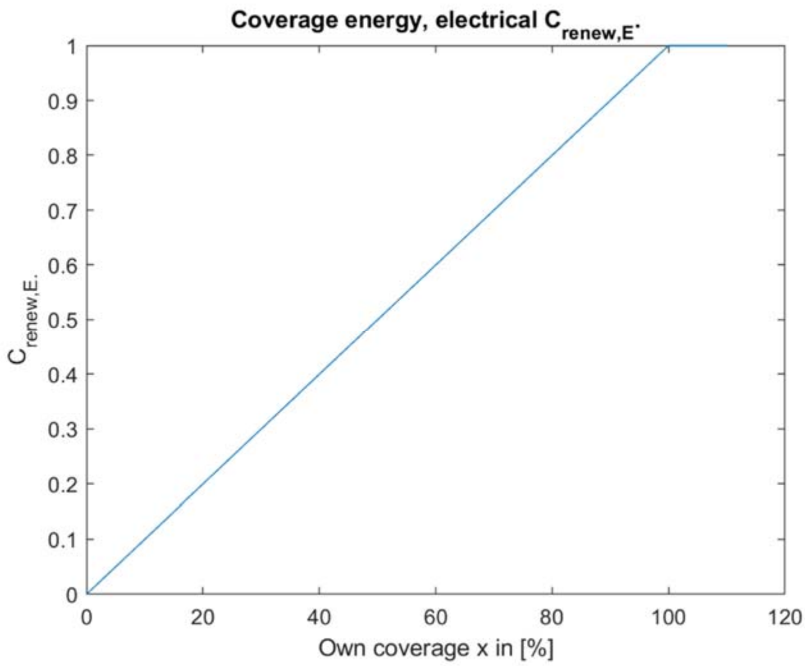
Calculation via the own cover ratio (Own coverage) electrically from Energy Performance Certificate.

$x = 0\% \rightarrow 0;$

$x = 100\% \rightarrow 1;$

x ... Own coverage ratio, this is calculated in ArchiPhysik.

$C_{renew.E} \coloneqq \min\left(\frac{x}{100}, 1\right)$



2.4 DAYLIGHT QUALITY

Brief summary

The Daylight Quality is defined by the Daylight Factor (DF) that describes a ratio which expresses the level of indoor light illuminance relative to outside illuminance. It is measured with an overcast sky (i.e. diffuse, non-directional light) and serves as an approximate measure of the amount of daylight in the interior.

Daylight factor

The numerical approach for the DF is as follows:

$$DF \coloneqq \frac{T \cdot A_W \cdot \Theta}{A \cdot (1 - R^2)}$$

With:

T ... diffuse visible light transmittance of glazing.

A_w ... net glazed area of window.

Θ ... angle of visible sky (rad).

A ... total internal surface area: walls, ceiling, floor.

$R \ldots$ average internal reflectance.

Initial deliberations

Scale is in 100%

min 2% anything less is unacceptable → 0

2% to 5% is good 5% → 0.5 wie vom signuid benotigt

10% is very good → 1 for 10% and up.

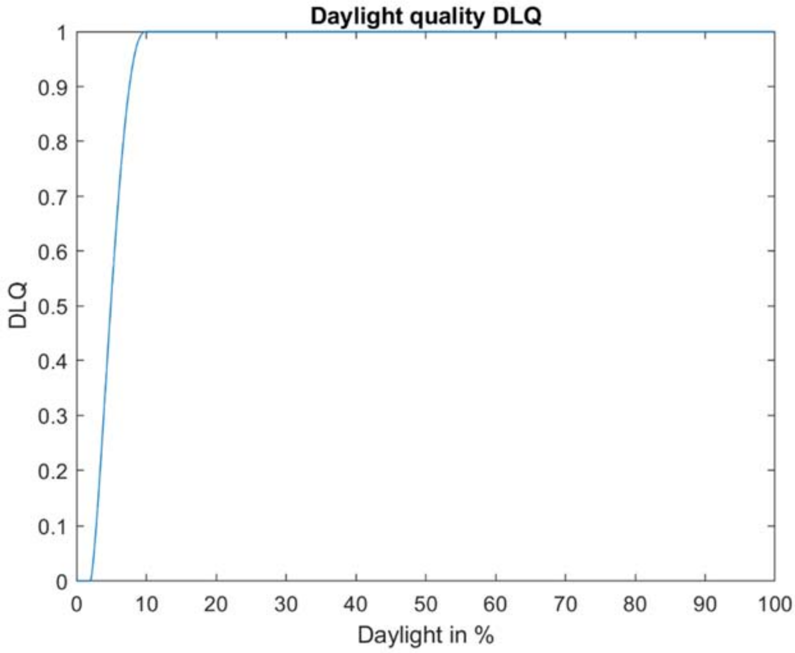
Definition DLQ (Daylight quality)

DL ... daylight indoors in % ($DF \rightarrow_{in\%} DL$).

DL_{min} ... required indoor daylight in %.

DL_{max} ... sufficient daylight indoors in %.

$$DLQ \coloneqq \left(1 - \min\left(\max\left(\frac{DL - DL_{min}}{DL_{max} - DL_{min}}, 0\right), 1\right)^{1.4}\right)^{2.5}$$

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tab = 2×6 table
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	DLQ1	DLQ2	DLQ3	DLQ5	DLQ7	DLQ10
1	1	2	3.0000	5.0000	7.0000	10
2	0	0	0.1305	0.5182	0.8386	1

2.5 ENERGY DEMAND- HEATING

Brief summary

The Heating Energy Demand (HED) describes the total amount of energy in kWh/m2a that is needed to heat the building to a defined internal temperature. The HED is dependent on the quality of the external building shell (e.g. quality of insulation, building form and orientation, area and quality and shading of transparent elements, shading of volume to floor area ratio).

Initial deliberations

Consider only building envelope and shape.

Used energy efficiency classes. A++, A+, A, B, C, D, E, F, G:

$A++ \rightarrow 1$

$B \rightarrow 0.5$

$G \rightarrow 0$

Tend to stay lower in the bad area.

Used energy efficiency classes.

$A++ \leq 10\frac{kWh}{m^2}$

$A+ \leq 15\frac{kWh}{m^2}$

$A \leq 25\frac{kWh}{m^2}$

$B \leq 50\frac{kWh}{m^2}$

$C \leq 100\frac{kWh}{m^2}$

$D \leq 150\frac{kWh}{m^2}$

$E \leq 200\frac{kWh}{m^2}$

$F \leq 250\frac{kWh}{m^2}$

$G > 250\frac{kWh}{m^2}$

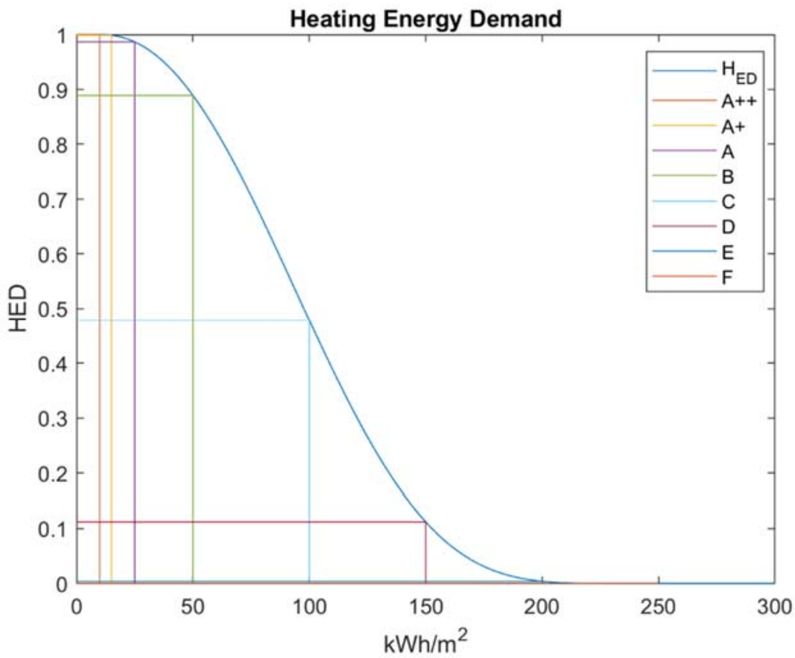
Definition $\boldsymbol{HED}$ (Heating Energy Demand)

Shown here for DoU of one year.

$E_{min} \coloneqq 10$

$E_{max} \coloneqq 250$

$$HED \coloneqq \left(1 - \min\left(\max\left(\frac{E_D - E_{min}}{E_{max} - E_{min}}, 0\right), 1\right)^{2.2}\right)^6$$



tab = 2×8 table

	AAA	AA	A	B	C	D	E	…
1 kWh	10	15.0000	25.0000	50.0000	100.0000	150.0000	200.0000	
2 CED	1	0.9988	0.9866	0.8890	0.4786	0.1122	0.0042	

2.6 SHARE ENERGY PRODUCTION RENEWABLE

Brief summary

The Share Energy Production Renewable indicator describes the share of energy (thermal and electrical) that is generated by renewable energy systems (RES) that are an integral part of the building in relation to the total energy demand (thermal or electrical) by the building.

Definition $\boldsymbol{SEP_{renew}}$

Sub-Indicators Thermal and Electrical

0 kWh Production renewable → 0

Shape $e^{\lambda kW}$

kWh Demand building = kWh Production renewable → 1

Indicator total: $P(A) \coloneqq P(A|B) \cdot P(B) + P(A|B) \cdot P(B^C)$. B corresponds to the total energy requirement thermal and B^C corresponds to the total energy requirement electrical (lighting,...)

Definition of the indicator mapping

$P(A)$ ... Energy Own production from renewable energy sources E_{OP}.

$P(B)$ ... Heating energy demand related to the end energy demand $\frac{HED}{EED}$.

$P(A|B)$ ... Own production of thermal energy from renewable energy sources $\frac{E_{T,OP}}{HED}$.

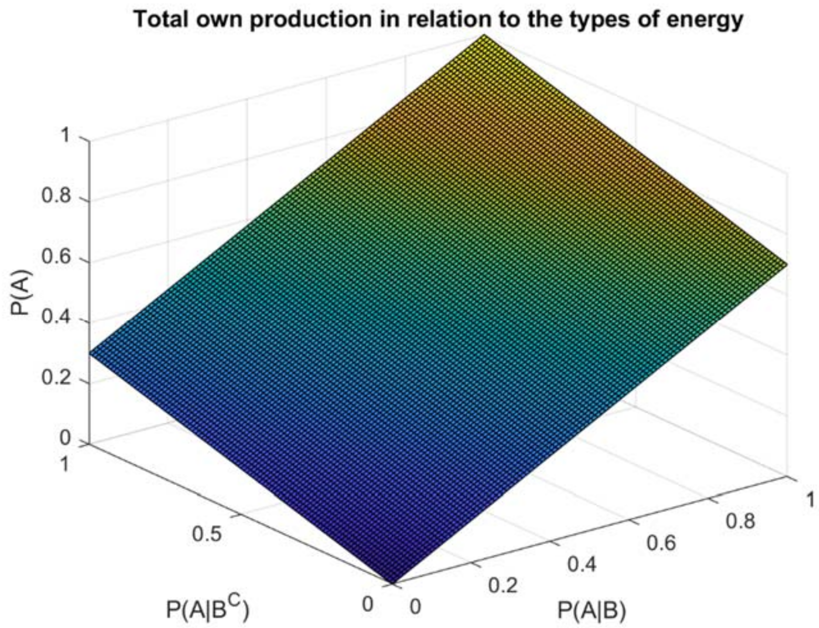
$P(B^C)$ ... Household electricity demand related to the end energy demand $\frac{HSD}{EED}$.

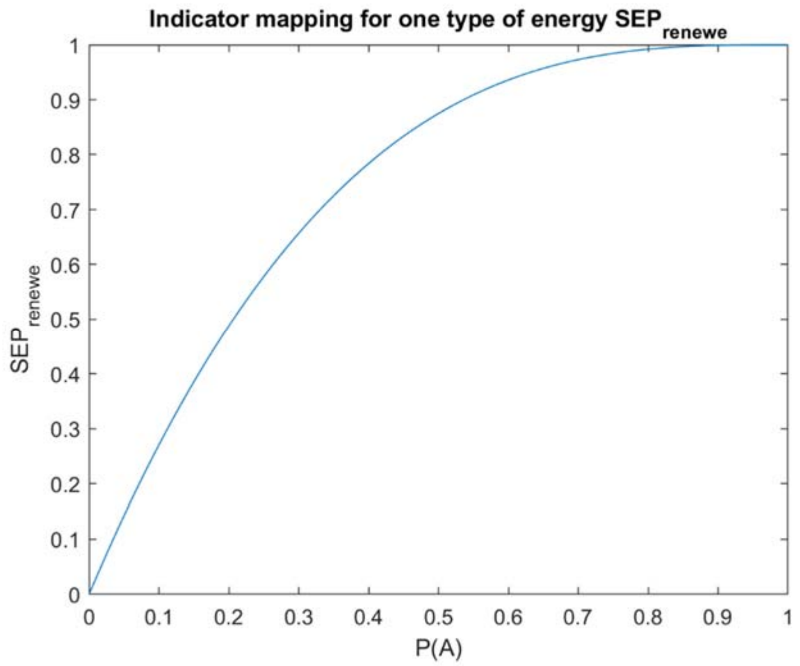
$P(A|B^C)$ ... Own production of electrical energy (share of household electricity demand) from renewable energy sources $\frac{E_{E,OP}}{HSD}$.

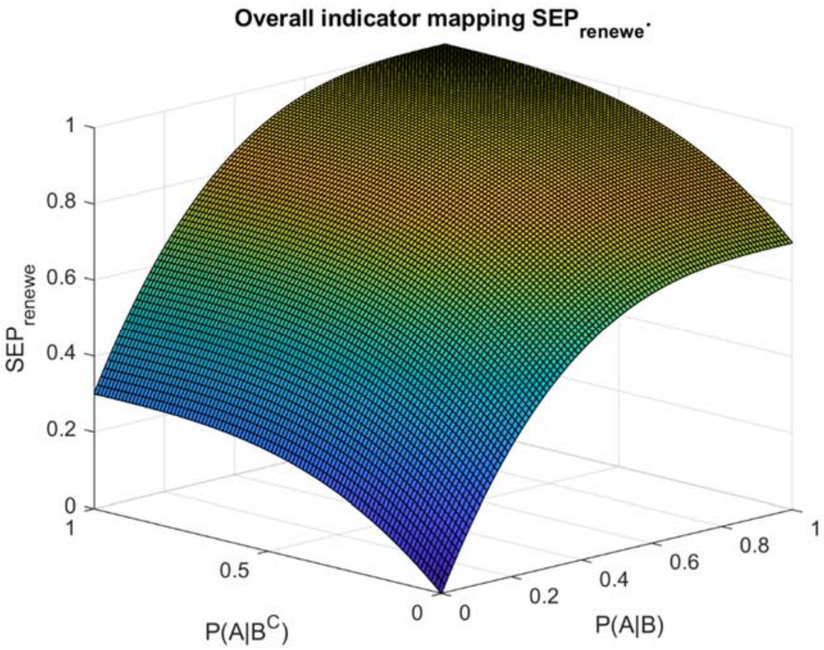
Property for checking the definition $P(B) + P(B^C) = 1$. $P(A|B)$ and $P(A|B^C)$ are treated as balance sheet items.

$SEP_{renew} \coloneqq 1 - \left(1 - \min\left(\frac{E_{T,OP}+E_{E,OP}}{EED}, 1\right)\right)^3$.

Visualization with $P(B) = 0.7$.


Total own production in relation to the types of energy
P(A)
1
0.8
0.6
0.4
0.2
0
1
0.5
0
P(A|B^C)
0
0.2
0.4
0.6
0.8
1
P(A|B)


Indicator mapping for one type of energy SEP_renewe
SEP_renewe
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
P(A)


Overall indicator mapping SEP renewe.
SEP renewe
1
0.8
0.6
0.4
0.2
0
1
0.5
0
P(A|B^C)
0
0.2
0.4
0.6
0.8
1
P(A|B)

2.7 LEVEL OF EASE OF ASSEMBLY

Brief summary

The level of ease of assembly describes the level of intensity of tools and knowledge in order to erect the building on site. Thus, the lower the need of specialized tools and equipment and the lower the specific skills and knowledge required by people involved in the erection of the building, the easier the assembly.

Definition $\boldsymbol{L_{ass}}$

The identified sub-processes are tools and knowledge.

Tools $\boldsymbol{T_i}$ $\boldsymbol{i \in \{1, \dots, 5\}}$

1. No special tools required.
- Small devices required.
- Electrical equipment with power supply required.
- Electrical equipment with power current supply required.
- Special equipment required.

Knowledge $\boldsymbol{K_i}$ $\boldsymbol{i \in \{1, \dots, 5\}}$

1. No special expertise required.
- Craftsmanship required.
- Experienced helpers required.
- Trained staff required.
- Specialist staff required.

Claim: Tools are easier to obtain and cheaper than skilled personnel. Based on this claim, knowledge is weighted higher.

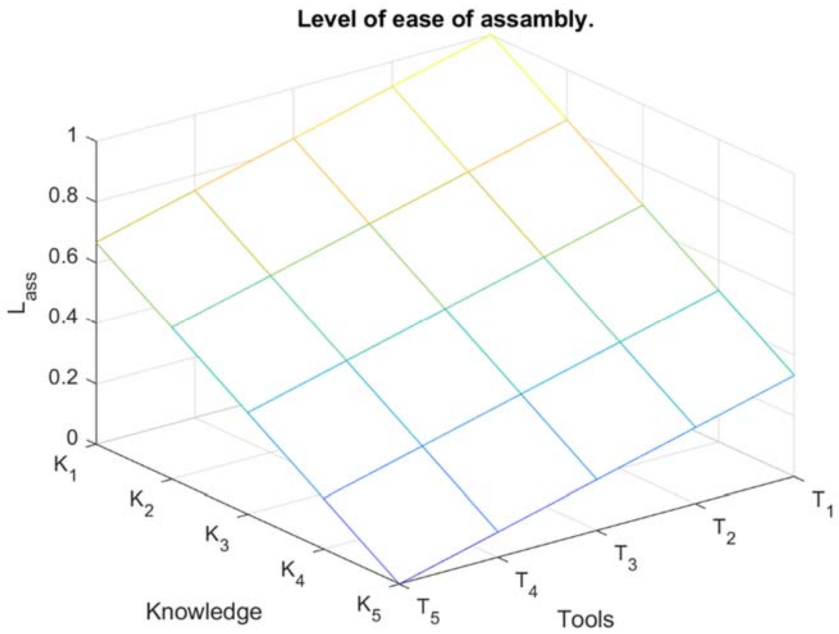
$\omega_K = \frac{2}{3}$ und $\omega_T = \frac{1}{3}$ different weighting.

Mappings

$L_{ass} \coloneqq T_i \cdot \omega_T + K_i \cdot \omega_K$

$T_i \coloneqq 1 - \frac{i-1}{i_{max}-1}$ $i \in \{1, \dots, 5\}$ … T_i means i-th category in Tools is fulfilled.

$K_i \coloneqq 1 - \frac{i-1}{i_{max}-1}$ $i \in \{1, \dots, 5\}$ … K_i means i-th category in Knowledge is fulfilled.


Level of ease of assambly.
1
0.8
0.6
0.4
0.2
0
L_ass
K_1
K_2
K_3
K_4
K_5
Knowledge
T_1
T_2
T_3
T_4
T_5
Tools

2.8 MAINTENANCE BUILDING

Brief summary

The *Maintenance of Building* describes the level of intensity of machinery, skills and frequency in order to maintain the building during operation. Thus, the lower the need of specialized machinery, specific skills and knowledge required by those carrying out the maintenance as well as periodicity, the lower the overall maintenance level.

Initial deliberations

This is an indicator, which must be defined based on qualitative criteria.

There are three relevant influencing factors (categories) that must be considered:

Categories

1. Skill Level: Required skill / training level of personnel carrying out the maintenance

Machinery Level: Required level of specialised machinery

Frequency: Required period of maintenance

ad 1: Skill Level (factors 1 to 5)

No special skills and no training required

- No special skills but informal training required
- No special skills but formal training required
- Skilled personnel with formal training required
- Skilled personnel with high-level training required

ad 2: Machinery Level (factors 1 to 5)

No specialised machinery and no tools required

- No specialised machinery and standard tools required
- No specialised machinery and specialized tools required
- Light specialised machinery and specialized tools required
- Heavy specialised machinery and specialized tools required

ad 3: Frequency (factors 1 to 5)

No periodic maintenance required

- 5 year periodic maintenance required
- year periodic maintenance required
- Yearly periodic maintenance required
- Half-yearly periodic maintenance required

For the calculation

All three categories should be treated equally (weighing factor 1/3 each)

In all three categories the following should apply:

factor 1 is very good (100%)

factor 2 is only a little less good than factor 1 (90%)

factor 3 is somewhere still less good, but not as bad as factor 4 (70%)

factor 4 is considerably less good than factor 3 (30%)

factor 5 is really bad (0%) (or the other way around with 0% being the best and 100% the worst; you can also slightly adapt the percentages to make a nicer curve).

Definition $\boldsymbol{MB}$ (Maintenace building)

$i \in \{1, \dots, 3\}$ ... number of category.

$j \in \{1, \dots, 5\}$ ... number of factor.

$c_j(j)$ ... coefficient of category factor.

$c_i(1) \coloneqq 1$

$c_i(2) \coloneqq 0.9$

$c_i(3) \coloneqq 0.7$

$c_i(4) \coloneqq 0.3$

$c_i(5) \coloneqq 0$

$MB = \frac{\sum_{i=1}^{3} c_i(j)}{3}$

tab = 125×4 table

	c1	c2	c3	MB
1	1	1	1	1.0000
2	1	1	2	0.9667
3	1	2	1	0.9667
4	2	1	1	0.9667
5	1	2	2	0.9333
6	2	1	2	0.9333
7	2	2	1	0.9333
8	1	1	3	0.9000
9	1	3	1	0.9000
10	2	2	2	0.9000
..				

2.9 MAINTENANCE BUILDING ENGINEERING SERVICES

Brief summary

The *Maintenance of Building eng. services* describes the level of intensity of machinery, skills and frequency in order to maintain the building eng services during operation. Thus, the lower the need of specialized machinery, specific skills and knowledge required by those carrying out the maintenance as well as periodicity, the lower the overall maintenance level.

Initial deliberations

This is an indicator, which must be defined based on qualitative criteria.

There are three relevant influencing factors (categories) that must be considered:

Categories

1. Skill Level: Required skill / training level of personnel carrying out the maintenance
2. Machinery Level: Required level of specialised machinery
3. Frequency: Required period of maintenance

ad 1: Skill Level (factors 1 to 5)

No special skills and no training required

- No special skills but informal training required
- No special skills but formal training required
- Skilled personnel with formal training required
- Skilled personnel with high-level training required

ad 2: Machinery Level (factors 1 to 5)

No specialised machinery and no tools required

- No specialised machinery and standard tools required
- No specialised machinery and specialized tools required
- Light specialised machinery and specialized tools required
- Heavy specialised machinery and specialized tools required

ad 3: Frequency (factors 1 to 5)

No periodic maintenance required

- 5 year periodic maintenance required
- year periodic maintenance required
- Yearly periodic maintenance required
- Half-yearly periodic maintenance required

For the calculation

All three categories should be treated equally (weighing factor 1/3 each)

In all three categories the following should apply:

factor 1 is very good (100%)

factor 2 is only a little less good than factor 1 (90%)

factor 3 is somewhere still less good, but not as bad as factor 4 (70%)

factor 4 is considerably less good than factor 3 (30%)

factor 5 is really bad (0%) (or the other way around with 0% being the best and 100% the worst; you can also slightly adapt the percentages to make a nicer curve).

Definition $\boldsymbol{MB_{es}}$ (Maintenace building eng. services)

$i \in \{1, \dots, 3\}$ ... number of category.

$j \in \{1, \dots, 5\}$ ... number of factor.

$c_i(j)$ ... coefficient of category factor.

$c_i(1) \coloneqq 1$

$c_i(2) \coloneqq 0.9$

$c_i(3) \coloneqq 0.7$

$c_i(4) \coloneqq 0.3$

$c_i(5) \coloneqq 0$

$$MB_{es} = \frac{\sum_{1=1}^{3} c_i(j)}{3}$$

```
tab = 125×4 table
```

	c1	c2	c3	MB
1	1	1	1	1.0000
2	1	1	2	0.9667
3	1	2	1	0.9667
4	2	1	1	0.9667
5	1	2	2	0.9333
6	2	1	2	0.9333
7	2	2	1	0.9333
8	1	1	3	0.9000
9	1	3	1	0.9000
10	2	2	2	0.9000
..				

2.10 LEVEL OF BUILDING CONTROL

Brief summary/description

The level of building control describes the degree of automatization coupled with user feedback for the quality of the building's indoor environment (e.g. air conditioning). It includes the degree of control of temperature, ventilation, shading and artificial lighting. The focus is on highest efficiency in the operation of the building and subsequently, the lowest emission whilst at the same time allowing user feedback to ensure a high-quality indoor environment.

Definition of B_A

- *4 control groups* C_{G_i}*;*

  Control groups:

  1. Temperature.
  2. Ventilation.
  3. Shading.
  4. Artificial light.

- *3 Degrees of automation* D_A *Degree (of) automatization*

  Degrees of automation:

  1. Manual
  2. Manual/Automated without feedback
  3. Fully automated, demand-driven with user feedback.

Not preferred: all manual or manual/automated without feedback. Preferred: Fully automated, demand-driven with user feedback. Mixing values: in between.

$$C_G := (C_{G_1}, \dots, C_{G_4}) \quad C_{G_i} \in D_A$$

$$D_{A,k} := \begin{pmatrix} 1 & if & k=1 \\ 2 & if & k=2 \\ 3 & if & k=3 \end{pmatrix}$$

$$c_k := \begin{pmatrix} 0.3 & if & k=1 \\ 0.6 & if & k=2 \\ 1 & if & k=3 \end{pmatrix}$$

$$N_k := \#\left(C_{G_i} = D_{A,k} \quad i \in \{1, \dots, 4\}\right)$$

$$B_A := \frac{\sum_{k=1}^{3} N_k \cdot c_k}{4}$$

$\#(.)$ ... Number of elements which fulfill the condition (.).

15×4 data table:

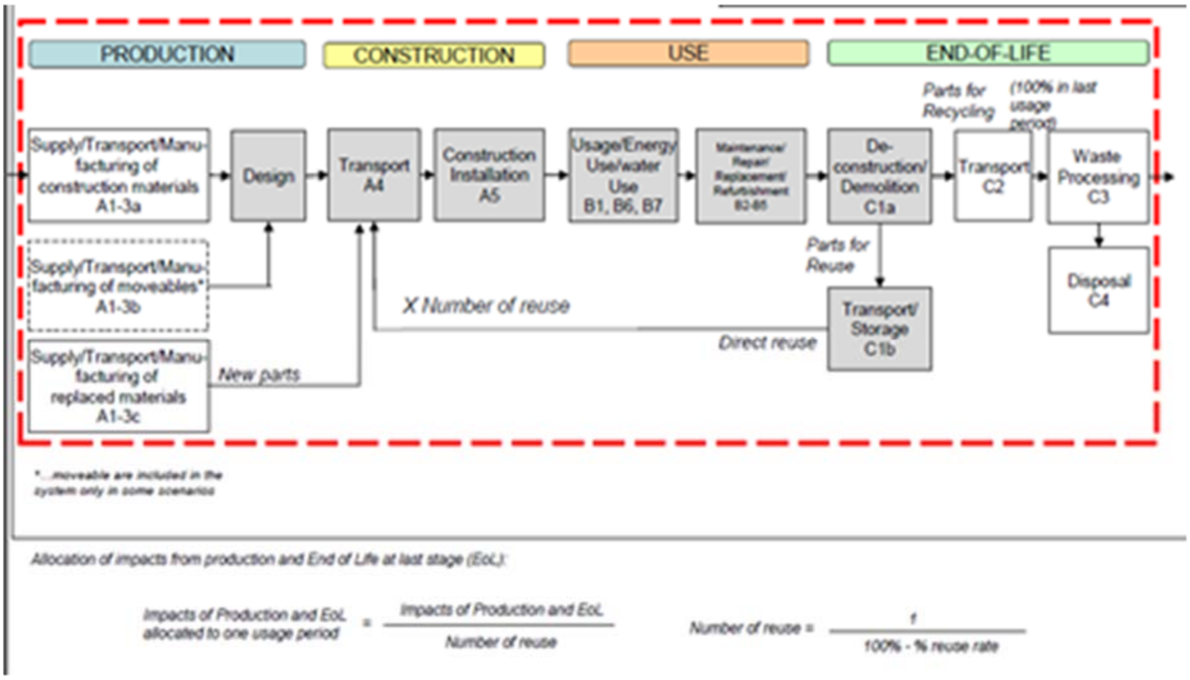
	N1	N2	N3	BA
1	0	0	4	1.0000
2	0	1	3	0.9000
3	1	0	3	0.8250
4	0	2	2	0.8000
5	1	1	2	0.7250
6	0	3	1	0.7000
7	2	0	2	0.6500
8	1	2	1	0.6250
9	0	4	0	0.6000
10	2	1	1	0.5500

2.11 SECONDARY MATERIAL UTILIZATION

General considerations

This indicator focuses **on the design / production phase at beginning of a life cycle**. It assesses the application of materials and gives a factor for the reused material and virgin material that is installed in a temporary building. Considering the life cycle stages of a building, it reflects the production stage, more precisely A1-3.

The indicator aims to provide a focus on the availability and use of secondary materials, and to make visible when many secondary materials are used in a construction project, thus complying with circular building design strategies regarding material use[13].



Measurement

1. Inventory of all materials to be procured and used (source: bill of materials)

   Assessment of the proportion of secondary and virgin materials and components in kg or t.

   Conversion to reference value m² of PUE (including housing and open spaces)

Recycling percentages in building materials are to a large extent not influenceable in this context. Many building materials available on the market contain recycled components (steel, aluminum, pressboard) from the outset. The Gabi Software (for LCA) therefore largely relies on material mixes.

---

[13] Circle Economy (2018): A framework for circular buildings. Indicators for possible inclusion in BREEAM.

Description

M_{reuse}: Material experienced at least one previous usage cycle, where material and shape were preserved.

M_{virgin}: Primary material, available on the market (depending on the production method, recycled content may also be included).

Note: Depending on the system boundaries of a model, this is not only about the building materials, but also about built-in household appliances, which are an essential part of the PUE and are therefore included in the calculation.

Material reuse rate: $M_{reuse} = \frac{\text{mas of secondary materials in finished PUE [t]}}{\text{total masss of finished PUE [t]}} \times 100\%$

Virgin material rate: $M_{virgin} = \frac{\text{mass of virgin materials in finished PUE [t]}}{\text{total mass of finished PUE [t]}} \times 100\%$

$$M_{virgin} + M_{reuse} = 100\%$$

Acceptance measure (0-1)

lower limit (0): M_{virgin} = 1 (only primary material is used)

mid-range value (0,5): M_{virgin} = 0,5 (half of the material is reused material, the other half is primary material)

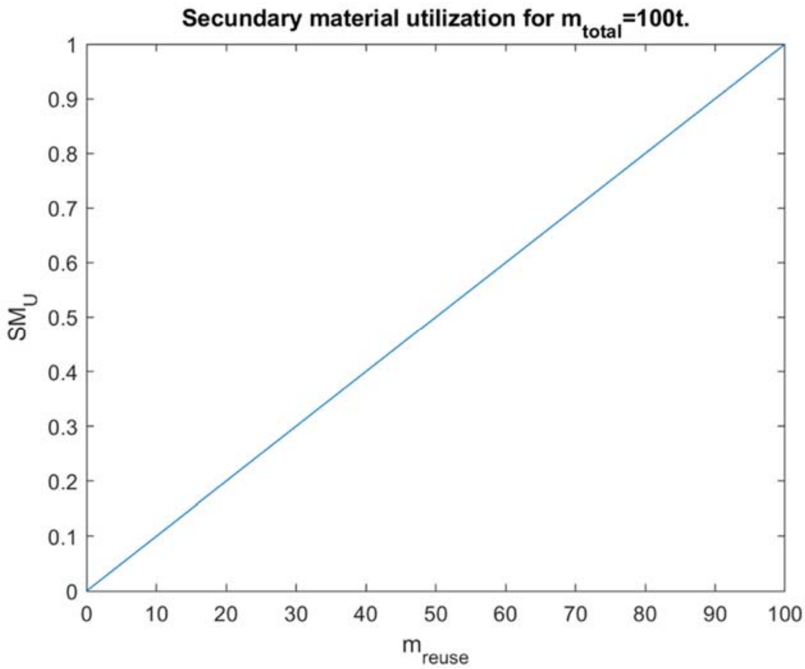
upper limit (1): M_{reuse} = 1 (only reused material is used, no new primary resource requirements are given)

Definition $\boldsymbol{SM_U}$ SM_U (Secondary material utilization)

m_{reuse} ... Mass of reused materials in finished PUE in $[t]$.

m_{total} ... Mass of materials total in finished PUE in $[t]$.

$$SM_U \coloneqq \frac{m_{reuse}}{m_{total}}$$


Secundary material utilization for m_total=100t.
SM_U
m_reuse
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
70
80
90
100

2.12 REUSE POTENTIAL (END OF LIFE - EOL)

General considerations

This indicator looks at the **end of a lifecycle** at the materials and components used and assesses the reuse possibilities. Waste prevention and reuse are at the top of the waste hierarchy, as this can reduce the environmental impact of consumption. Re-use or extending the life of products, for example by repairing them, is therefore a priority.

It is important to not mix reuse potential and recycling potential, as they are different concepts.

It is important to note this indicator only focuses on the end of life phase and not on the design phase (This is covered in the indicator secondary material utilization).

It has to be noted, that the indicators Reuse potential (End of Life), Recycling potential and realizable recycling potential are not independent of each other but have to be viewed in relation to each other:

1. The starting point is the total mass of the building in question.
2. From this, in a first step, the reuse potential is calculated and the respective mass is subtracted from the total mass of the building.
3. The remaining mass is the starting point for calculating the recycling potential. Priority is given to reuse before recycling, as it is in line with circularity considerations.
    a. The realizable recycling potential focusses on the masses calculated in the recycling potential only
4. The remaining masses of the building are neither reused or recycled and have to be disposed of.

Measurement

- Inventory of the materials used and the composition of the individual components (source: bill of materials)
- Assessment von qualities & composition of materials
- Assessment of reuse potential of material and components with the help of a decision tree.

(If PUE consist of components, that are clearly independent, the decision tree should be applied for the different components separately and the overall reuse potential should then be determined afterwards (weight shares in the total PUE))

Sub processes

Reusability of the material or components with no or only minor loss of value (<10%)

- Durability of materials and components
- Loss of value: functionality is weighted with 80%, 20% aesthetic wear and tear (e.g. dents, discolorations)

Preparation for reuse (repairability, maintenance, cleaning)

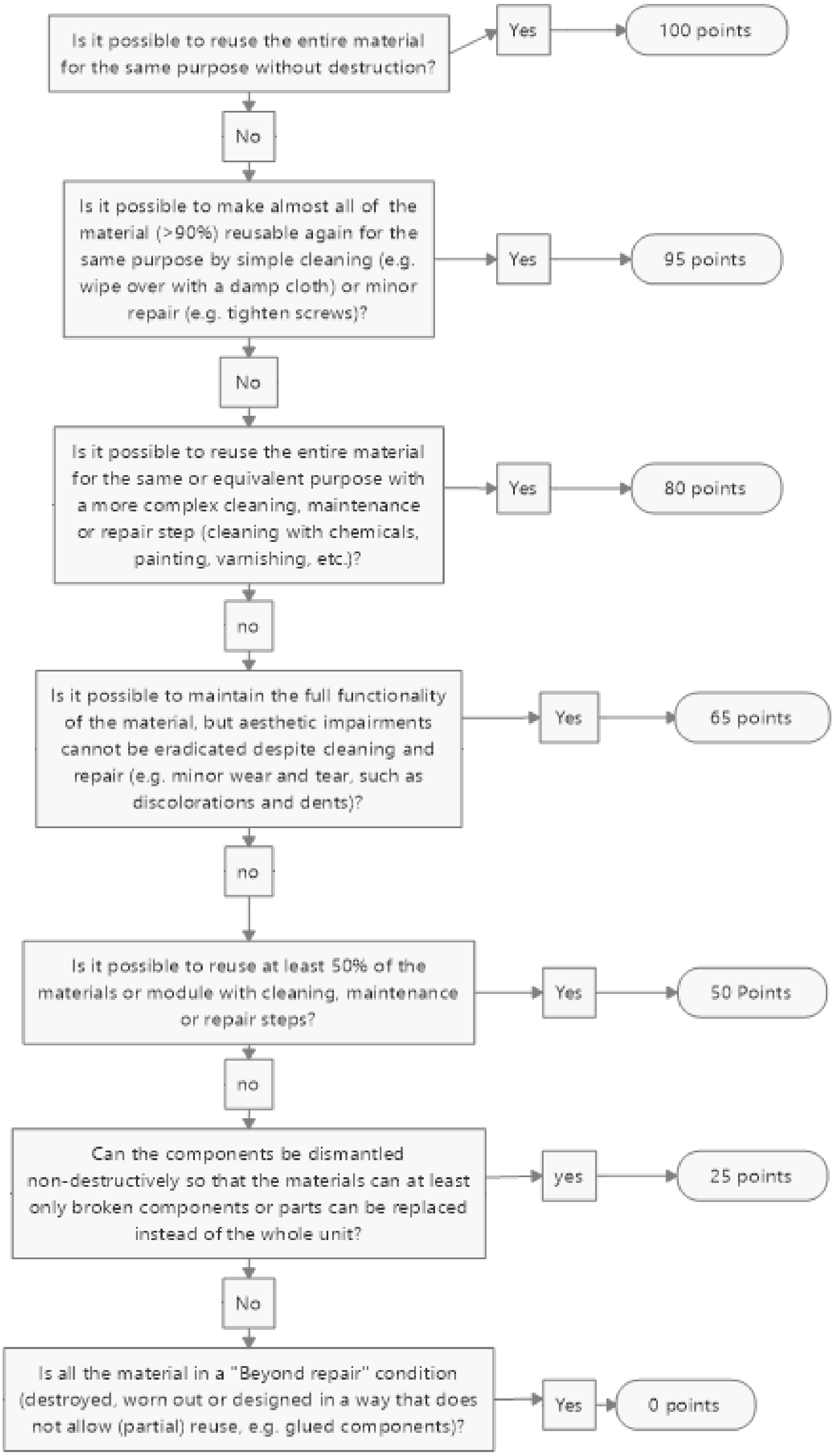
- Repairability: expert assessment or testing of the ease of repair process, e.g. crucial functions are accessible

Dismountability without loss of value (Design reassembly)

- The item is assembled through demountable / remountable connections, of which the preservation of similar quality can be guaranteed. Assessment of quality of connection of components (e.g. plugged, skewed, glued)

Modularity of components

- simplification of usability and exchangeability


Is it possible to reuse the entire material for the same purpose without destruction?
Yes
100 points
No
Is it possible to make almost all of the material (>90%) reusable again for the same purpose by simple cleaning (e.g. wipe over with a damp cloth) or minor repair (e.g. tighten screws)?
Yes
95 points
No
Is it possible to reuse the entire material for the same or equivalent purpose with a more complex cleaning, maintenance or repair step (cleaning with chemicals, painting, varnishing, etc.)?
Yes
80 points
no
Is it possible to maintain the full functionality of the material, but aesthetic impairments cannot be eradicated despite cleaning and repair (e.g. minor wear and tear, such as discolorations and dents)?
Yes
65 points
no
Is it possible to reuse at least 50% of the materials or module with cleaning, maintenance or repair steps?
Yes
50 Points
no
Can the components be dismantled non-destructively so that the materials can at least only broken components or parts can be replaced instead of the whole unit?
yes
25 points
No
Is all the material in a "Beyond repair" condition (destroyed, worn out or designed in a way that does not allow (partial) reuse, e.g. glued components)?
Yes
0 points

Formula

$$D_{reuse} = \frac{\sum mass\ of\ individual\ components\ [t] \times reuse\ factor\ [0-100]}{total\ mass\ of\ PUE\ [t]}$$

Acceptance measure (0-1)

No components of the completed infrastructure are reusable → 0 (0 points)

All components of the completed infrastructure are reusable → 1 (100 points)

Definition $\boldsymbol{RP_{EOL}}$ (Reuse Potential (end of life - EOL))

$m_c \coloneqq (m_{c_1}, \dots, m_{c_n})$ ... Mass of individual components in $[t]$. m_{c_i} ... Mass of component i.

$r_f \coloneqq (r_{f_1}; \dots; r_{f_n})$ ... Reuse factor of individual components. r_{f_i} ... Reuse factor of component i.

$$r_{f_i} = \frac{points\ for\ component\ i}{100}$$

n ... Number of components.

m_{total} ... Mass of materials total in finished PUE in $[t]$.

$$D_{reuse} \coloneqq \frac{m_c \times r_f}{m_{total}}$$

m_c = 1×4

10 10 10 10

r_f = 4×1

1.0000

0.5000

0.3000

0

m_total = 40

D_reuse = 0.4500

2.13 RECYCLING POTENTIAL

General considerations

This indicator looks at the materials and components at the end of a life cycle: This indicator focusses on material recycling. A distinction should be made between material recycling and downcycling, thermal recycling and the non-recyclable rest[14]. It focuses on a technical perspective, and the market economy perspective is not taken into account (e.g. existence of a market for secondary raw materials, which is considered in more detail in the indicator realizable recycling factor).

Note: As mentioned in the indicator Reuse Potential, this indicator is not independent of the others, and only focused on the mass of building material left after the mass for reuse potential has been substracted.

Measurement

- Inventory of the materials / components used in PUE (bill of materials)
- Estimation of the materials and components that are suitable for reuse without alterations
- List of different materials (excluding reuse materials and components) in t
- Determination of the **separability**(specific compound situations) of the different materials into pure material flows (how much effort is needed to separate the materials, mechanical separation steps).
- if the materials cannot be separated from other materials, this leads to a different recovery or disposal route (lower recycling potential)

Identification of the following recycling process chains and possible internal processes:

- **material recycling:** Recycling returns products to the cycle from which they were once removed. Waste products are processed and transformed into new raw materials, thereby gaining a new benefit and returning to the cycle. The quality of the product is not impaired by the reprocessing process.
- **material recycling, downcycling**: Downcycling is the process of converting a product into a lower quality end product.
- **Thermal recycling**: material recycling is not possible, but it is used for energy generation via incineration
- **Not recyclable (=disposal)**: The material composites do not allow for recycling (e.g. due to hazardous components)

Ternary mapping of material in percentage of total mass (minus reuse components)

- material recycling (incl. downcycling)
- thermal recycling
- disposal

[14] König et al (2009): Lebenszyklusanalyse in der Gebäudeplanung

The shares are assigned a weighting factor (0-7)

(Assessment, if recycling processes can possibly take place again on-site (without transportation) – e.g. for subsequent use on plot (e.g. shredding of concrete and reinstallation in permanent structure of use)

wf: weighting factor

	Weighting Factor
Material recycling	7
Downcycling	5
Thermal recycling	3
No recycling (disposal)	1

$$Recy - Potential = \frac{\sum_{i=1}^{n} (\text{Mass of seperated materialflow for meterial recycling [t]} * wf + \text{mass of separated material flow for downcycling [t]} * wf + \text{mass of se}}{totalmassoftemporarystructure[t]}$$

Acceptance measure (0-1)

No components of the completed structure can be recycled → 0.

Minimum 100 points: (100% of material is disposed x Factor 1) → 0.

increasing distribution between 100-700 points, e.g. 400 points → 0.5.

Definition $\boldsymbol{R_P}$ (Recycling Potential)

$\omega_P := (\omega_{P_1}, \ldots, \omega_{P_N})$ … Weighting vector in which is indicated how good or efficient the recycling can be for the respective product category i.

$\omega_{P_i} \in [0,1]$ … describes the potential for recycling from 1 an equivalent product can be produced again with little effort to 0 no more use can be gained from the product and it can only be sent to disposal.

$M_P = (M_{P_1}, \ldots, M_{P_N})$ … Column vector containing the quantities of the individual components, divided according to their recycling potential.

$R_P := \frac{\omega_P \times M_P}{\sum_{i=1}^{N} M_{P_i}}$ … Recycling Potential.

M_P = 5×1

5

5

5

5

5

wP = 1×5

1 1 1 1 1

2.14 REALIZABLE RECYCLING FACTOR

General considerations

This indicator looks at the materials and components at the end of a life cycle: This indicator focusses on the real material recycling, considering the availability of recycling technologies and the existence of markets for secondary raw materials in the region. The indicator Recycling potential (Rp) is the basis and has to be calculated beforehand.

Measurement

- Indicator Recycling potential has to be calculated (see indicator description)
- Factors for assessing the realization/weighing factors:
    - availability of technology within a region/ certain perimeter
    - availability of market / use cases for secondary materials
    - Assessment, if recycling processes can possibly take place on-site (without transportation) – e.g. for subsequent use on plot (e.g. shredding of concrete and reinstallation in permanent structure of use)

Acceptance measure (0-1)

technical realization (availability of technology within a region):

- recycling on-site/at the location: (1)
- recycling plant within 100 km (0,75)
- recycling plant within 300 km (0,5)
- recycling plant within 500 km (0,3)
- recycling plant >1000 km (0,1)
- no full-scale real recycling plant available (0)

market (availability of market / use cases for secondary materials):

- 100% utilisation of recyclate possible, e.g. high market value, high demand on market → 1
- 50% utilization of recyclate possible, e.g. medium market value, limited demand on market (due to seasonal differences, strong dependence on primary raw material costs etc.) → 0.5
- No market available, nearly no (current) demand for the recyclate → 0

Definition R_R

$\omega_P := (\omega_{P_1}, \dots, \omega_{P_N})$ … Weighting vector in which is indicated how good the recycling potential is for the respective product category i.

$\omega_R := (\omega_{R_1}; \dots; \omega_{R_N})$ … Weighting vector in which is indicated how good or realizable the recycling is for the respective product category i.

$\omega_M := (\omega_{M_1}; \dots; \omega_{M_N})$ … Weighting vector in which an available market is indicated.

$\omega_D \coloneqq \left(\omega_{D_1}; \ldots; \omega_{D_N}\right)$ … Weighting vector in which the distance to a recycling facility is indicated.

$\omega_{R_i} \coloneqq \omega_{M_i} \cdot \omega_{D_i} \ldots \omega_{M_i}$

$\omega_{P_i} \in [0,1]$ … Describes the potential for recycling from 1 an equivalent product can be produced again with little effort to 0 no more use can be gained from the product and it can only be sent to disposal.

$\omega_{R_i} \in [0,1]$ … Describes the quality of the realization for the recycling, from 1 it is a minimum of necessary effort for the recycling to 0 it is an effort for the recycling which cancels the advantage of the recycling.

M_P … Diagonal matrix containing the quantities of the individual components, divided according to their potential mass for recycling

$R_R \coloneqq \omega_P \times M_P \times \omega_R$ … Recycling Realization.

```
M_P = 5×5
      5     0     0     0     0
      0     5     0     0     0
      0     0     5     0     0
      0     0     0     5     0
      0     0     0     0     5

wP = 1×5
      1     1     1     1     1

wR = 5×1
      1
      1
      1
      1
      1

R_R = 1
```

2.15 MATERIAL CIRCULARITY INDICATOR

General considerations

The Material Circularity Indicator (MCI) tool, which is part of a broader 'Circular Indicators Project' developed by The Ellen MacArthur Foundation and Granta Design[15], allows companies to identify additional, circular value from their products and materials, and mitigate risks from material price volatility and material supply.

MCI measures how restorative the material flows of a product.

The Material Circularity Indicator (MCI) for a product measures the extent to which linear flow has been minimised and restorative flow maximised for its component materials, and how long and intensively it is used compared to a similar industry-average product.

This indicator is included, as it summarizes the previous indicators regarding building circularity in one concise number. The calculations / estimations going into this indicator have to coincide with the assumptions / calculations of the previous indicators.

Measurement

The MCI is essentially constructed from a combination of three product characteristics:

- the mass V of virgin raw material used in manufacture,
- the mass W of unrecoverable waste that is attributed to the product,
- and a utility factor$X$ that accounts for the length and intensity of the product's use.

The associated material flows are summarized for technical materials.

15 https://www.ellenmacarthurfoundation.org/assets/downloads/Circularity-Indicators-Methodology.pdf

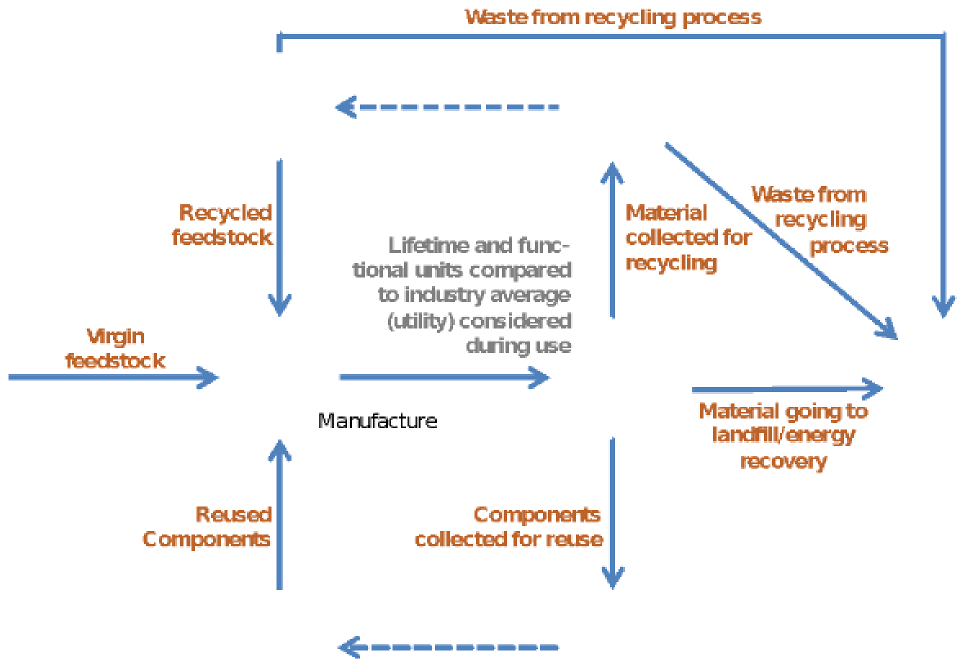


Figure 3: Diagrammatic representation of material flows

Acceptance measure (0-1)

0: Any product that is manufactured using only virgin feedstock and ends up in landfill at the end of its use phase can be considered a fully ‘linear’ product.

1: On the other hand, any product that contains no virgin feedstock, is completely collected for recycling or component reuse, and where the recycling efficiency is 100% can be considered a fully ‘circular’ product.

In practice, products will sit somewhere between these two extremes and the MCI measures the level of circularity in the range 0 to 1. The dashed lines in th Figure above indicate that the methodology does not require a closed loop. That is to say, for example, that recycled feedstock does not have to be sourced from the same product but can be sourced on the open market. This is a deliberate feature and reflects the grounding of the methodology on the mass-flow within the product system - the calculation for which is the same regardless of whether it is an open or closed loop.

For the calculation of this indicator, a MCI calculation tool should be used.

3 SITE QUALITY

These indicators have been elaborated by members of ILAP and IRUB in active collaboration of all team members.

Various inputs derive from theory of open space planning (among others documented in publications of Kasseler Schule) as well as basics and values from publications by the City of Vienna (such as STEP 2025's thematic concept Green and Open Spaces (Werkstattbericht 154) and Gender Mainstreaming in Urban Planning and Urban Development (Werkstattbericht 130)). The indicators represent the basic needs of users as well as the technical requirements of the selected modules. The availability and quality of geodata was used as a criterion in the development of the indicators.

3.1 SUITABILITY OF SITE

Preparatory considerations

This indicator is intended to represent the general suitability of sites from a civil engineering perspective.

Objectives

The site for the THE should be suitable for the proposed use without requiring a significant amount of preparation.

The following influencing factors are considered:

- Slope (max. permissible inclination),
- Natural hazards (flooding),
- soil conditions (statics),
- Existing contamination and remaining residues of previous uses (buildings, waste?)

Measurment

Description of influencing factors

The **slope** of the existing natural terrain is essential for the buildability and especially important, as in the case of temporary housing, for the rapid feasibility of projects. A slope that is too steep results in considerable additional planning and implementation costs (e.g.: terrain changes, supports and staircase systems). In addition, excessive slope may limit site accessibility.

Note:

A slope inclination of 10% corresponds to 1 m height difference over a horizontal distance of 10 m.

Slope	Suitability	Description
0,5%	1	very suitable
>5-10%	0,5	suitable
>10-20%	0,2	limited suitable
>30-40%	0,1	hardly suitable

>40-100%	0,0	not suitable

For the evaluation of **natural hazards**, the flood hazard zone plan for Vienna can be used. This shows the flood zones for 30-, 100- and 300-year flood events as well as the hazard zone plans derived from them, which determine the buildability. For temporary residential uses, it remains to be clarified to what extent flood events, given the low probability of occurrence, will impair or endanger the respective intended use.

Landslides are not present in the data, but are implicitly considered in the slope gradient.

Information on **soil conditions**, which has to be determined depending on the module, can be taken from the subsoil cadastre (available in Vienna). An automatic GIS-supported evaluation is not possible, since the individual borehole profiles can only be retrieved individually as pdf files. In addition, an interpretation by experts is necessary.

Existing contamination of individual sites can lead to increased effort in preparation or even make sites unsuitable for the use of temporary housing. Information about the subsurface can be obtained from the register of contaminated sites. Since the extent and form of contaminated sites can be very heterogeneous, an Interpretation and estimation of potential contamination must be made on a case-by-case basis. Remaining residues of previous uses can be estimated with aerial photographs.

Note:

Only slope gradient can be performed automatically to evaluate the general suitability of sites. The assessment of the suitability of sites with regard to the factors of natural hazards, soil conditions and existing contamination must be carried out on a case-by-case basis.

Required data	Sources
Digital elevation model Vienna	Digitales Höhenmodell Wien: data.gv.at
Flood Hazard Zone Plan Vienna	Hochwasser-Gefahrenzonenplan Wien: data.gv.at
Vienna subsoil cadastre	Baugrundkataster Wien: https://www.wien.gv.at/baugk/public/
Register of contaminated sites	Altlastenkataster: https://secure.umweltbundesamt.at/altlasten/?servicehandler=publicgis
Orthophotos	data.gv.at

Definition S_{Site} (Suitability of Site).

$slope$ ... slope in $[\%]$.

$slmin = 5\%$ ... The slope from which it is assumed that these begin to negatively affect the construction of the buildings.

$slmax = 40\%$ ... Slope gradient above which it is assumed that a building development is no longer expedient under normal circumstances.

$$Sl(slope) := \left(1 - \min\left(\max\left(\frac{slope - slmin}{slmax - slmin}, 0\right), 1\right)^{l}\right)^{k}$$

$N_H \in [0,1]$ ... the evaluation of N_H natural hazards is carried out by means of an expert assessment. Where 1 stands for no expected natural hazards and 0 stands for a site in which development should not take place for these reasons.

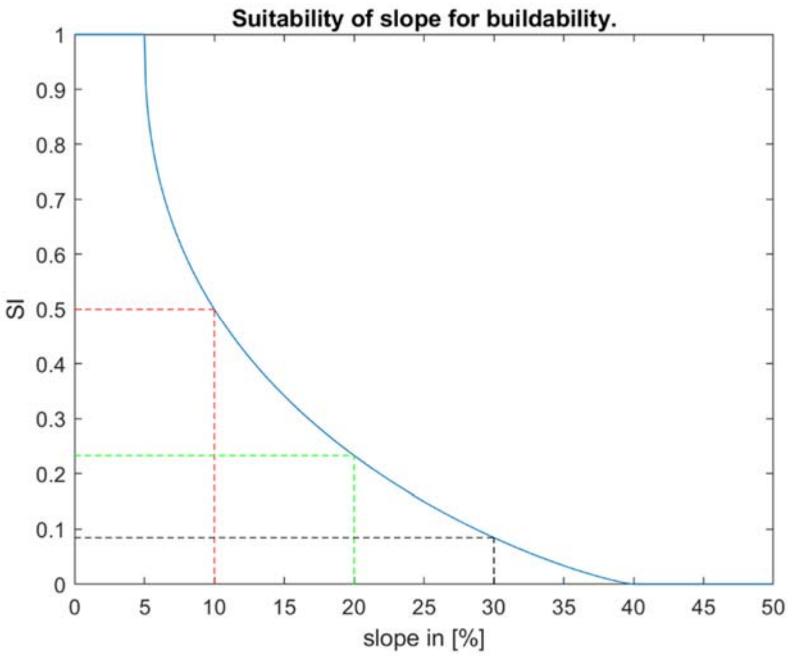
$S_C \in [0,1]$ ... the evaluation of S_C soil conditions is carried out by means of an expert assessment. Where 1 stands for soil conditions that can be built on without additional action and 0 stands for soil conditions on which building should not take place.

$E_C \in [0,1]$ ... the evaluation of E_C existing contamination is carried out by means of an expert assessment. Where 1 stands for no soil pollution and can be built without additional actions and 0 stands for soil pollution on which, even with remediation actions, a building should not take place.

$S_{Site} := SI \cdot N_H \cdot S_C \cdot E_C$

Note: The project assumes building sites without a negative impact on N_H, S_C and E_C.

ans = 0.5000



Tab = 6×6 table

text	slope	SI	N_H	S_C	E_C	S_Site
1	0	1.0000	1	1	1	1.0000
2	5	1.0000	1	1	1	1.0000
3	10	0.5000	1	1	1	0.5000
4	20	0.2332	1	1	1	0.2332
5	30	0.0848	1	1	1	0.0848
6	40	0	1	1	1	0

3.2 SUITABILITY FOR RESIDENTIAL USE DEPENDING ON AMBIENT NOISE

Preparatory considerations.

Objectives

The impairment of THE or its residents by immissions (noise) should be as low as possible, depending on the scenario or application, but in any case should comply with the legal requirements.

Background

Depending on the scenario or application, THE are (1) intended for certain user groups with increased sensitivity, (2) intended for locations outside or at the edge of areas intended for residential use, (3) possibly more exposed to immissions such as noise due to constructional aspects (e.g. lightweight construction). This increases the immission-related risk. In order to take this into account, various indicators are applied.

Note

The higher threshold value in Vienna Lden (noise level day, evening, night) represents the 24h average value, in contrast to Lday of the WHO recommendation. The level for living rooms and bedrooms (night 30 dB according to WHO recommendation) depends on the architecture and construction (not considered in the assessment). The limit value cannot be checked on the basis of noise maps and must be verified by suitable methods if necessary.

Measurement

Data from strategic noise maps (motorways and motorways, provincial roads B and L > in Vienna all roads are covered, rail traffic, air traffic, IPCC industrial plants) are used to determine whether the targets have been met.

The complete assessment is carried out in 2 steps:

1. general suitability of the location for temporary housing

   Discounts/surcharges based on the specific architecture and construction of the modules

   below the thresholds $\rightarrow 1$

   below threshold Lnight (45-50 dB) $\rightarrow 0.8$

   below threshold Lday (45-60 dB) $\rightarrow 0.6$

   above thresholds $\rightarrow 0.3$

Definition $\boldsymbol{SR_{AN}}$ (Suitability for residential use depending on ambient noise).

n_L ... noise at the location. n_R ... noise reduction through the construction.

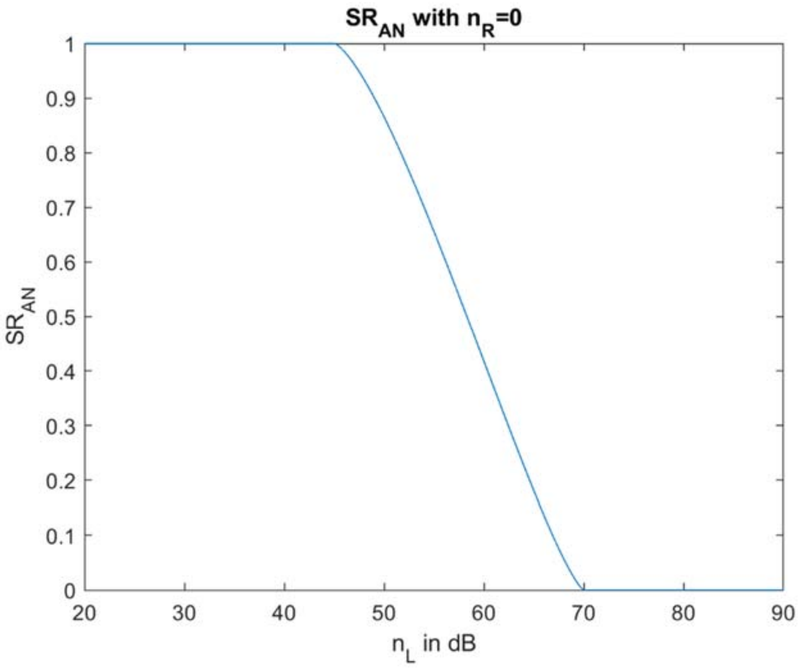
$$SR_{AN} := \left(1 - \min\left(\max\left(\frac{n_L - N_R - dBmin}{dBmax - dBmin}, 0\right), 1\right)^l\right)^k$$

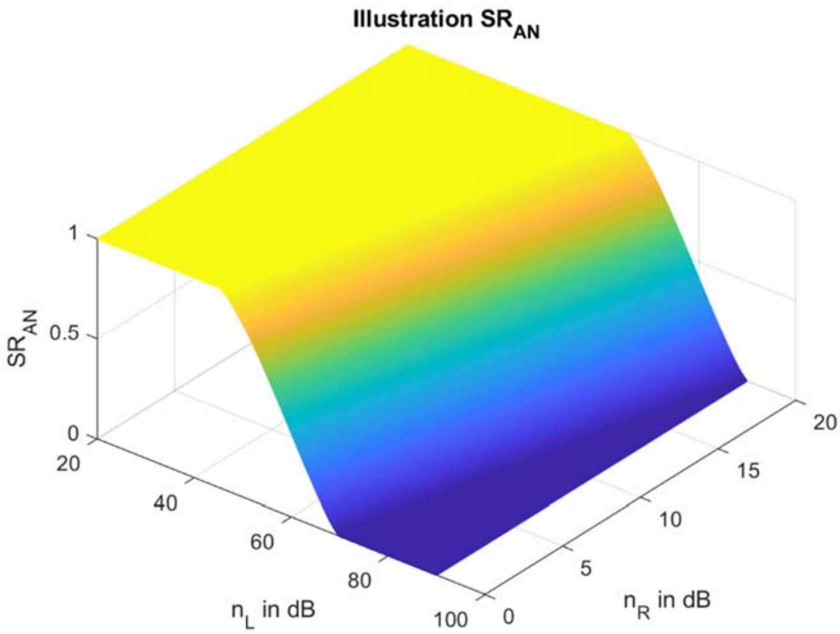
SRAN45 = 1

SRAN50 = 0.8656

SRAN60 = 0.4177

SRAN70 = 0





3.3 CONSUMPTION OF ECOLOGICALLY SENSITIVE AREAS

Summary

The evaluation of the use of ecologically sensitive areas is carried out based on the sensitivity of the areas and the significance of the intervention.

Objectives

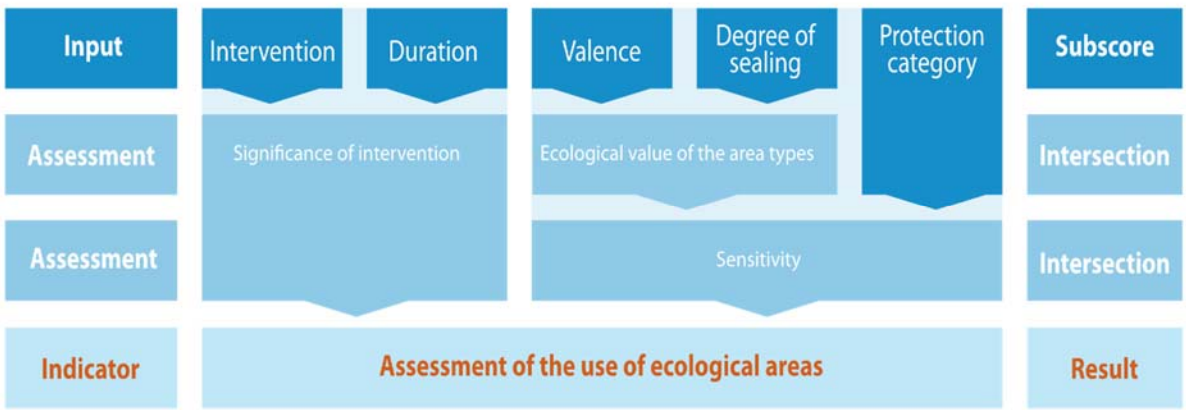
The aim is to have as little impact as possible on ecologically sensitive areas.

Depending on the scenario or case of application, THEs may have to be established within protected areas. In this case, the decisions (preference matrices) that have led to this should be documented and the extent (area + impact) recorded.·The generalized zoning is used as a basis for the areas. This enables the estimation to be integrated into the strategic framework of urban planning, which allows at least a medium-term planning perspective to be incorporated.

The influence is only estimated based on the available information of the modules. The influence of the use of the areas (depending on the scenario) would have to be considered in a second indicator.

Measurement

Indicator formation for the assessment of the use of ecologically sensitive areas:



Presentation of the indicator formation

Significance of intervention	Sensitivity					Value	Description	Number
	5	4	3	2	1			
5	0	0	0,25	0,5	0,5	0	unacceptable	1
4	0	0,25	0,5	0,5	0,75	0,25	high	2
3	0,25	0,5	0,5	0,75	0,75	0,5	medium	3
2	0,5	0,5	0,75	0,75	1	0,75	low	4
1	0,5	0,75	0,75	1	1	1	none	5

Representation of the preference matrix for the assessment of the consumption with the dimensions of significance of intervention and sensitivity.

Definition C_{ES} (Consumption of ecologically sensitive areas)

M_S ... significance matrix.

$v_I := (v_{I_5}, \dots, v_{I_1})$ ... Vector for the intervention. v_{I_i} is 1 if the relevance of the intervention is i and 0 otherwise.

$v_S := (v_{S_5}; \dots; v_{S_1})$ ... Vector for the sensitivity. v_{S_i} is 1 if the relevance of the intervention is i and 0 otherwise.

$C_{ES} := v_1 \times M_S \times v_S$

MS = 5×5

0	0	0.2500	0.5000	0.5000
0	0.2500	0.5000	0.5000	0.7500
0.2500	0.5000	0.5000	0.7500	0.7500
0.5000	0.5000	0.7500	0.7500	1.0000
0.5000	0.7500	0.7500	1.0000	1.0000

Tab = 5×3 table

	C_ES	v_I	v_S
1	1.0000	1	1
2	0.2500	5	3
3	0.5000	3	3
4	0.7500	2	2
5	0	5	5

3.4 GREEN INFRASTRUCTURE ON THE PLOT – GIP

Preparatory considerations

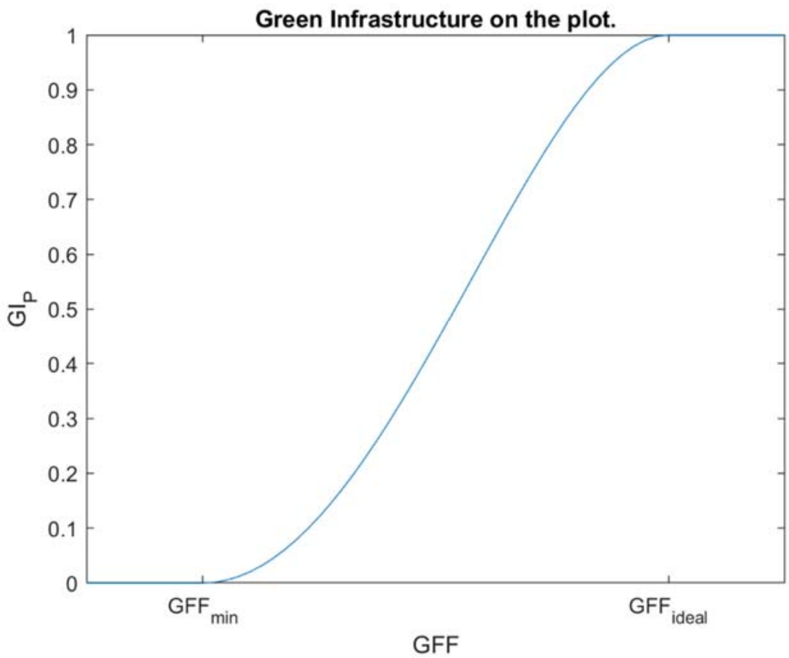
This indicator is calculated by the green and open space factor (GFF), a quantitative target for the provision of urban green infrastructure, is intended to support the creation of climate resilient neighborhoods. This tool has been developed within various institutes of BOKU, green4cities GmbH, ZAMG, AIT, Wien3420 and MA22 (https://forschung.boku.ac.at/fis/suchen.projekt_uebersicht?sprache_in=de&menue_id_in=300&id_in=11730, accessed 31/03/2020).

The GFF is composed of the GFFs climate regulation, biodiversity and well-being. Here, the GFFs climate regulation and biodiversity are used, since the usability of private and building-related open spaces is considered in the social indicators.

Depending on the type of development and temporary residential example, the experts must specify the limit values (ideal GFF and lower limit GFF).

Definition $\boldsymbol{GI_P}$ (Green Infrastructure on the plot)

$GI_P \coloneqq 1 - \left(1 - \min\left(\max\left(\frac{GFF - GFF_{min}}{GFF_{ideal} - GFF_{min}}, 0\right), 1\right)^l\right)^k$. GFF_{min} … lower limit GFF. GFF_{ideal} … ideal GFF.



3.5 ACCESS TO PUBLIC OPEN SPACES IN THE QUATER AND CITY

Preparatory considerations

Note: in the case of heterogeneous conditions, the "best road" or the closest open space that meets the requirements is used.

1. In the immediate residential area (within 200m) there are attractive, versatile and safe street spaces. [Function between 1 and 0 is composed of the evaluation of the individual points; each point "weighs" one sixth].
   - Street lighting available.
   - Footpaths friendly to pedestrians (residential street, meeting zone, pedestrian zone and/or a minimum sidewalk width of 2m if pedestrian traffic is kept separate from motorised traffic).
   - The zoning of the open road space supports a safe and attractive stay (well suited zoning sequence, similar zones adjoin each other).
   - The street open spaces are accessible to everyone (suitable for everyday use, designed to be low-barrier: short, low-barrier paths lead to all local recreation open spaces and facilities for everyday needs, crossing possibilities).
   - The frequency and speed of motorised traffic is such that it is comfortable to stay in the open spaces of the road. (Proposal: 30km/h, DTV <15,000).
2. In the neighborhood there are public open spaces in a maximum distance of 250m to stay like squares or parks. [Corner points for evaluation: Distance to open space <250m=1; distance 250-325m=0.99-0.5; 326-500m=0.49-0; >500m=0]
3. In the residential area there are public green open spaces of at least 1 ha in a maximum distance of 500m. Key points for evaluation: Distance to open space <500m=1, distance 500-650m=0.99-0.5; distance 651-1000m=0.49-0; >1000m=0].
4. Residents have access to public green open spaces in the district within 1500 m, covering an area of at least 3 ha. [Key points for evaluation: Distance to open space <1500m=1, distance 1500-1950m=0.99-0.5; distance 1951-3000m=0.49-0; >3000m=0].
5. Within 6 km the residents have access to green open spaces with a total urban importance of >50 ha. (open-use open spaces of the district edges, inner city edges and agricultural and forestry open spaces of the city edges) [Key points for evaluation: Distance to open space <6km=1, distance 6-7.8km=0.99-0.5; distance 7.81-12=0.49-0; >10000m=0].

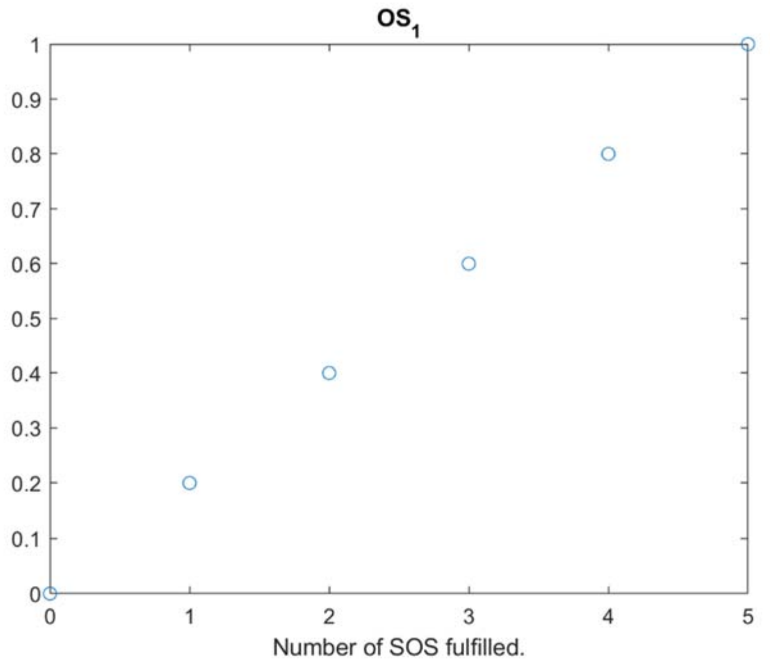
Definition $\boldsymbol{POS_{QC}}$ (Access to public open spaces in the quarter and city)

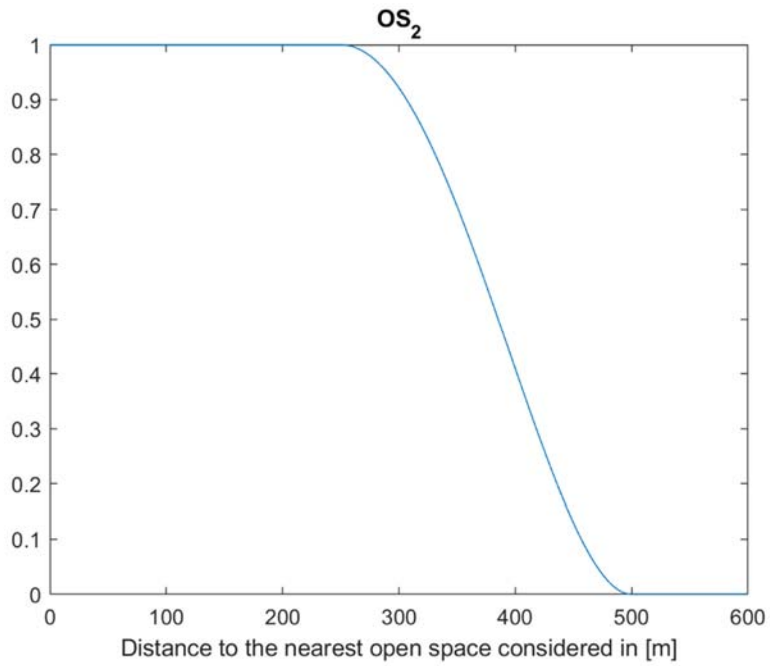
OS_i ... Open Spaces. N ... Number of open spaces.

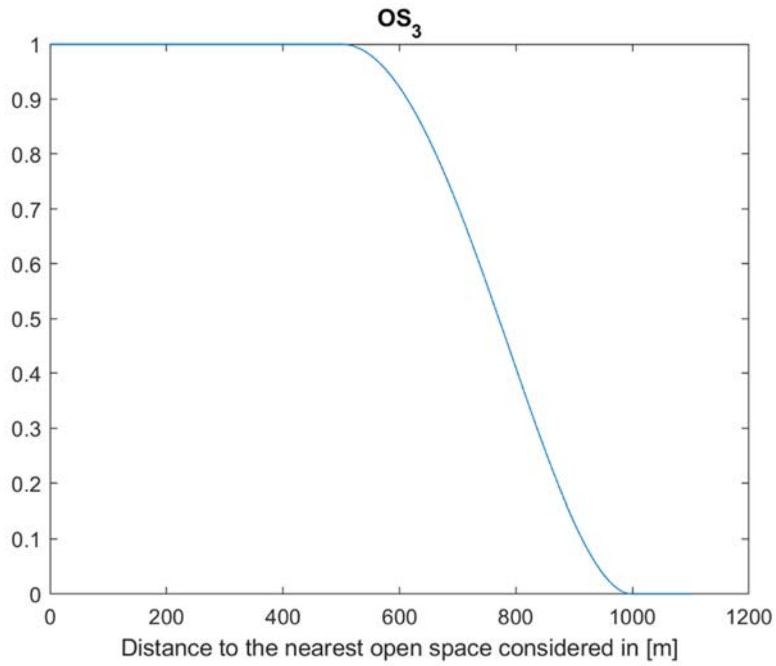
$OS_1 := \frac{\sum_{j=1}^{M} SOS_j}{M}$, SOS_j ... Sub Open Space. $SOS_j \in [0,1]$. M ... Number of sub open spaces.

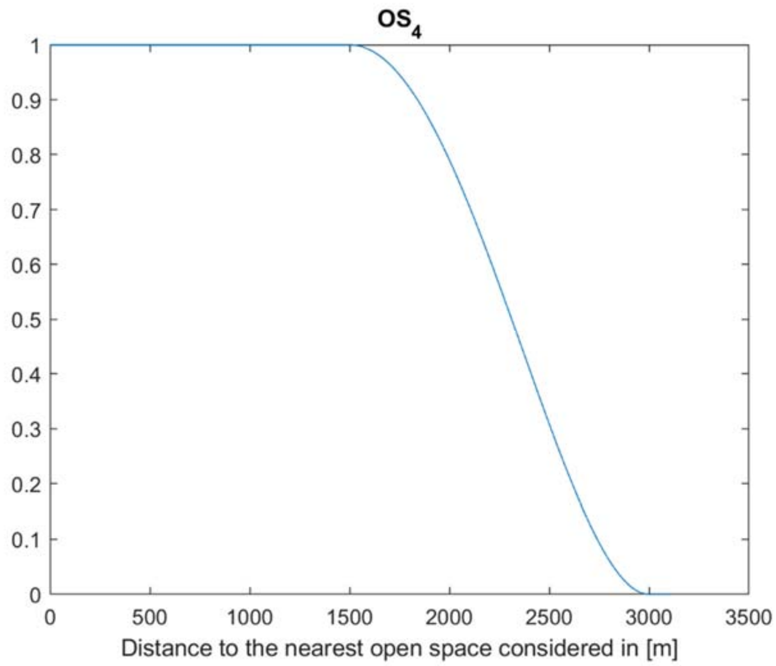
$OS_{2-5} := \left(1 - \min\left(\max\left(\frac{x-dmin}{dmax-dmin}, 0\right), 1\right)^l\right)^k$. $dmin$ ... minimum distance and $dmax$ ... maxinum distance in m.

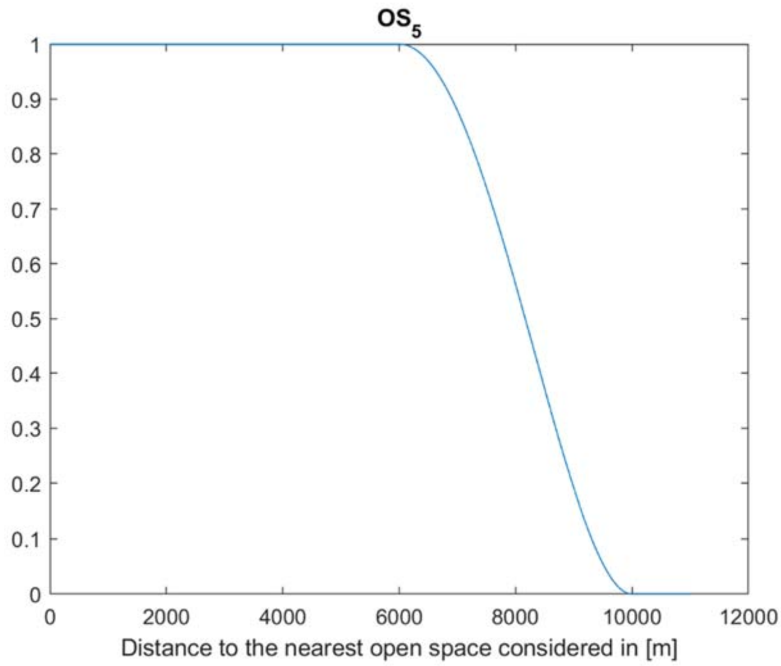
$POS_{QC} := \frac{\sum_{i=1}^{N} OS_i}{N}$


OS1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
Number of SOS fulfilled.


OS2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
Distance to the nearest open space considered in [m]


OS3
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Distance to the nearest open space considered in [m]


OS4
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
3000
3500
Distance to the nearest open space considered in [m]




```
SOS = 1×5
    1    1    1    1    1
OSges = 1×5
    1    1    1    1    1
POS = 1
SOS = 1×5
    0    1    0    1    1
OSges = 1×5
   0.6000    0.5625    1.0000    1.0000    1.0000
POS = 0.8325
SOS = 1×5
    0    1    0    1    1
OSges = 1×5
   0.6000    0.5625    0.5625    1.0000    1.0000
POS = 0.7450
SOS = 1×5
    0    1    0    1    1
OSges = 1×5
   0.6000    0.5625    0.5625         0    1.0000
POS = 0.5450
```

SOS = 1×5

0 0 0 0 0

OSges = 1×5

0 0 0 0 0

POS = 0

Tab = 4×6 table

	SUM_SOS	dist2	dist3	dist4	dist5	POS
1	5	250	500	1500	6000	1.0000
2	3	375	500	1500	6000	0.8325
3	3	375	750	1500	6000	0.7450
4	0	500	1000	3000	10000	0

3.6 PROXIMITY TO USE-SPECIFIC OBJECTS AND FACILITIES

Objectives

The (walking) accessibility of the local supply facilities within 600m should be given.

Facilities that are important for certain user groups should be within walking distance or available in the neighborhood. For health and education 1000m can be assumed.

In particular, the distance between THE and housing-related play areas for infants and young children should be ≤ 200m. Play areas are to be built on a project-specific basis, if necessary on adjacent areas.

For public playgrounds 1000m can be assumed.

Sports facilities are not considered due to the heterogeneous requirements.

Measurement

Objects and facilities	Designation	Data availability	Search radius	Comments, definitions
Local supply (daily needs)	Local supply facilities	openstreetmap.org	600 m	Supermarkets
	Markets	data.gv.at	600 m	see data source
Health	Pharmacies	data.gv.at	1000 m	see data source
	Medical practices (general medicine)	data.gv.at	1000 m	see data source
Education	Kindergartens	data.gv.at	1000 m	see data source
	Schools	data.gv.at	1000 m	Elementary schools, NMs, AHS, lower level; see data source
Leisure and recreation	Parcs	data.gv.at	1000 m	see data source
	Public playground	data.gv.at	1000 m	see data source

Notes

The decision for the search radius was made based on the frequency of the paths.

Evaluation of the general suitability of the location

Table 2: Indicator proximity to use-specific objects and facilities.

Number of facilities	Leisure/ Recreation	Health	Education	Local supply
0	0	0	0	0
1-3	0,5	0,5	0,5	0,5
>3	1	1	1	1
general weighting	0,25	0,25	0,25	0,25

Classification: 0=no; 1-3=medium supply; > 3=good supply. The higher the number, the more likely it is to be assumed that there is good accessibility and the possibility of a chain of paths.

Definition $\boldsymbol{P_{OF}}$ (Proximity to use-specific objects and facilities)

$g \coloneqq (g_1, \dots, g_4)$ … goodness factors for the accessibility of the facility. g_1 … Leisure/Recreation. g_2 … Health. g_3 … Education, g_4 Local supply.

$\omega \coloneqq (0.25; 0.25; 0.25; 0.25)$ … weights.

$P_{OF} \coloneqq g \times \omega$

Tab = 5×2 table

P_OF	**g**	**P_OF**			
1	0	0	0	0	0
2	0.2500	1.0000	0	0	0
3	0.3750	0.5000	1.0000	0	0
4	0.6250	1.0000	0.5000	1	0

3.7 CONNECTION TO PUBLIC TRANSPORT

Objectives

THE is to be planned/built in the sense of promoting sustainable mobility in areas with appropriate quality of public transport.

The modeling of the public transport quality classes serves as a data source and is used for the classification of public transport accessibility (A - <G = 1-0).

In a second step, the needs of the users can be met by weighting the stop category (e.g.: high frequency of trips = stronger weighting of A-C).

Vulnerable groups can be given special consideration via differentiated distances to stops.

Strategic target values (federal government, city of Vienna) serve as orientation values for the assessment of the quality of supply. Accordingly, the distance to subway stations should not exceed 500 m, to streetcar and bus stations not more than 300 m. Deviations are conceivable depending on the scenario and application.ups can be given special consideration by the distance to the stops.

Background

The public transport quality classes are a composite indicator consisting of stop category, distance to the stop and assignment to the spatial context. Thus, an additional evaluation of the planning quality is included, which is not necessary for a pure evaluation of the public transport development. For Vienna it can be assumed that all locations were assigned to the urban context.

Measurment

The public transport quality classes are available in a 100 m grid. The highest quality class on a site is used as relevant. Assignment to public transport quality class 0-1 (unsuitable-very suitable)

Haltestellen-kategorie	Distanz zur Haltestelle				
	≤ 300 m	301 – 500 m	500 – 750 m	751 – 1.000 m	1.001 – 1.250 m
I	A	A	B	C	D
II	A	B	C	D	E
III	B	C	D	E	F
IV	C	D	E	F	G
V	D	E	F	G	G
VI	E	F	G		
VII	F	G	G		
VIII	G	G			

Indicator public transport accessibility: Assessment using the model of public transport quality classes.

public transport quality class $:= \{A, B, C, D, E, F, G, non\}$ and Suitability (acceptance measure} $:= [0,1]$

$A := 1$; $B := 0.9$; $C := 0.8$; $D := 0.7$; $E := 0.6$; $F := 0.5$; $G := 0.4$; $non := 0$

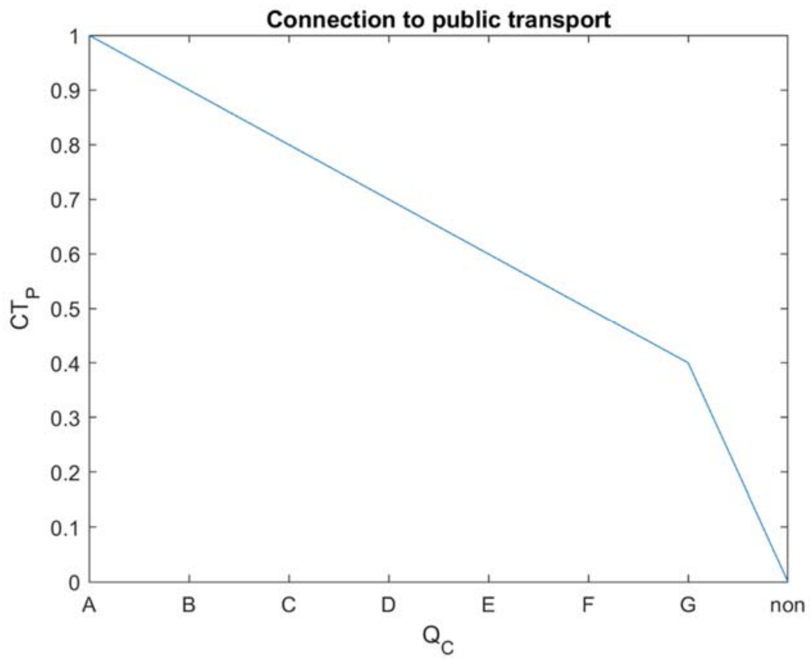
Definition CT_P (Connection to public transport).

Q_C ... Quality class; ω ... Weighting of the quality class.

$\omega(A) := 1$; $\omega(B) := 0.9$; $\omega(C) := 0.8$; $\omega(D) := 0.7$; $\omega(E) := 0.6$; $\omega(F)$; $\omega(G)$; $\omega(non) := 0$

$CT_P := \omega(Q_C)$

Example



3.8 ACTIVE MOBILITY ON THE PLOT

Structural conditions on the plot for active mobility

Active mobility is supported by structural requirements. There should be sufficiently large, well located, covered and safe (lockable) bicycle parking facilities on the ground floor/parcel.

Points may be deducted from the number of bicycle parking spaces; max. rating of course 0 (not negative).

Number of bicycle parking spaces per resident [1-0.9Parking space=1; 0.6Parking space = 0.5; 0.1=0].

1. The bicycle storage is lockable [Yes+0; No-0,2].

All bicycle parking space are protected from the weather. [Yes+0; No-0,2].

The bicycle parking space are at ground level/barrier-free/accessible with ramps [Yes+0; No-0,2].

The bicycle parking spaces are practically organised (single parking 90°, single parking 45° or double parking 90°) [Yes+0; No-0,2].

The distance of the bicycle parking spaces is less than 10m to the entrance of the building [Yes+0; No-0,1].

If babies and toddlers are part of the user group: There is a room for the parking of prams [Yes+0; No-0,1].

Definition $\boldsymbol{AM_P}$ (Active mobility on the plot)

ω_i ... Amount of the weighting of the conditions. N ... Number of conditions. P_{min} ... Lower acceptable proportion of parking spaces. P_{max} ... Upper acceptable proportion of parking spaces.

$$c_i := \begin{cases} condition\ i\ is\ met\ \ c_i = 0 \\ condition\ i\ is\ not\ met\ \ c_i = 1 \end{cases}$$

$$\omega := 1 - \frac{\sum_{i=1}^{N} \omega_i \cdot c_i}{\sum_{i=1}^{N} \omega_i}$$

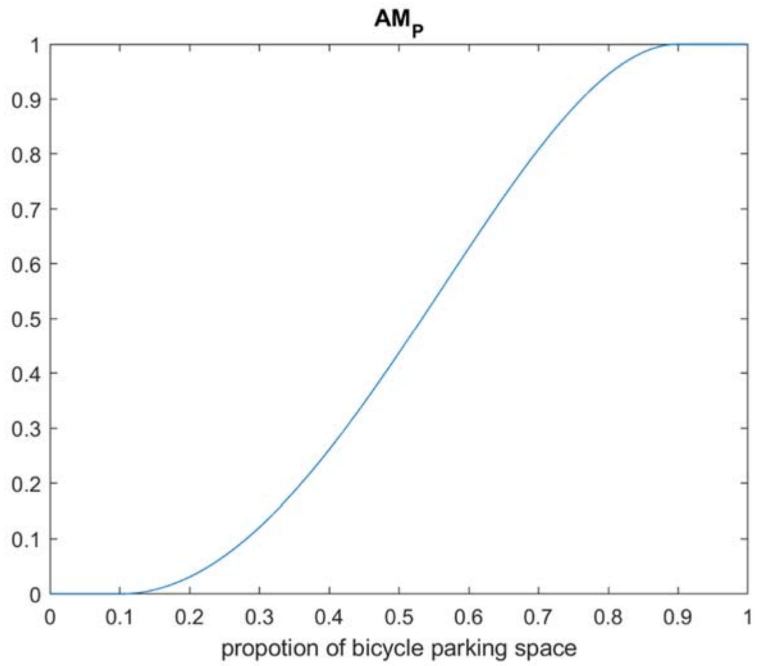
$$AM_P := \left(1 - \min\left(\max\left(\frac{x - P_{min}}{P_{max} - P_{min}}, 0\right), 1\right)^l\right)^k \cdot \omega$$

Example

(In the following illustrations, the reduction factors 1-6 are shown in the vector c. A 1 means that this reduction factor applies).

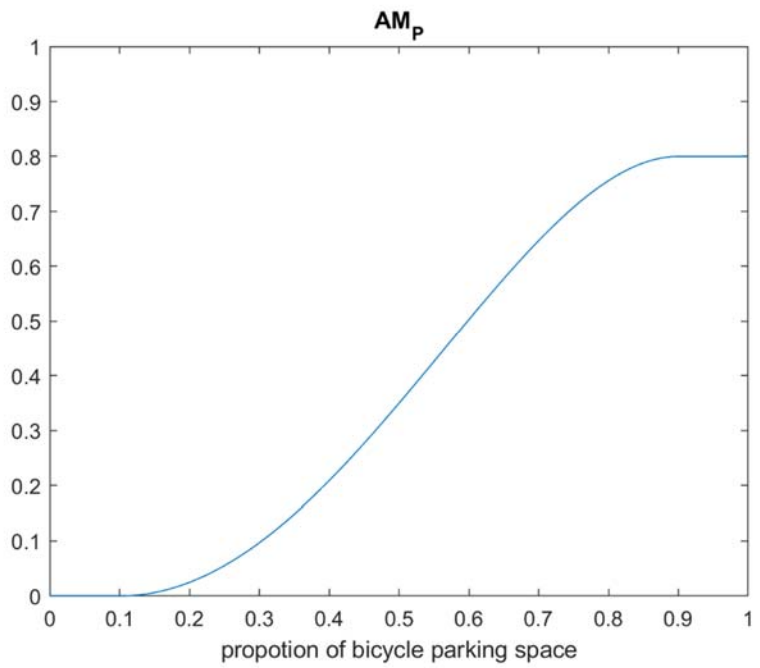
c = 1×6

0 0 0 0 0 0



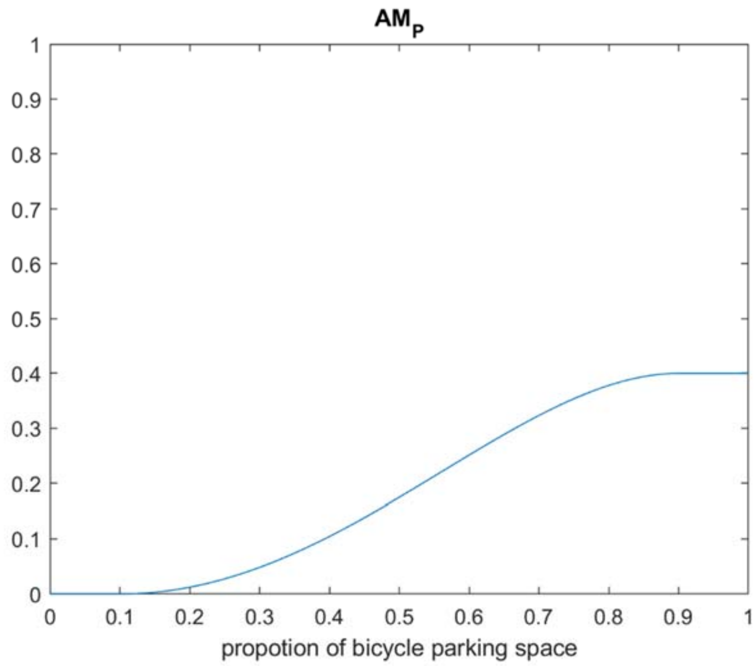
c = 1×6

1 0 0 0 0 0



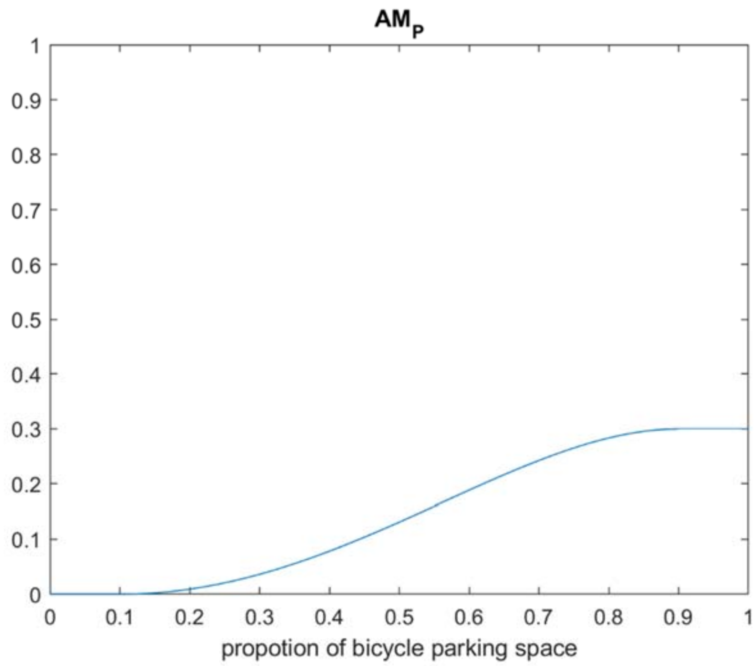
c = 1×6

1 1 0 1 0 0



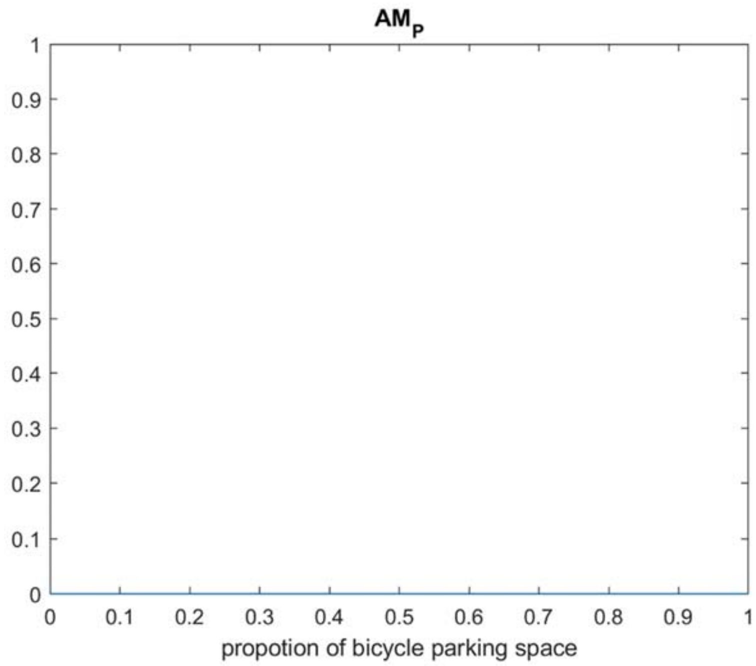
c = 1×6

1 1 0 1 0 1



c = 1×6

1 1 1 1 1 1


AM_P
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
propotion of bicycle parking space

3.9 ACTIVE MOBILITY IN THE QUARTER

Objectives

THE should be as directly accessible as possible, i.e. have a connection to public roads or spaces (basic requirement).

THE should be accessible on foot and by bicycle to promote active mobility.

Bicycle parking facilities should be available in the neighborhood (with possible destinations within a radius of 1500 m) to increase the attractiveness of bicycle use.

THE should be connected to the bicycle traffic infrastructure (bicycle traffic facilities RVA and bicycle facilities RFA -- in the sense of the StVO and RVS) and should not exceed 200 m.

Measurement:

Data source: “Sidewalk widths Vienna 2016” (pedestrian zones and squares are not included > therefore 50 m buffer)

The "public accessibility" via public areas is seen as a basic requirement (value 0.5 if fulfilled) and an approximation of a distance between THE and the public area according to the road graph of maximum 20 m is assumed. If this is not met, the area is considered to be publicly inaccessible (value: 0), which is considered a KO criterion here.

If THE is accessible via public areas and in addition the nearest sidewalk is not more than 50 m away (distance based on sidewalk data set), a favorable pedestrian access is assumed (value: 0.7, otherwise 0.5). +0,2!

An availability of cycling facilities (max. 50 m distance) means a favorable location from the point of view of bicycle traffic (value 0.9). +0,2!

If there are additional bicycle parking facilities within a radius of 1500 m, a further attractiveness of the bicycle traffic is to be assumed (value 1) +0.1!

Definition $\boldsymbol{AM_Q}$ (Active mobility in the quarter).

$p_a \coloneqq \begin{cases} 1 & if\ accessible \\ 0 & if\ not \end{cases}$ ... public accessible.

$I \coloneqq (I_1, I_2, I_3)$ ... is the THE land I_1 accessible via public areas or is the THE available of cycling facilities I_2 or are there additional bicycle parking facilities I_3. $I_i = 1$ if yes and $I_i = 0$ if no.

$\omega \coloneqq (0.2; 0.2; 0.1)$ ... weights.

$AM_Q \coloneqq p_a \cdot (0.5 + I \times \omega)$

Tab = 5×3 table

	A_ADO	pa	I		
1	0.5000	1	0	0	0
2	0.7000	1	1	0	0
3	0.9000	1	1	1	0
4	1.0000	1	1	1	1
5	0	0	1	1	1

3.10 ACCESSIBILITY FOR ASSEMBLY, DISMANTLING AND OPERATING PHASE

Objectives

THE should be accessible by navigable waters (for water-related applications).

THE should be accessible by road. Due to the proximity to a road, the accessibility by delivery and construction vehicles should be given (not applicable for Life on tracks and DonAutonom)

Background

For the provision of an efficient and effective THE, accessibility during the entire life cycle has to be considered. This includes the logistics surrounding construction and dismantling, but also supply and maintenance during the utilization phase.

Measurement

Considerations regarding accessibility by road:

Accessibility of sites by road for the construction and removal of modules.

Questions:

Which modules have which requirements?

What are the requirements for roads (width, strength)?

Simplified analysis method: GIS buffer (20 m) via road graph. Values: 1/0 → reachable/not reachable

Considerations on the accessibility of running waters:

It should be possible to transport the "floating modules" to and from the site by ship. Running waters: Selection

of navigable waters (Danube, Danube channel, harbour basin) Shore condition (fortified bank), landing stages,

Values: 1/0 suitable/unsuitable

Selection of boatable areas.

Shore condition.

Definition A_{ADO} (Accessibility for assembly, dismantling and operating phase). Subprocesses

$I := (I_1, I_2)$ ... is the THE land I_1 or water based I_2. $I_i = 1$ if yes and $I_i = 0$ if no.

$\omega_1 := \begin{cases} 1 \text{ if reachable} \\ 0 \text{ if not} \end{cases}$ ... weighting for land-based accessibility.

$\omega_2 := \begin{cases} 1 \text{ if suitable} \\ 0 \text{ if not} \end{cases}$ ... weighting for water-based accessibility.

$A_{ADO} \coloneqq I \times \binom{\omega_1}{\omega_1 \cdot \omega_2}$ ... For the accessibility of water-based THE, this definition requires both road and waterway access.

Tab = 5×4 table

	A_ADO	**pa**	**I**		
1	1	1	0	1	0
2	0	1	0	0	1
3	0	0	1	1	0
4	0	0	1	0	1
5	1	0	1	1	1

3.11 LAND USE EFFICIENCY

Objectives

In accordance with general objectives of quality spatial development, temporary housing environments should be integrated into the existing urban structure in the most resource and land-saving manner possible, without or with as little additional land use or soil sealing as possible. In this sense, the use of existing structures, especially the activation of vacant buildings or areas and the use of brownfields, can contribute to efficient and sustainable land use. Primarily, existing built structures are to be used. Otherwise, the highest possible efficiency in land use should be reached. Therefore, the following ranking of land use will be used as the base for the assessment:

- Vacant land
- previously developed land (brownfields)
- undeveloped land (greenfields).

Assessment

Assessment of suitability of the existing land use:

Type	Value
Building land -- existing buildings (e.g. vacant space in existing building structures)	1
Building land -- developed, partially developed (e.g., brownfield, greyfield)	0,7
Building land -- sealed, undeveloped (e.g. parking lot)	0,6
Building land -- developed, undeveloped or previously developed (e.g. building gap)	0,5
Building land -- not developed	0,2
Grassland -- undeveloped (e.g. greenfield)	0

4 SOCIAL AND RESIDENTIAL QUALITY

This chapter includes indicators that are refer to the quality of life that is facilitated by the organizational, built and spatial structures of the building and open spaces on plot. Indicators that are majorly influenced by organizational arrangements or indoor structures were primarily developed by Junior and Senior Scientists of ITA (‘social quality’), indicators that are influenced by arrangement of the buildings and open spaces were generated by members of ILAP (‘residential quality’). The indicator ‘Gender+ and diversity aspects of built and open space structures on the plot’ (43) was built together by members of both institutions and gathers several other indicators; it is used to show the housing model’s performance regarding gender+ and diversity aspects at a glance.

Social indicators

For the development of the social indicators, the first step consisted of researching already existing indicators for human well-being in practice. These indicators were collected from sources such as the OECD (2011) and EUROSTAT. They were documented and described within a table. The literature research on human needs was used to analyze whether these indicators cover all defined human needs (subsistence, affection, understanding, participation, idleness, freedom, protection, creation & identity, see also chapter on human needs presented in D1), to gain a better understanding of possible gaps. Seeing as this collection served as an informative basis, at this stage all relevant indicators were collected, regardless of feasibility within the project-context. In early July 2019 the collection of social indicators encompassed: 1) living space available, 2) overcrowding, 3) weight of housing costs on household income, 4) satisfaction with housing, 5) population living in households considering they suffer from noise, 6) housing deprivation, 7) unmet need for medical examination and care, 8) private space available, 9) availability of public transport, 10) accessibility of key services, and 11) possibility to participate.

Having collected existing indicators, the next step consisted of comparing these and reducing their number either by combining similar indicators (indicators measuring the same thing with different methods) or eliminating indicators which cannot be assessed within the project frame (for instance indicators based on user experiences). Indicators had to be adapted to be project-specific, which consisted of a translation into the temporary context and the Viennese context. The project team further made the decision to restrict the number of indicators per field to keep the complexity of the modelling as low as possible. Ideas were exchanged on the possibilities of creating indicators made up of several sub-indicators for the social indicators in August and September 2019. All changes to the social indicators went through several revision processes within the Junior Group and subsequently within the entire project team where the changes were proposed and decisions were presented with their reasoning. The indicator “satisfaction with housing” was removed because there was no way of determining a value for this indicator in advance. The indicator “unmet need for medical examination and care” was combined with “accessibility of key services”, and the indicators “availability of public transport” and “accessibility of key services” were moved to the field “location quality”. The indicator “weight of housing costs on household income” was removed as an indicator, as the decision was made not to analyze the economic dimension in such detail, as to make such an assessment possible. The process and evolution of the social indicator table is documented within meeting minutes, emails, PowerPoint presentations, retired versions of working documents and handwritten notes on printouts. The social indicators were expanded by the dimension of landscape planning, adding several new indicators from this field.

The project meeting on the 20.09.2019 was to be used to allow the entire project team to vote on relevant indicators to include in the modelling in order to trim down the extensive list. The feedback of the project team included the introduction of the target criteria “gendersensitivity”. Two smaller-scale meetings between seniors and the junior team were held on the 14. &18.10.2019 to collect feedback on the indicators of the respective fields of the present seniors.

By mid-March 2020, the indicators for each target criteria were refined by each responsible discipline. The target criteria “flexibility of the living area” was added, as an area of particular interest for temporary housing. The list of target criteria and indicators for the social and residential quality were as follows:

Target criteria	Indicator
Adequate interior space (private)	Effective area per person (private)
	Occupancy rate
	Facility category
Adequate interior space (community)	Effective area per person (community)
	Spaces conducive to communication
Flexibility of the living area	Changeability of room size and layout
Sense of security and safety	Visibility
Barrier-free accessibility	Barrier-free accessible rooms
Gender + sensitivity	Compatibility of family and paid work
	Fair distribution of resources
	Visibility
Participation	Type of participation

In two meetings on the 24.03.2020 and 31.03.2020 within the sub-group for social and residential quality, the target criteria were discussed and refined further, with the objective of reaching a description of the indicators suited for the modelling phase of the project and developing a step-by-step description of the assessment. On the 01.04.2020 there was a Zoom call with the colleague responsible for the modelling to talk through the developed indicators. Feedback was gathered and adaptations were made.

On the 22.04.2020 during a project team meeting feedback was provided on the indicators via a google form. On the following day, the 23.04.2020, discussions were held surrounding this feedback. At this point it was decided that the occupancy rate should not be an indicator for the modelling, seeing as whether or not a practical implementation houses more individuals than was intended cannot be controlled by the project team in advance. It was decided to investigate this aspect closer in the risk assessment. The feedback from these meetings was incorporated into the further development of the social indicators as follows:

Indicator	Incorporation of feedback
Effective area per person (private) (8)	None
Effective area per person (community) (11)	None
Facility category (9)	Assessment incorporates aspect of lockable/not lockable showers
Changeability of room size and layout (14)	Assessment regards flexibility of room and flexibility of use
Barrier-free accessible rooms (13)	Assessment regards if there is at least one barrier-free access point
Spaces conducive to communication (12)	"Space" needs to be defined. Assessment should regard amount of spaces, not the size.
Empowerment and type of participation (44)	Development in progress
Visibility (sense of security)	Dissolved and integrated into gender+sensitivity
Occupancy rate	Struck and moved to risk assessment

After this round of adaptations, the first calculations were conducted, on the basis of which more fine-tuning of the indicators commenced.

Residential indicators

The creation of the residential indicators was carried out in the same manner as the social indicators. Literature was screened for already existing indictaros and target criteria. Various inputs derive from theory of open space planning (among others documented in publications of Kasseler Schule) as well as basics and values from publications by the City of Vienna (such as STEP 2025's thematic concept Green and Open Spaces (Werkstattbericht 154) and Gender Mainstreaming in Urban Planning and Urban Development (Werkstattbericht 130)). The discussions of the senior scientists and feedback of the project team in the mentioned meetings as well as on June 30th, 2020 is documented in the file 'Bewertung der LAP-Indikatoren 20200916.docx".

The final list of indicators that regard the quality of the open space refer to Private open space (45), Communal open spaces (46), Open spaces of areas with mixed use (47) and Residential quality in the district (51).

4.1 EFFECTIVE AREA PER PERSON (PRIVATE)

Consideration

This indicator means to help describe privacy.

A private room is defined for this indicator as a room containing at least one bed. It makes a difference in quality of privacy whether someone has a single room, shares the room with another occupant or with multiple occupants. The more people share a bedroom, the lower the quality for privacy.

In addition, the size of the room will have an impact on the quality. We define 3m2/person as the lowest limit and 12m2/person as the top limit where no more increase in quality can be attained.

Measurement

STEP 1: (Counts for 70% of total value)

- How many % of bedrooms for 1 occupant?
- How many % of bedrooms for 2 occupants?
- How many % of bedrooms for 3 occupants?
- How many % of bedrooms for 4 and more occupants?

100% 1 occupant = 1 (of 70%, this means, if there are only single rooms which are very small (>3 qm), then the value can be at max. =,7)

100% 2 occupants = 0,7

100% 3 occupants = 0,5

100% multiple occupants (4 or more) = 0,4

STEP 2: (Counts for 30% of total value)

- individually designated floor space per person in private rooms based on ground plans.
- private rooms defined as rooms containing beds
- private room sizes divided by number of inhabitants (m2/person)
- Evaluated according to a root function with y-axis from .
- 3m2 /person as the lowest limit value (0).
- 12m2/person as highest value (1)

6m2 = 0,5

STEP 3 Aggregating to environment

P for 0-1 = 0,25

If one category = 0 then all = 0

Definition $\boldsymbol{Ea_{P_p}}$ (Effective area per person (private))

Level 1 assessment

Subprozess 1 (Occupants)

$\omega := (1,0.7,0.5,0.4)$ ... weightings for the number of occupants.

$s := (s_1; s_2; S_3; S_4)$ ... share of room types in the PHE in %. s_i ... is the room type with i residents in $(0,1)$ relative to the total number (=1) of private rooms in the PHE. Let be $\sum_{i=1}^{4} s_i = 1$ $\sum_{i=1}^{4} s_i = 1$.

$O_{C_T} := \omega \times s$ ... Occupant Types. $\times$ ... vector multiplication.

tab = 6×2 table

	s				OcT
1	1.0000	0	0	0	1.0000
2	0	1.0000	0	0	0.7000
3	0	0	1.0000	0	0.5000
4	0	0	0	1.0000	0.4000
5	0.5000	0	0.2000	0.3000	0.7200
6	0.2500	0.2500	0.2500	0.2500	0.6500

Subprozess 2 (Area)

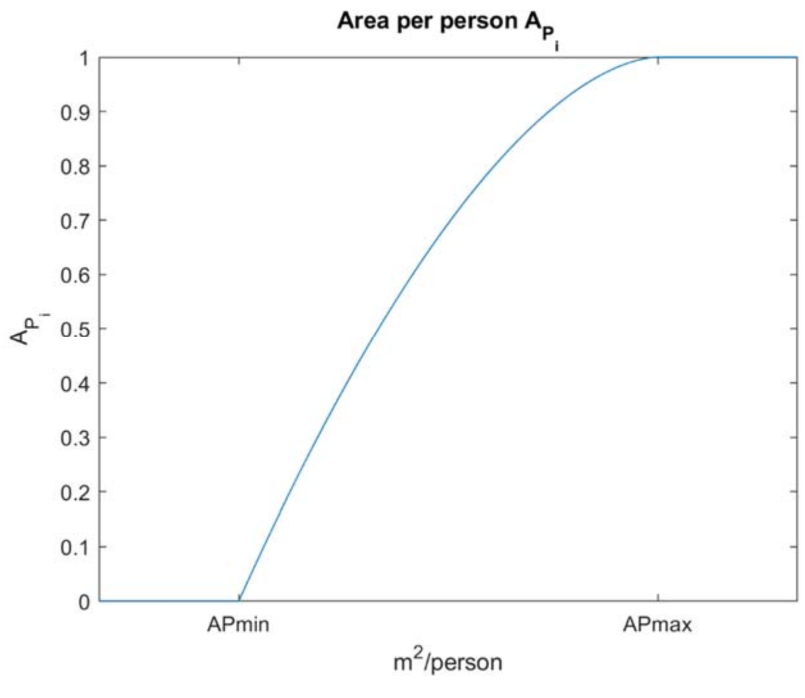
$A_{P_i} := 1 - \left(1 - \min\left(\max\left(\frac{A - A_{Pmin}}{A_{Pmax} - A_{Pmin}}, 0\right), 1\right)^l\right)^k$ ... i-th room variant for m^2 per person.

Lower limit $3\frac{m^2}{person} \to 0$.

Upper limit $12\frac{m^2}{person} \to 1$.

A ... $\frac{m^2}{person}$.

AP_6 = 0.5000



Level 2 assesment

$A_P := \frac{\left\|\left(A_{P_1},\ldots,A_{P_N}\right)\right\|}{\|1_N\|}$ ... evaluation factor in respect of room size. 1_N ... N dimensional vector with ones.

$C_{min} := \begin{cases} 1 \; if \; all \; A \geq A_{P_{min}} \\ 0 \; lese \end{cases}$ ... Coefficient for the minimum requirement.

$Ea_{P_P} := \left(0.7 \cdot Oc_T + 0.3 \cdot A_p\right) \cdot C_{min}.$

AP_01 = 0.2500

tabin = 6×2 table

	s				A		
1	1.0000	0	0	0	12	NaN	NaN
2	0	1.0000	0	0	12	3.0000	NaN
3	0	0	1.0000	0	12	2.9990	NaN
4	0	0	0	1.0000	9	6.0000	NaN
5	0.5000	0	0.2000	0.3000	12	10.0000	NaN
6	0.2500	0.2500	0.2500	0.2500	12	5.0000	3

tabout = 6×4 table

	OcT	APi			AP	EaP
1	1.0000	1.0000	NaN	NaN	1.0000	1.0000
2	0.7000	1.0000	0	NaN	0.2500	0.5650
3	0.5000	1.0000	0	NaN	0.2500	0
4	0.4000	0.8471	0.5000	NaN	0.6622	0.4787
5	0.7200	1.0000	0.9236	NaN	0.9614	0.7924
6	0.6500	1.0000	0.3492	0	0.2812	0.5394

4.2 FACILITY CATEGORY

Consideration

We look at toilets, bathing facilities and cooking facilities. It makes a difference in the quality of life whether they can used privately or whether they are used collectively. We also assume that the use of toilets has a more serious impact on the quality of life than the use of a kitchen. A further distinction is made between lockable showers and non-lockable showers for shared bathrooms. For this we introduce a reduction factor of 30% if the shared showers are not lockable.

One household in this context is defined as a bedroom (number of bedrooms = number of households). Number of households does not necessarily equate number of people. Both values "households" and "people" are assessed for this indicator.

Seeing as there can be staff who are present during the day but who are not inhabitants, a different assessment is used for public facilities. These are assessed as a bonus.

Val_Res. Describes the availability to people and Val_Pub. describes the additional public facilities of the building.

Measurement

First Val_Res is determined. It is counted how many people of the different households share a certain facility and how often this occurs. For example:

2 people sharing a WC: 12 cases

1 person using a WC: 8 cases

2 people sharing a bathroom: 12 cases

Lockable: yes

1 person using a bathroom: 8

Lockable: yes

2 people sharing a kitchen: 14 cases

1 person using a kitchen: 4 cases

The number of residents and staff: 32

The same is done for Val_Pub. where the public facilities are regarded. For example:

32 people sharing a WC: 2 cases

32 people sharing a bathroom: 0 cases

32 people sharing a kitchen: 1 case

Assessment

A rating between 0-1 can be defined for each household. Finally, the average value is calculated.

1. WC counts for 50% of this value

- Each "yes" is evaluated as 1
- Each "no" is calculated as a linear function of negative slope divided by the number of people sharing (function intersects the y-axis at x=1 and the x-axis (y=0) at a defined value of maximum number of people sharing. Max=15)
- The max value for public facilities is 40.

2. Bathing facilities count for 30% of this value

- Each "yes" is evaluated as 1
- Each "not lockable" bathing facilitiy is rated as 1/3.
- Each "no" is calculated as a linear function of negative slope divided by the number of people sharing (function intersects the y-axis at x=1 and the x-axis (y=0) at a defined value of maximum number of people sharing. Max=15)
- The max value for public facilities is 40.

3. Cooking facilities count for 20% of this value

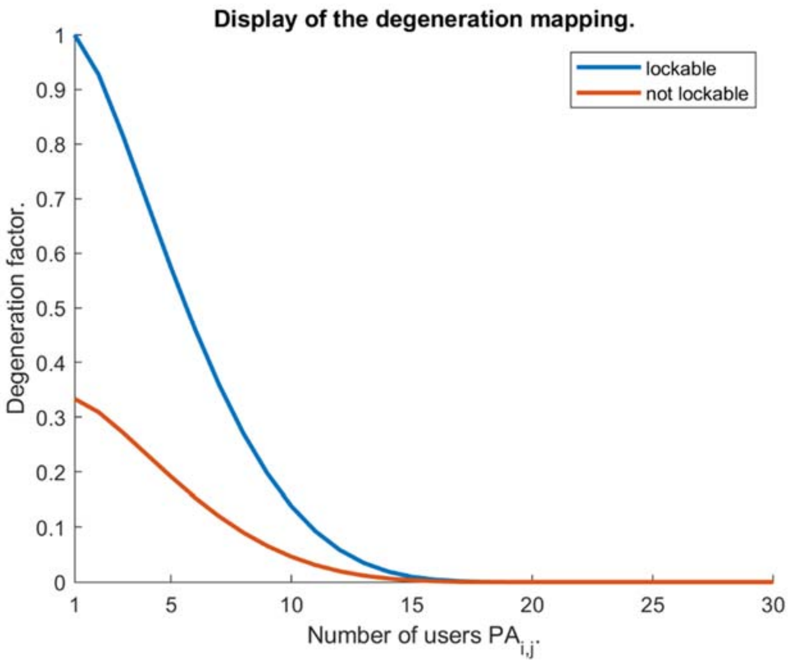
- Each "yes" is evaluated as 1
- Each "no" is calculated as a linear function of negative slope divided by the number of people sharing (function intersects the y-axis at x=1 and the x-axis (y=0) at a defined value of maximum number of people sharing. Max=15)
- The max value for public facilities is 40.

Definition **F**$_C$ (Facility category)

Sub processes

1. Group size.

- $P_{A_{i,j}}$ ... Number of persons j using the equipment i.
- $P_M := 15$ ... Maximum tolerable number of common users of a facility.
- Degradation factor $f_{D_{i,j}} := \left(1 - \left(\frac{\min\left(P_{A_{i,j}}, P_M\right) - 1}{P_M}\right)^a\right)^b$ lockable.
- Degradation factor $f_{D_{i,j}} := \frac{\left(1 - \left(\frac{\min\left(P_{A_{i,j}}, P_M\right) - 1}{P_M}\right)^a\right)^b}{3}$ not lockable bathing facilitiy.



Facilities

1. WC weighting $\omega_1 := 0.5$.
2. Bathroom weighting $\omega_2 := 0.3$.
3. Kitchen weighting $\omega_3 := 0.2$.

N_R ... Number of residents +staff.

N_{F_i} ... Number of equipments of the categories i (1:=WC, 2:=Bathroom, 3:= Kitchen)

$$F_C := \frac{\sum_{i=1}^{3} \omega_i \sum_{j=1}^{N_{F_i}} f_{D_{i,j}}}{N_R}$$

FC = 0.6981

FC = 0.7100

4.3 EFFECTIVE AREA PER PERSON (COMMUNITY)

Consideration

The quality does not increase continuously with increasing effective area per person. The curve is assumed to follow a curve according to a root function.

Measurement

Recording of m^2 usable floor space of community areas per person based on ground plans

- NO functional areas such as boiler room, machine room, stairwells, elevators, ramps, etc.
- NO private areas.
- NO unroofed outside areas except balconies
- Common areas count as 100%.
- Access areas ("Erschliesungsflächen"), balconies/terraces and common bathrooms count as 50%.
- The number of (total) people includes not only residents, but also people who are e.g. professional caretakers or administrators on site.

Assessment

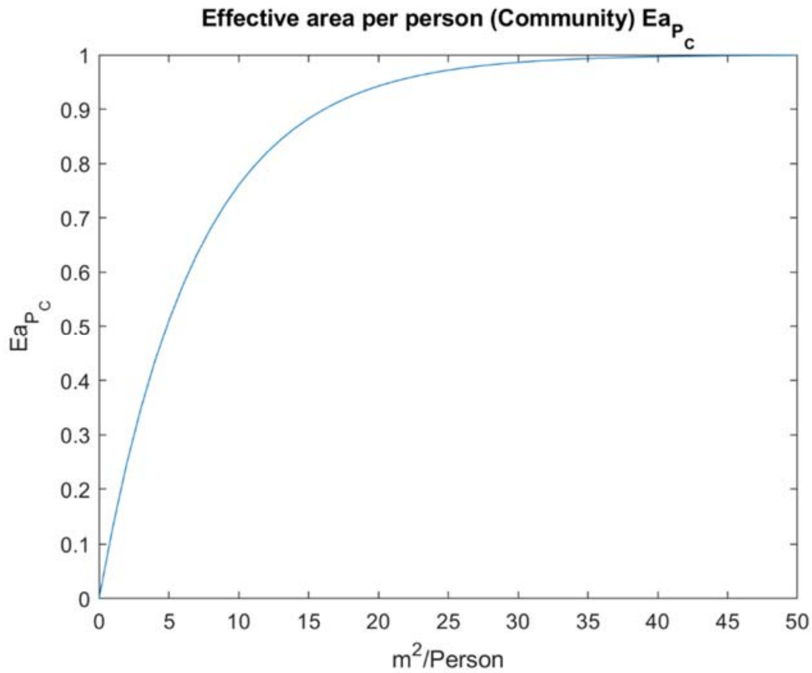
Evaluated according to a root function with y-axis from $0 \rightarrow 1$.

Definition **Ea$_{P_C}$** (Effective Area per person (Community))

- a_S ... Shared areas.
- a_A ... Access areas.
- a_{B_C} ... Community bathrooms.
- N_R ... Number of residents and staff.
- $a_{P_C} := \dfrac{a_S + (a_A + a_{B_C}) \cdot 0.5}{N_R}$ ... Community level of use per person.

$$Ea_{P_C}(a_{P_C}) := 1 - e^{-\frac{a_{P_C}}{\lambda}}$$

- Uper limit $\lim\limits_{x \to \infty} Ea_p = 1$.
- Support: Effective area $\mathbb{R}_0^+$ (Positive part of $\mathbb{R}$ inclusive 0).



tab = 2×1 table

	Ea_p						
1 m²/person	0	5.0000	10.0000	15.0000	20.0000	25.0000	30.0000
2 Ea_P_C	0	0.5105	0.7603	0.8827	0.9426	0.9719	0.9862

4.4 SPACES CONDUCIVE TO COMMUNICATION (ADEQUATE AVAILABILITY OF COMMON AREAS AND ROOMS)

Consideration

The more common rooms are available, the greater the possibility of interaction. Our hypothesis is that 10 rooms for 300 people can have the same quality as 3 rooms for 30 people. This has to be considered. Rooms are therefore regarded in relation to the number of residents. It must also be considered that with the same number of residents, each additional room does not mean an even increase in quality. A course according to a root function is assumed.

It is distinguished between common and semi-private rooms. Semi-private rooms are rooms which are shared by a limited number of households and not by the entirety of the inhabitants. An example is a common room with a kitchenette which can be accessed from two bedrooms (a household is defined as a bedroom) but not by all inhabitants. Semi-private rooms receive a reduction of the value by being multiplied with 0.3.

Measurement

- Rooms are defined as: closed rooms with assigned functions, niches that are not clearly separated but have assigned uses and outdoor spaces as soon as functions are recognizable (e.g. terrace & entryways).
- Multifunctional rooms only count as one room.
- Balconies are considered as part of the room they are connected to and therefore are not considered as separate rooms
- Number of common rooms open to all inhabitants are counted
- Number of semi-private common rooms are counted

Assessment

- Evaluated according to a root function with y-axis from 0-1.
- Considering different numbers of people.
- Different functions for group sizes.

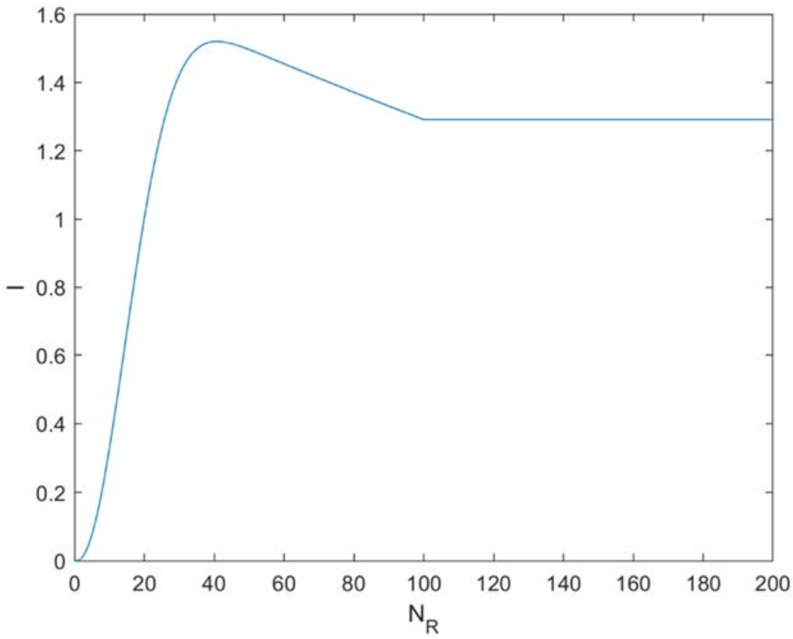
Definition **S_{CC}** (Spaces conducive to communication)

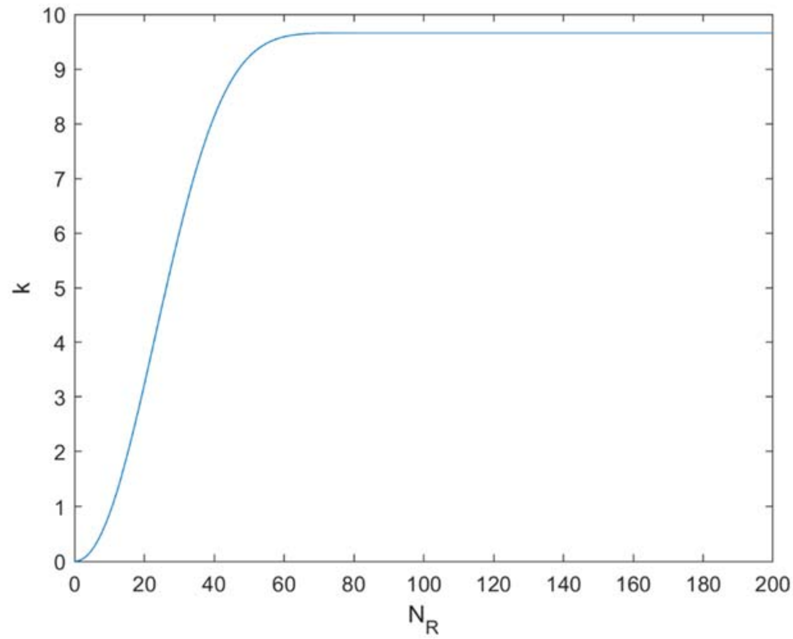
- N_R ... Number of Residents.
- N_{S_C} ... Number of spaces conducive to communication.
- $N_{S_C} = N_{S_G} + \frac{N_{S_{SP}}}{3} \ldots$ with the number N_{S_G} generally accessible by all residents and the number N_{S_{SP}} semi public spaces used by e.g. only two households.

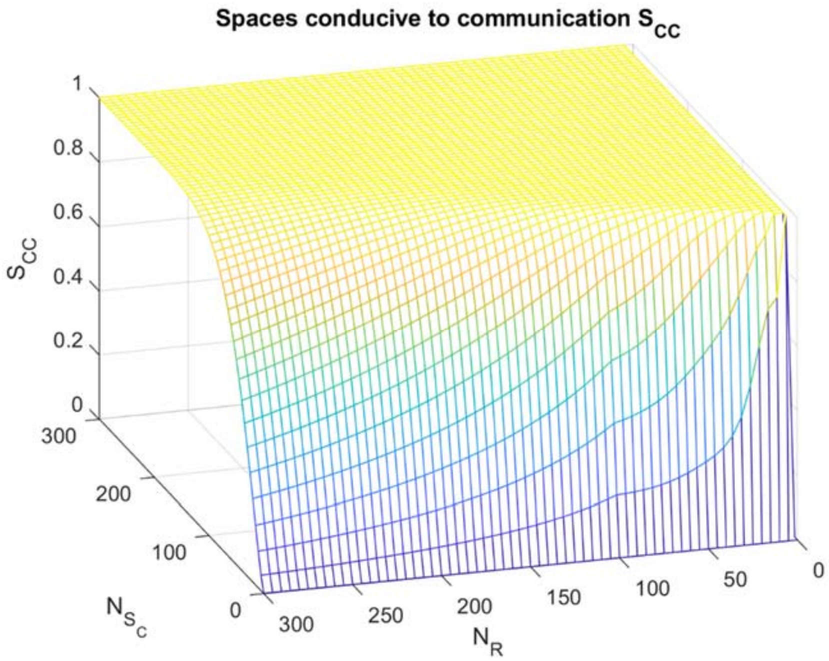
$$k(N_R) := \Re\left(1 - \left(1 - \min\left(1, \max\left(\frac{N_R}{100}, 0\right)\right)\right)^{2.095}\right)^{11.63} \cdot 9.663\right)$$

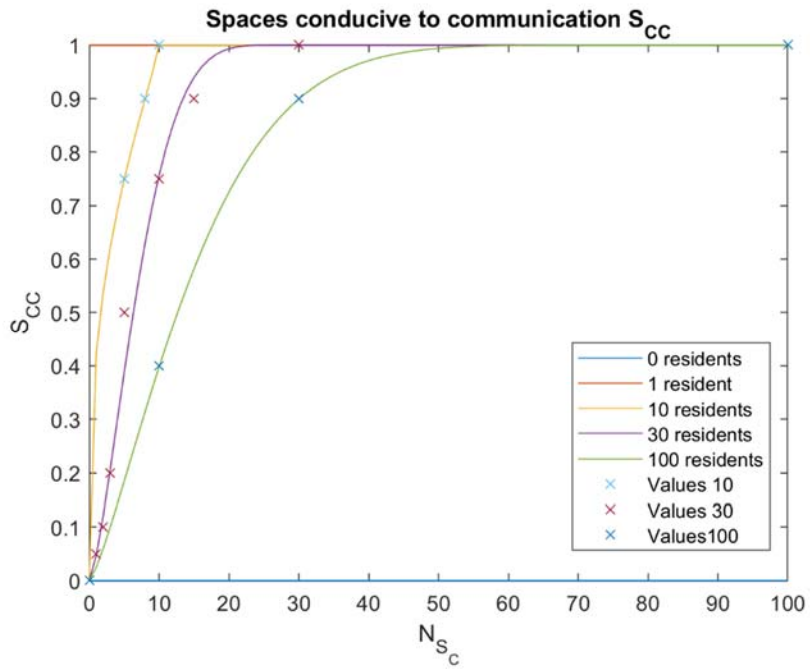
$$l(N_R) \max \left(0, \Re\left(\left(1-\left(1-\min\left(\max\left(\frac{N_R}{100},0\right),1\right)^{2.024}\right)^{25.73} - \left(1-e^{\left(-\min\left(N_R,100\right)\cdot 0.002022\right)}\right)\cdot 1.376\right)\cdot 1.726\right)\right)$$

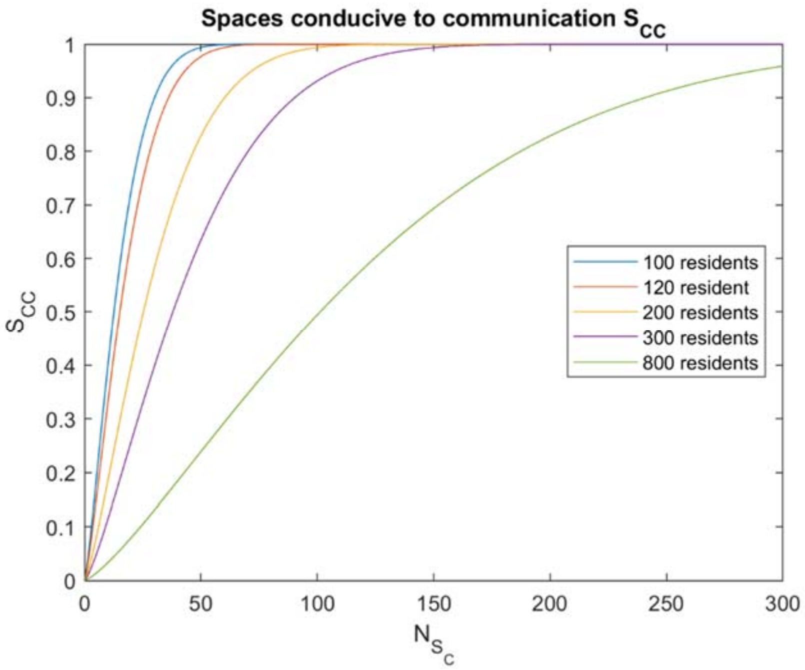
$$S_{CC}(N_{S_C}, N_R) = \Re\left(1-\left(1-\max\left(\min\left(\frac{N_{S_C}}{N_R},1\right),0\right)^{l(N_R)}\right)^{k(N_R)}\right)$$






Spaces conducive to communication S_{CC}
1
0.8
0.6
0.4
0.2
0
S_{CC}
300
200
100
0
N_{S_C}
300
250
200
150
100
50
0
N_R


Spaces conducive to communication S_{CC}
S_{CC}
N_{S_C}
0 residents
1 resident
10 residents
30 residents
100 residents
Values 10
Values 30
Values100



tab = 10×1 table

	SSC					
1 NR	0	1	10.0000	100.0000	500.0000	1000
2 NSC=0	0	1	0	0	0	0
3 NSC=1	0	1	0.4236	0.0250	0.0032	0.0013
4 NSC=2	0	1	0.5385	0.0602	0.0077	0.0032
5 NSC=3	0	1	0.6215	0.0997	0.0130	0.0053
6 NSC=5	0	1	0.7486	0.1846	0.0250	0.0103

4.5 BARRIER-FREE ACCESSIBLE ROOMS

Consideration

The indicator "barrier-free accessible rooms" provides information on the accessibility of rooms for individuals using wheelchairs, walkers or other devices. Room type is regarded rather than amount of rooms. Only one entrance to one room of a specific room type is required for this room type to be considered barrier-free.

Barrier-free accessible rooms with barrier-free transitions & entrances with clear passage widths of at least 90cm, special control elements and sufficient movement areas for wheelchair users.

Measurement

Calculation on the basis of planning documents.

Does the building have at least one barrier-free access? Yes or no. If no → value is 0. If yes → indicator is measured as follows.

% Types of common rooms (including, if applicable, adequate sanitary facilities) are designed to be accessible barrier-free.

% of the private rooms (including adequate sanitary facilities, if applicable) are designed to be barrier-free.

Differentiation between common areas and private rooms.

Private housing units: Here a value of 20% barrier-free vlt. is already sufficient, so from 20% the value 1 is already reached.

Common rooms: Here we want to get very close to 100%, whereby we should not count the number of rooms per se but consider the room types. (For example: There are 5 common rooms, of which 2 are communal kitchens which are both accessible and 3 laundry rooms of which only one is accessible. Instead of counting 3 of 5 rooms as accessible, we should rather note that 2 room types out of 2 available room types are barrier-free. So 2 out of 2 instead of 3 out of 5 are accessible).

Definition BF_{AR} (Barrier-free accessible rooms)

C_E ... Barrier-free access. If yes $C_E \coloneqq 1$. If no $C_E \coloneqq 0$.

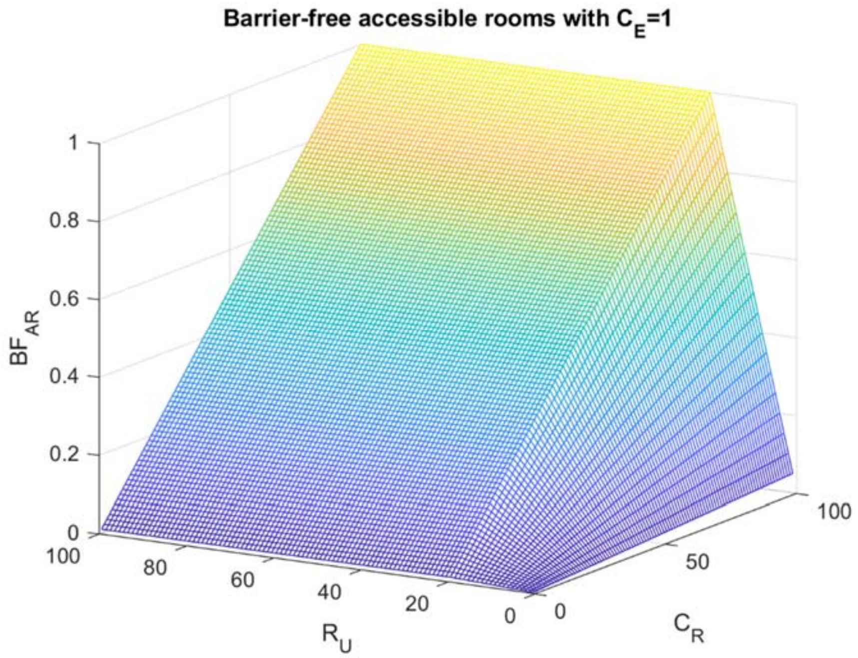
C_R ... Percentage of types of common rooms that are barrier-free. (Common rooms).

R_U ... Percentage of private rooms are barrier free. (private rooms).
Private rooms $20\% \rightarrow 1$.

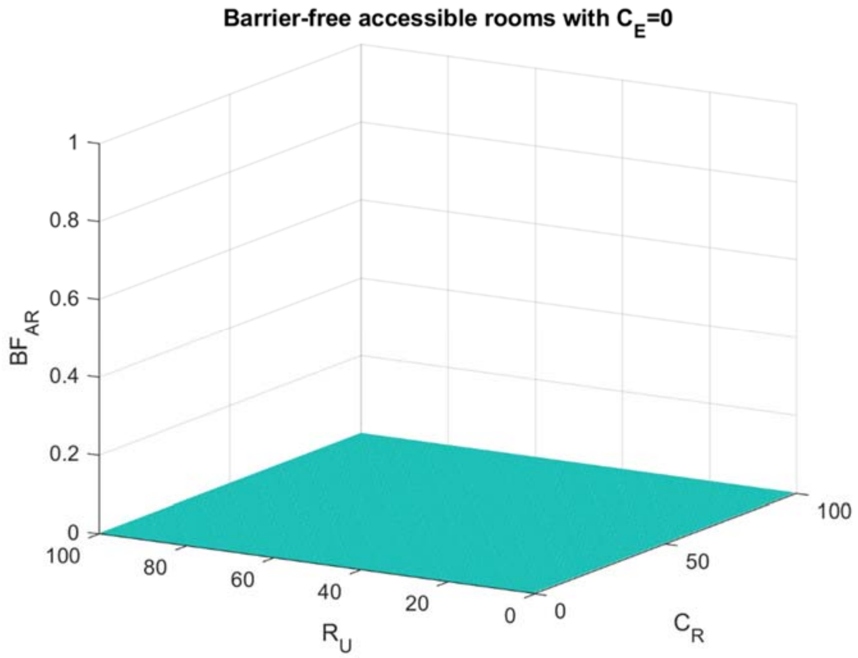
Types of common rooms $100\% \rightarrow 1$. If there are no types of common rooms, their accessibility is $C_R \coloneqq 1$.

$BF_{AR} \coloneqq C_E \cdot \frac{C_R}{100} \cdot \min(R_U \cdot 0.05, 1)$

Example: Barrier-free access YES



Example: Barrier-free access NO



4.6 CHANGEABILITY OF THE ROOM SIZE AND LAYOUT

Consideration

The flexibility in relation to rooms is assessed. A distinction is made between flexible use and flexibility of the rooms themselves. Bathrooms, WCs and functional areas (boiler rooms, stairwells, elevators etc.) are excluded.

Rooms are defined as: closed rooms with assigned functions, niches that are not clearly separated but have assigned uses and outdoor spaces as soon as functions are recognizable (e.g. terrace & entryways).

Flexible rooms are rooms which can be expanded or divided, for example through the addition of modules.

Rooms with flexible use are rooms where their interior can be changed to allow flexible uses, for example through multifunctional furniture (fold-up beds) or moveable partitions.

Measurement

For each room it is determined:

- Is the room flexible? (e.g. flexible walls, expandable modules)
- Does the room have flexible use? (e.g. multifunctional furniture)

Assessment

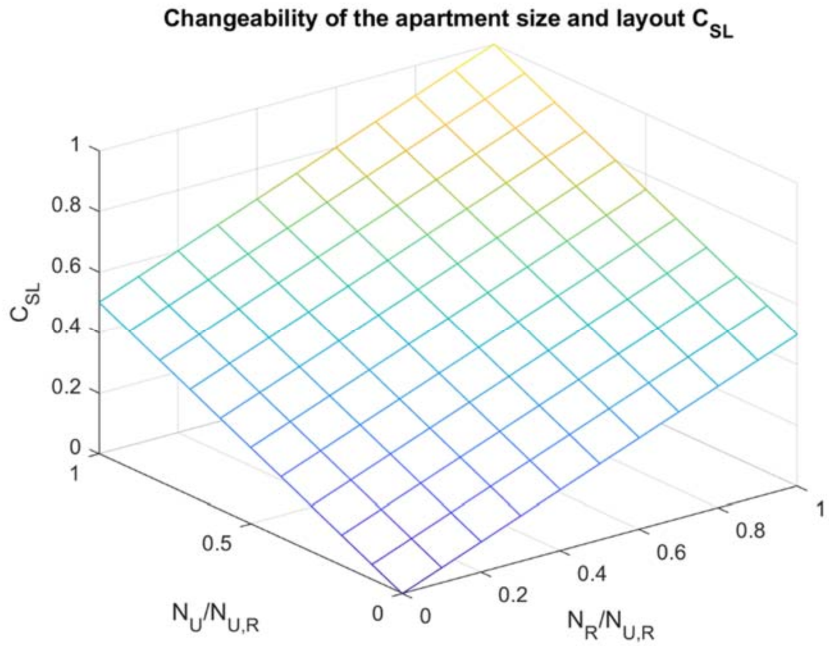
For each room it is determined:

- Is the room flexible? (e.g. flexible walls, expandable modules) YES or NO. YES $\rightarrow 1$. NO $\rightarrow 0$
- Does the room have flexible use? (e.g. multifunctional furniture) YES or NO. YES $\rightarrow 1$. NO $\rightarrow 0$

3.11.1 Definition **C$_{SL}$** (Changeability of the room size and layout)

- $N_R \ldots$ Number of flexible rooms.
- $N_U \ldots$ Number of rooms with flexible use.
- $N_{U,R} \ldots$ Total number of rooms of rooms. (exclusion of bathrooms, WC, functional areas)

$$C_{SL} := \frac{N_R + N_U}{2 \cdot N_{U,R}}$$


Changeability of the apartment size and layout C_{SL}
C_{SL}
1
0.8
0.6
0.4
0.2
0
$N_U/N_{U,R}$
1
0.5
0
$N_R/N_{U,R}$
0
0.2
0.4
0.6
0.8
1

4.7 PRIVATE OPEN SPACE

Preparatory considerations

Private open space is an indispensable part of a complete housing environment consisting of *Innenhaus* (indoor space) and *Außenhaus* (outdoor space). Private open space can expand the indoor rooms and provides space for domestic and recreational activities. Qualities that define private open space are queried as following:

General mask - private open space

Accessed directly from the residential unit [Yes/No= 1/0.5].

Barrier-free access from the residential unit [Yes/No =1/0.5].

Distance from the residential unit in m and floors [directly developed/max. 6 floors, max. 100m=1/0].

Open space corresponds to minimum dimensions: balcony/loggia/terrace 1.2x2m (0.1m tolerance); Ground floor garden/tenant garden on plot: 4x3m (0.5m tolerance); Bed in community garden 1x0,5m (no tolerance) [Yes/No=1/0].

Location of open space [back to yard/side of building/front to street = 1/0,7/0,5].

Size per person depends on the type of open space: Balcony: m² per person [(0,5-2,5m²) (2,5m²=1;1,87m²=0,75 1,25m²=0,5; 0,75m²=0,3] / garden (function analogous to balcony: >25m²=1; 7,5m²=0,3) / tenant garden (function analogous to balcony: >25m²=1; 7,5m²=0,3) / bed in community garden (function analogous to balcony: >1m²=1; 0,3m²=0,3)

Measurement

Determination on the basis of planning documents according to the following assessment criteria.

Private open space within the building: balcony/loggia/terrace

If a residential unit has more than one open space of the same type (e.g. balcony and loggia), the one with the best rating will be used.

> Directly accessible from the residential unit [Yes/No 1/0.5].
>
> Barrier-free access from the residential unit [Yes/No = 1/0].
>
> Distance from the housing unit in m and floors [directly developed/max. 6 floors, max. 100m=1/0].
>
> Corresponds to minimum dimensions of 1.20m x 2.0m, tolerance of 0.1 m [Yes=1, No=0].
>
> Location of open space [back to yard/side of building/front to street= 1/0,7/0,5].
>
> Size per person balcony/loggia/terrace: m² per person [(0,5-2,5m²) (exemplariliy: 2,5m²=1;1,87m²=0,75 1,25m²=0,5; 0,75m²=0,3].

Private open space: ground floor garden/house garden/tenant garden on plot

If a housing unit has more than one open space of the same type (ground floor garden and tenant garden on the plot), the one with the best rating will be used.

Directly accessible from the residential unit [Yes/No 1/0.5].

Barrier-free access from the residential unit [Yes/No = 1/0].

Distance from the housing unit in m and floors [directly developed/max. 6 floors, max. 100m=1/0].

Corresponds to minimum dimensions of 5.0 x 4.0 m, Tolerance of 1 m [Yes=1, No=0].

Location of open space [back to yard/side of building/front to street= 1/0,7/0,5].

Size garden/tenant garden: m² per person [function analogous to balcony: >25m²=1; 7,5m²=0,3].

Private open space: Bed in community garden on plot

Directly accessible from the residential unit [Yes/No 1/0.5].

Distance from the housing unit in m and floors [directly developed/max. 6 floors, max. 100m=1/0].

Corresponds to minimum dimensions of 0.5 x 1 m, no tolerance of 1 m [Yes=1, No=0].

Location of open space [back to yard/side of building/front to street= 1/0,7/0,5].

area of the bed: m² per person [function similar to balcony: >1m²=1; 0.3m²=0.3].

Definition $\boldsymbol{OS_P}$ (Open spaces private)
Subprocesses

a) level of the residential unit:

1. Balcony/loggia/terrace (very similar in use).

Ground floor garden/house garden/tenant garden on plot.

Bed in community garden on plot.

$v_{i,j}$ ... Value of the sub-indicator for $i = 1 \rightarrow$ Balcony/loggia/terrace, $i = 2 \rightarrow$ Ground floor garden/house garden/tenant garden on plot, $i = 3 \rightarrow$ Bed in community garden on plot and j stands for a subgrouping e.g. at $i = 1 \rightarrow$ applies to $j = 1 \rightarrow$ balcony, $j = 2 \rightarrow$ loggia, $j = 3 \rightarrow$ terrace.

Definition of $\boldsymbol{v_{i,j}}$

Input

$C_d(x_d, n_f)$ ... Distance to the residential unit (directly accessible $\rightarrow 1$); x_d ... Walking distance $x_d = 100\ m \rightarrow 0$. n_f ... Number of floors to the open space $n_f = 6 \rightarrow 0$.

$C_s(l_1, l_2)$ ... Shape of the open space. (minimum side lengths).

C_{bf} ... Barrier-free accessible. $Yes \rightarrow 1$. $No \rightarrow 0.5$.

$C_o(o_i)$ ... Location of the open space. o_i ... Orientation of the open space. $i = 1 \rightarrow$ back in the yard. $i = 2$ ... on the side of the house. $i = 3$ ... in front to the street. $C_o(o_1) \coloneqq 1$; $C_o(o_2) \coloneqq 0.75$; $C_o(o_3) \coloneqq 0.5$.

$C_a(x_a)$ ... Area of open space per user. x_a ... Area per user (suggestion: number of users for which the housing unit was designed).

Definition of the mappings.

$v_{i,j} \coloneqq C_d \cdot C_s \cdot C_o \cdot C_{bf} \cdot C_a$

$v_i \coloneqq \max_{j=1,\ldots,n_j} (v_{i,j})$ ... Grouping of the similar open spaces over the maximum.

$V \coloneqq (v_1, \ldots, v_n)$ ... Are they individual n subprocesses v_i vectorized.

$OS_{P,k} \coloneqq \frac{\|V\|_p}{\|1\|_p}$ ... Indicator per residential unit. k ... k-th residential unit. p ... Parameters for the "Curve".

Illustration C_d

CD0_0 = 1

CD0_1 = 0.9452

CD1_0 = 0.9998

CD100_6 = 0

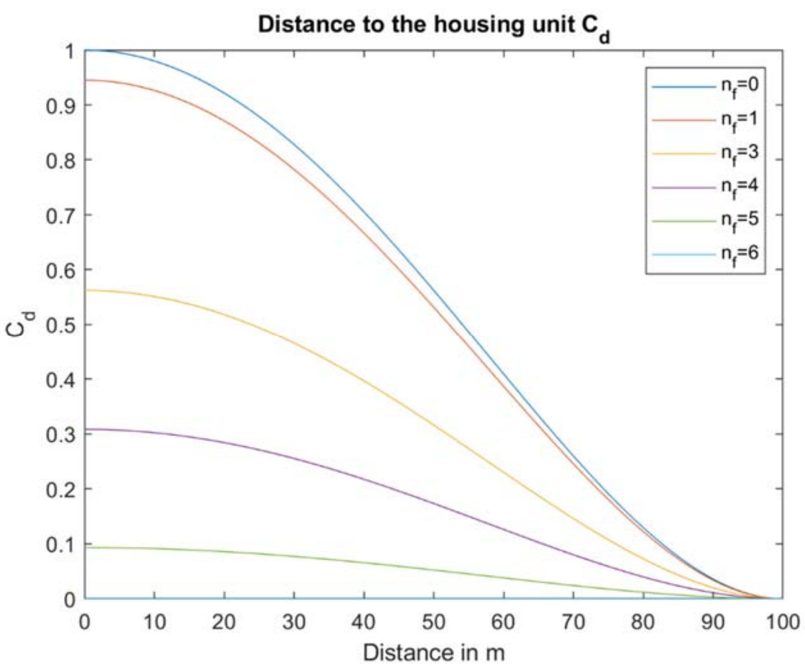
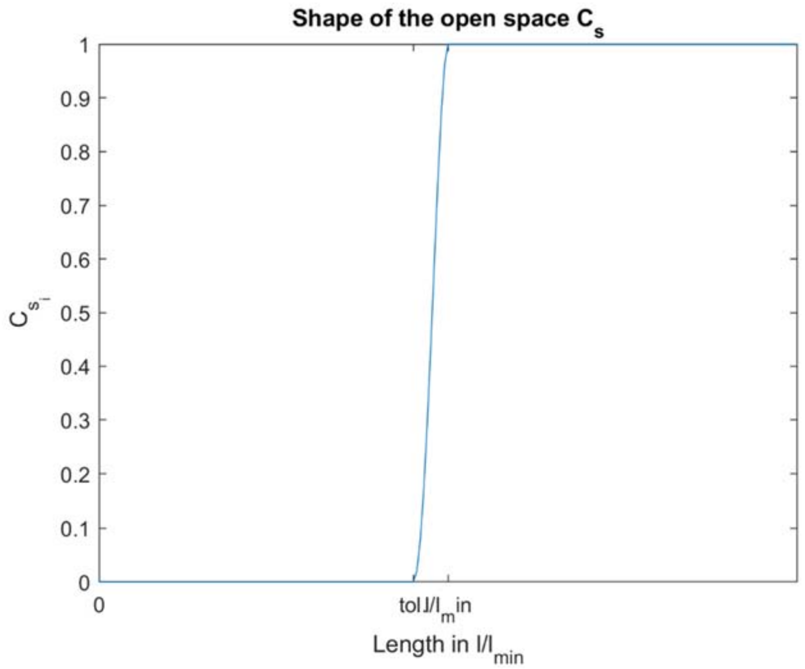


Illustration C_s

$C_s \in \{0,1\}$ Plot noch anpassen



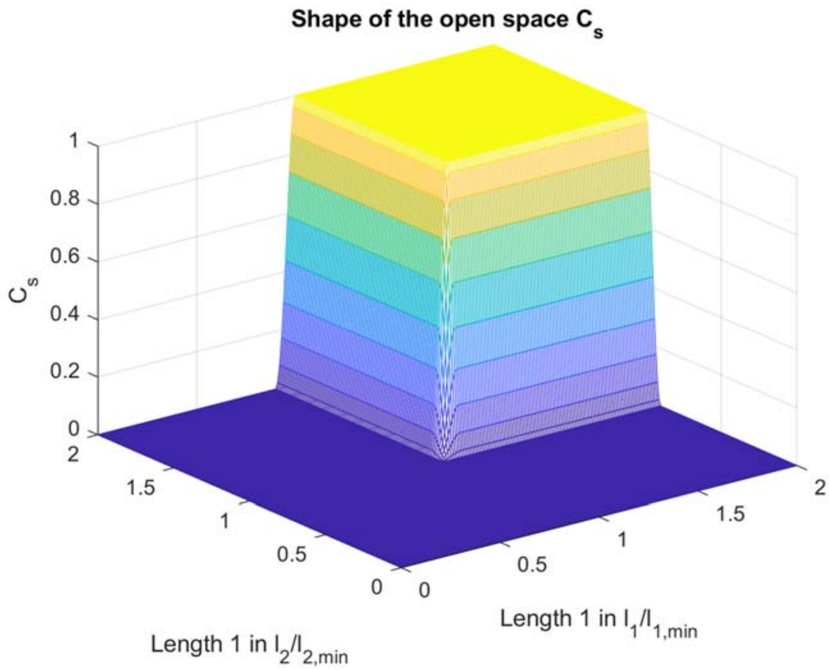
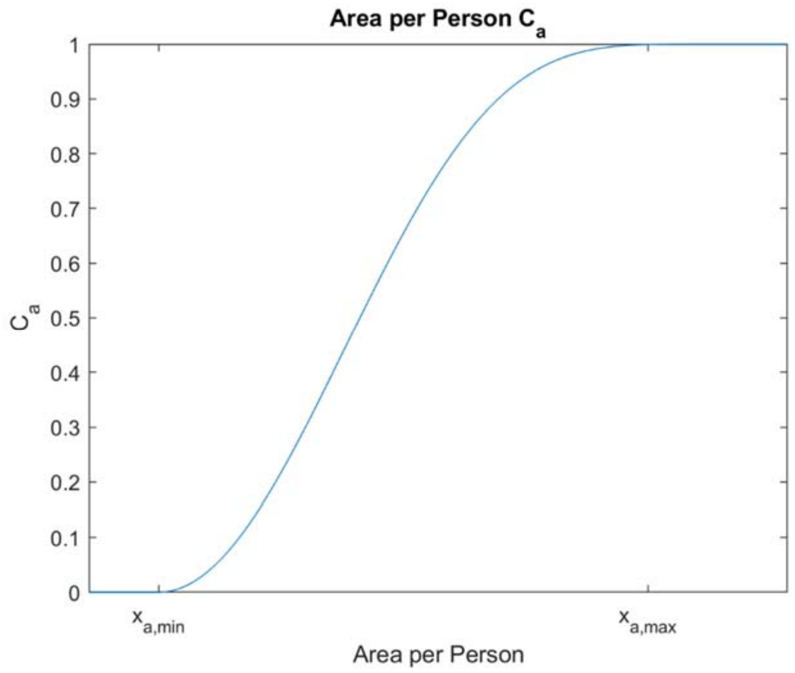


Illustration ***C*~a~**

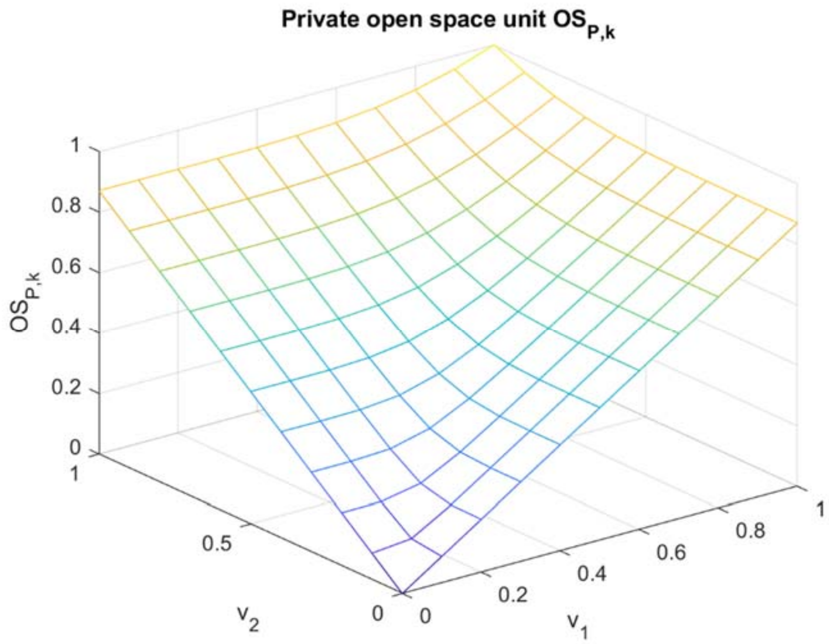


CAamin = 0

CAamax = 0.9993

Illustration $OS_{P,k}$

In the version shown, an uneven configuration of the individual open spaces is taken into account to a greater extent with regard to the better configured open spaces.



ans = 0.8027

b) Level of the building unit:

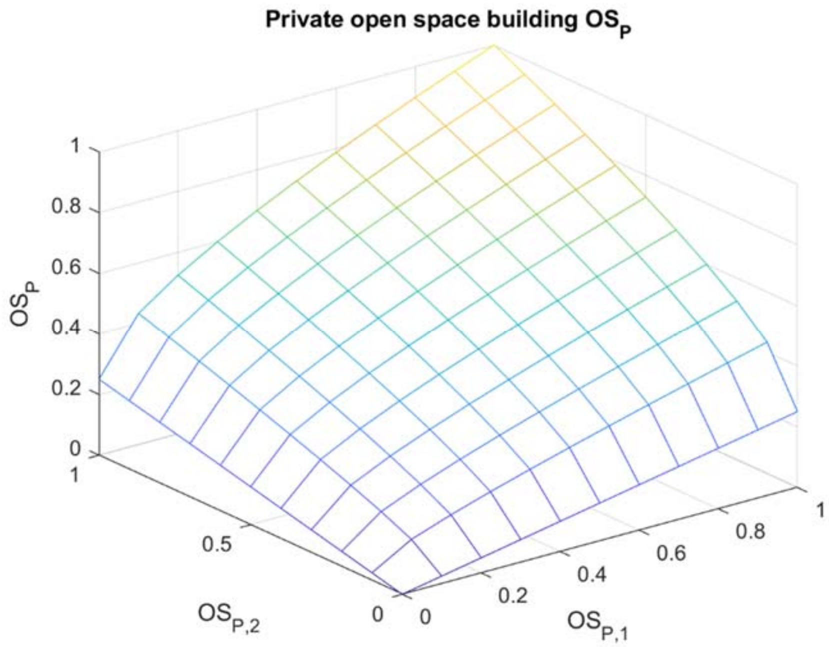
When a multi-unit building is valued, the residential unit-based view should be projected onto a building based-view.

$\overline{OS_{P,n_k}} := (OS_{P,1}, \ldots, OS_{P,n_k})$ ... Vector from the individual sub-indicators (residental units).

$$OS_P := C_{bf} \cdot \frac{\left\| \overline{OS_{P,n_k}} \right\|_p}{\left\| 1_{n_k} \right\|_p}$$

Illustration OS_P

Graphical representation only for $n_k = 2$. The behaviour in the case of differently developed $OS_{P,k}$ is maintained at higher dimensions $(n_k > 2)$. In the version shown, an uneven configuration of the individual residential units is more strongly taken into account with regard to the less well equipped residential units.



4.8 COMMUNAL OPEN SPACES

Preparatory considerations

Communal open space of multi-unit housing environments provide an important possibility of contact and interaction. Depening on the characteristics of the open space (entrance area, inner courtyard, cultivation area), different properties provide differing qualities. The different open spaces (zones) are queried and a mean values of all spaces is generated.

General mask - communal open space:

The open spaces allow a suitable use: The location, zoning, accessibility and equipment of development zones and street-oriented open spaces promote communication and encourage contact. Open spaces on the courtyard side enable appropriation through location, zoning, (reduced) accessibility and equipment [all 4 apply=1; none apply=0].

The zoning of open spaces enables a differentiated appropriation of space (different sexes, ages, cultures) [Function: Yes=1; Conditional=0.5; No=0].

There are facilities for the communal social life of the residents in the open space [Yes, there are all three=1; at least one = 0.75; no, none=0]: Facilities for gardening; Play sports or recreational facilities (playground, ball baskets / goals, etc.); seating area, get-togethers.

Size (area) of all communal open spaces [[>10m²=1; 3,5-10m²/person=0,2-1; <3,5=0;]

If there are several communal open spaces in the residential example, the mean value of all spaces is recorded.

Definition $\boldsymbol{OS_C}$ (Open spaces communal)
Subprocesses:

a) level of the communal space:

su_i ... suitable use i. $su_i = 1$ if the suitable use i applies and $su_i = 0$ if not. N ... number of suitable uses.

$SOS_1 := \frac{\sum_{i=1}^{N} su_i}{N}$ ... sub open space 1 (SOS_1)

$SOS_2 := \begin{cases} 1 \ \ if\ yes \\ 0.5 \ \ if\ conditional \\ 0 \ \ if\ no \end{cases}$ ... sub open space 2

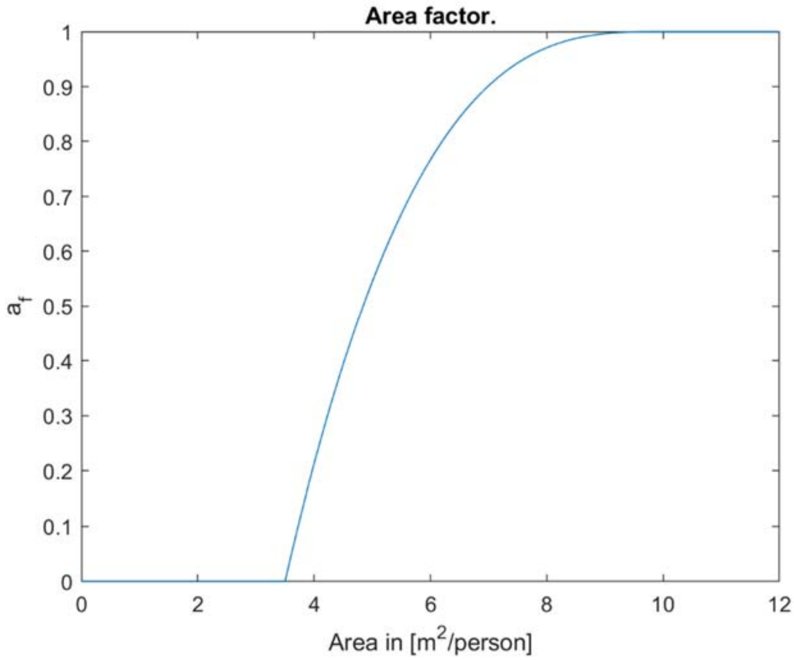
$SOS_3 := \begin{cases} 1 \ \ 3\ exist \\ 0.75 \ \ at\ least\ 1\ exists \\ 0 \ \ non\ exists \end{cases}$ ... sub open space 3

$OS_i := \frac{\left(\sum_{j=1}^{M} sos_j^p\right)^{\frac{1}{p}}}{\|1\|_p}$ ... open space j. M ... number of open spaces.

b) Level of the building unit:

a_f ... factor for the size of the areas. N ... number of open spaces.

$OS_C := \frac{\sum_{i=1}^{N} OS_i}{N} \cdot a_f$



Example evaluation of communal open space: Gapsolutely Fitting:

sos1 = 1×3

0.7500 0 0

OS1 = 0.4330

sos2 = 1×3

1.0000 0 0.7500

OS2 = 0.7217

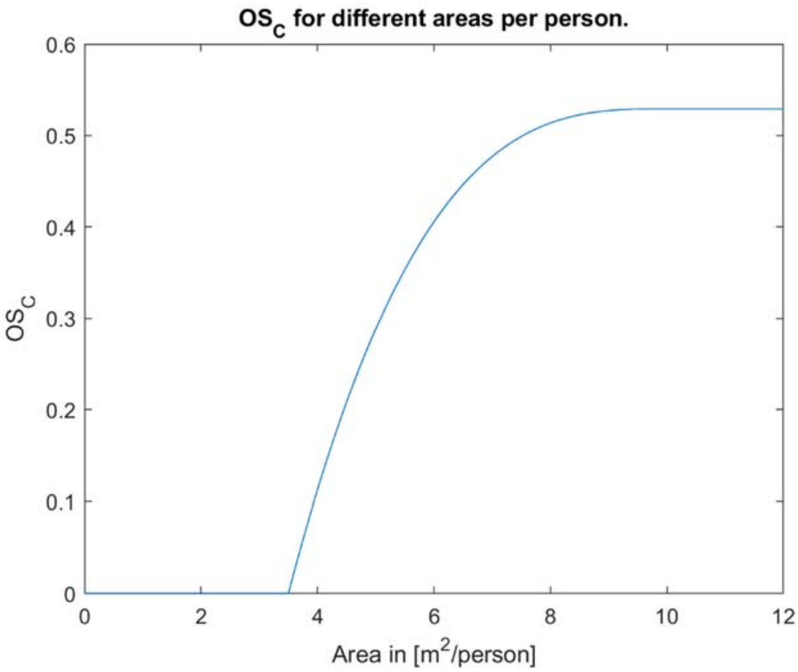
sos3 = 1×3

0.7500 0 0

OS3 = 0.4330

af = 1

OSC = 0.5292


OSC for different areas per person.
0.6
0.5
0.4
0.3
0.2
0.1
0
OSC
0
2
4
6
8
10
12
Area in [m2/person]

4.9 OPEN SPACES OF AREAS WITH MIXED USE

Preparatory considerations.

This indicator applies always. If there are no outdoor spaces of uses other than residential (e.g. Storage Room, Co-Working Space, etc.), therefore (part of the) open space that is intended for all users (not only residents), it depends on if it would be suitable/required to have one (=0) or if not (=1, thus the requirements are met). If such spaces exist, each of them are queried.

Is composed of:

There is a direct connection between the interior spaces of the use and the open space associated with them [Yes=1; No, you have to go through "communal open space" or "private open space"=0].

The zoning of the open spaces allows a differentiated appropriation of space (different genders, ages, cultures, etc.) [Yes/No = 1/0].

The open spaces of mixed use have mainly positive effects on the social aspects of the (open spaces of the) residents* [yes=1/neutral=0.5/no=0]

There are regulations that avoid possible conflicts between the uses of the open space. These regulations were developed together with the residents. if there are no regulations=0; otherwise: evaluation scheme analogous to "44. Partecipation - Category 2" Information + Intensity range: nothing (+0.0) to complete (+0.5) Exchange (feedback, advice, consultation) + Intensity range: nothing (+0.0) to complete (+0.3). Decision-making options (e.g. residents have voting rights on the board) + Intensity range: nothing (+0.0) to complete (+0.2)].

The open spaces of mixed use have no negative environmental impact (emissions such as odor, noise, etc.) on the areas of the residents* (private and communal use) [yes=1; partly already=0.5; no=0].

Measurment:

1. does the building need indoor spaces for uses other than housing. (is needed and is useful)? yes/no

   only then the extent of indoor spaces for uses other than housing is determined.

This procedure should lead to a standardization of the results. That means that if a model only needs one such space it should have the same possibility to reach values between 0 and 1 as a model which needs 4 or more such spaces. However, it should be distinguished whether a building does not need such a space or whether it would need such a space but simply does not have one. In the case that a building does not require such a space and would not make sense, it is assumed that if in this case no such space is available, the needs represented by this indicator are fully met and therefore the indicator is set to 1. Please do not mistake this with the case that there is no such space but it is necessary and useful. In this case the indicator is 0.

Definition AMU_P (Areas with mixed use on the plot).

$H \in \mathbb{N}_0$ Number of spaces needed.

Subprocesses:

a) level of the space:

$$C_{i,1} := \begin{cases} 1 \ \ if \ yes \\ 0 \ \ if \ no \end{cases}$$

$$C_{i,2} := \begin{cases} 1 \ \ if \ yes \\ 0 \ \ if \ no \end{cases}$$

$$C_{i,3} := \begin{cases} 1 \ \ if \ yes \\ 0.5 \ \ if \ neutral \\ 0 \ \ if \ no \end{cases}$$

$$C_{i,4} := \frac{\sum_{j=1}^{N} g_j \cdot \omega_j}{\sum_{j=1}^{N} \omega_j}.$$

ω_j ... weighting for possible services (Information $\omega_1 := 0.5$; Exchange $\omega_2 := 0.3$; Decision making $\omega_3 := 0.2$). N ... total number of possible services. $g_j \in [0,1]$ ... goodnessfactor (nothing $g_j = 0$ to complete $g_j = 1$).

$$C_{i,3} := \begin{cases} 1 \ \ if \ yes \\ 0.5 \ \ if \ partly \\ 0 \ \ if \ no \end{cases}$$

$U_i := \frac{\|C_i\|_p}{\|1\|_p}$, $C_i := (C_{i,1}, \dots, C_{i,5})$ ... Vector of components, U_i ... assessment of the space for use i. 1 ... n-dimensional vector with only ones.

b) Level of the building unit:

$$AMU_P := \begin{cases} 1 \ \ if \ H = 0 \\ \frac{\left(\sum_{i=1}^{H} U_i^p\right)^{\frac{1}{p}}}{\left(\sum_{i=1}^{H} 1\right)^{\frac{1}{p}}} \ \ if \ H \in \mathbb{N} \end{cases}$$

Example

H=0

H = 0

AMU_p = 1

H=1

w = 1×3

0.5000   0.3000   0.2000

g = 1×3

1   1   1

C = 1×5

1   1   1   1   1

```
AMUp = 1
g = 1×3
   0.5000    1.0000    0.7000
C = 1×5
   1.0000    1.0000    0.5000    0.6900    0.5000
AMUp = 0.7715
g = 1×3
     0     0     0
C = 1×5
     0     0     0     0     0
AMUp = 0
H=2
g1 = 1×3
     1     1     1
C1 = 1×5
     1     1     1     1     1
g2 = 1×3
   0.5000    0.5000    0.5000
C2 = 1×5
   1.0000         0    0.5000         0    1.0000
Up = 1×2
   1.0000    0.6708
AMUp = 0.8515
```

4.10 RESIDENTIAL QUALITY IN THE DISTRICT

Preparatory considerations

This indicator measures the quality of living of the residents of the temporary building and the neighbourhood. Since it is measured on the structures of the plot, it is located here and not with the qualities of the site where it also would fit. One aspect that assessed this quality is NGFZ (Nettogeschoßflächenzahl, which can be translated by Netto-Floor-Area-Ratio (FAR).

General mask

1. The building structure on the plot corresponds to the quarter: Deviation of the NGFZ (net floor area) of the surrounding area (= building block per area on map or 50m periphery). [indicate deviation of NGFZ, for example: NGFZ+<0,5=1/NGFZ+0,5-1=0,5/NGFZ=+>1=0]

   Adequate building height (max. 6 floors) so that there is a connection between building and open space (visual and call contact)[1floor=1; 3floor=0,75;>7floor=0; 0].

   Manageable neighbourhood = number of residential units per development unit (horizontal and vertical development together). 1 residential unit=1; 50 residential units=0.5; 100 residential units=0]

   Tight foodpaths/road grid of max. 150m between footpaths is meet in order to support a positive social-spatial relationships Development grid. Here the shortest distance to a street crossing is taken [<151m=1; 195m=0,67; 300m=0]

   Tract depth max. 15 m (east-west orientation) or 12 m (north-south orientation): corresponds to the maximum tract depth. To determine the lengths, the outermost points of the building are projected onto the corresponding axes. Both directions (east-west, north-south are evaluated [<15 (O-W) or <12m (N-S) wing depth=1; +3m=0.5;+>3m=0]

   The building entrance situation is clearly arranged with visual and call contact. [Yes=1; partially=0.5; no=0]

Definition $\boldsymbol{RQ_d}$ (Residental quality in the district)

$dGFZ \coloneqq NGFZ - GFZ$ ... is the difference between the GFZ of THE and the NGFZ of the neighbourhood.

$Q_1 \coloneqq \left(1 - \min\left(\max\left(\frac{dGFZ - dmin}{dmax - dmin}, 0\right), 1\right)^l\right)^k$. $dmin$ ... lower limit of the dGFZ. $dmax$ ... upper limit of the dGFZ.

$Q_2 \coloneqq \left(1 - \min\left(\max\left(\frac{nf - nmin}{nmax - nmin}, 0\right), 1\right)^l\right)^k$. nf ... number of floors. $nmin$ ... lower limit of the floors. $nmax$ ... upper limit of floors.

$Q_3 \coloneqq \left(1 - \min\left(\max\left(\frac{r_U - umin}{umax - umin}, 0\right), 1\right)^l\right)^k$. r_u ... residential units in the THE. $umin$ ... lower limit for the units of the THE. $umax$ ... upper limits for the units of the THE.

$Q_4 \coloneqq \left(1 - \min\left(\max\left(\frac{l-lmin}{lmax-lmin}, 0\right), 1\right)^l\right)^k$. l ... length between footpaths. $lmin$ ... lower limit of length. $lmax$ ... upper limit of length.

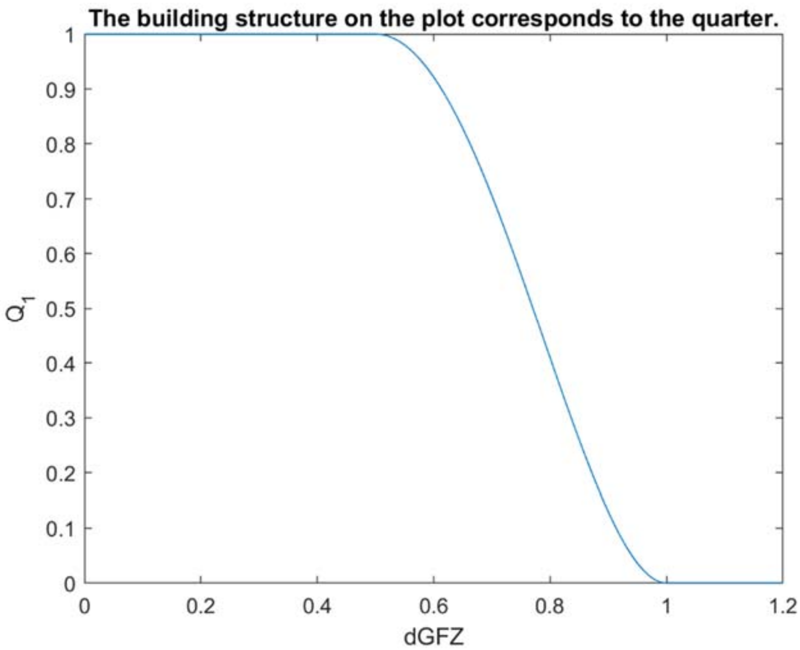
$d_{EW} \coloneqq \left(1 - \min\left(\max\left(\frac{l_{EW}-lmin}{lmax-lmin}, 0\right), 1\right)^l\right)^k$. l_{EW} ... length of the tract depth E-W. $lmin$ ... lower limit of length of the tract depth. $lmax$ ... upper limit of length of the tract depth.

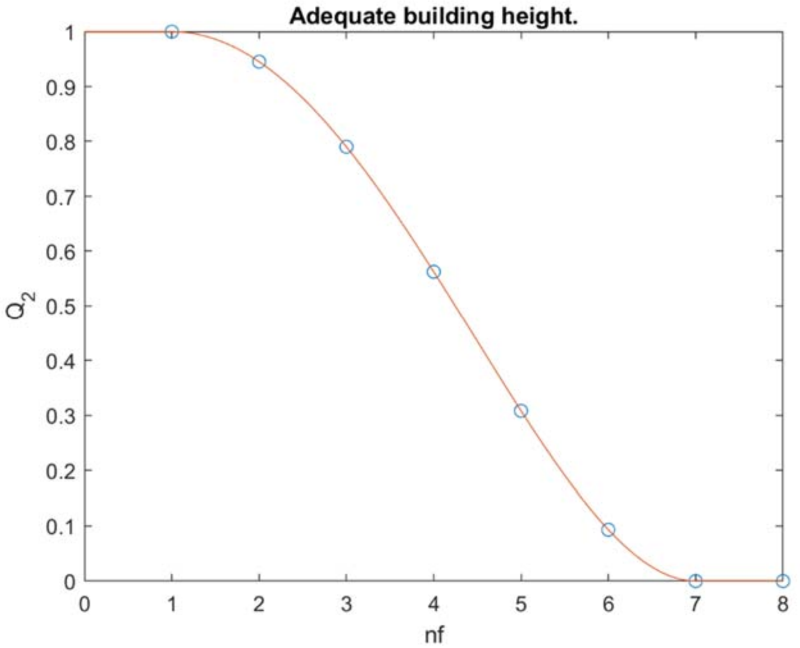
$d_{NS} \coloneqq \left(1 - \min\left(\max\left(\frac{l_{NS}-lmin}{lmax-lmin}, 0\right), 1\right)^l\right)^k$. l_{EW} ... length of the tract depth N-S. $lmin$ ... lower limit of length of the tract depth. $lmax$ ... upper limit of length of the tract depth.

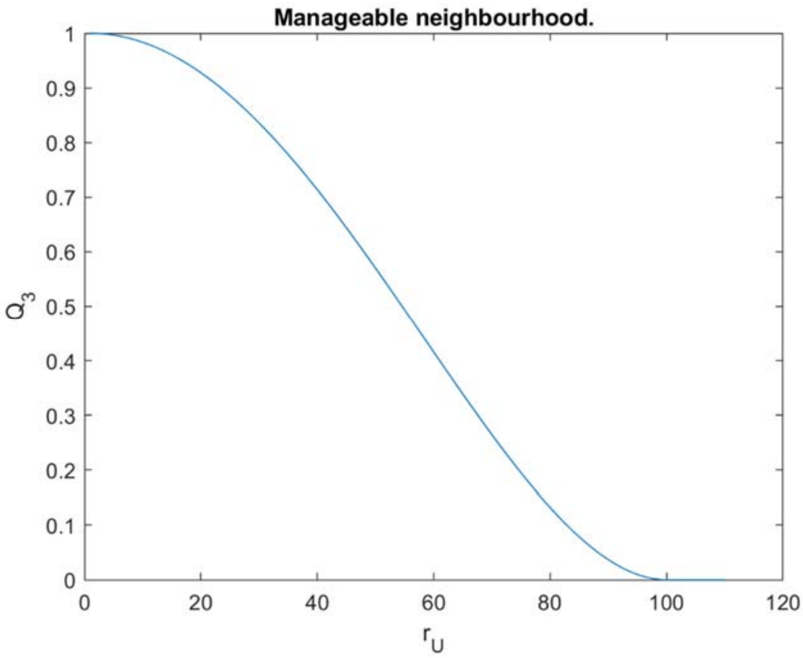
$Q_5 \coloneqq \max(d_{EW}, d_{NS})$.

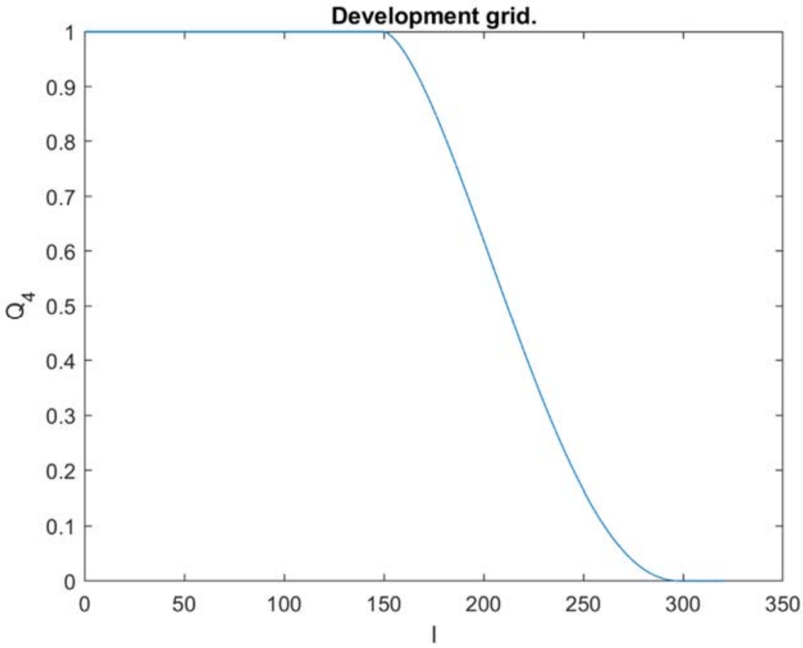
$$Q_6 \coloneqq \begin{cases} 1 \ \ if\ yes \\ 0.5 \ \ if\ partially. \\ 0\ if\ no \end{cases}$$

$RQ_d \coloneqq \frac{\|Q\|_p}{\|1\|_p}$, $\coloneqq (Q_1, \dots, Q_n)$ ... qualities, n ... number of qualities. 1 ... n-dimensional vector with only ones.

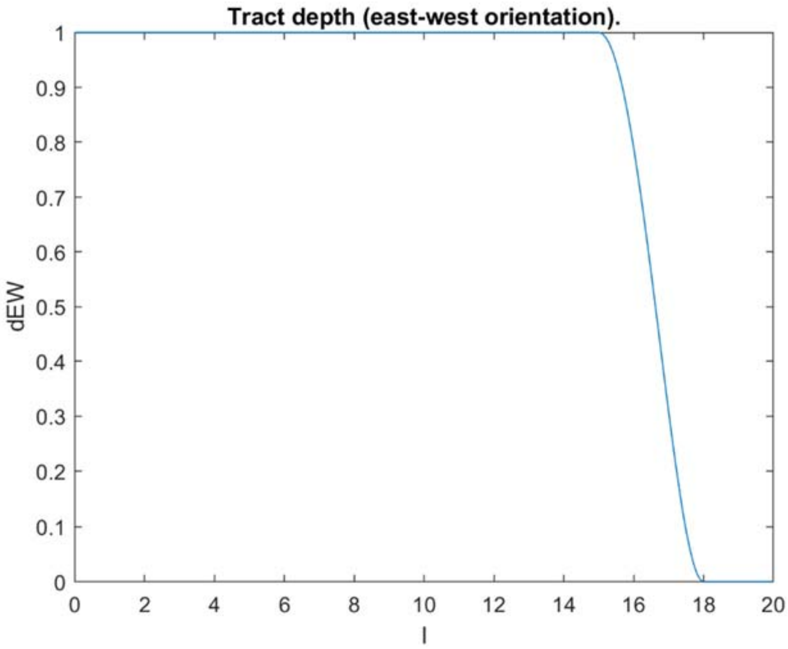


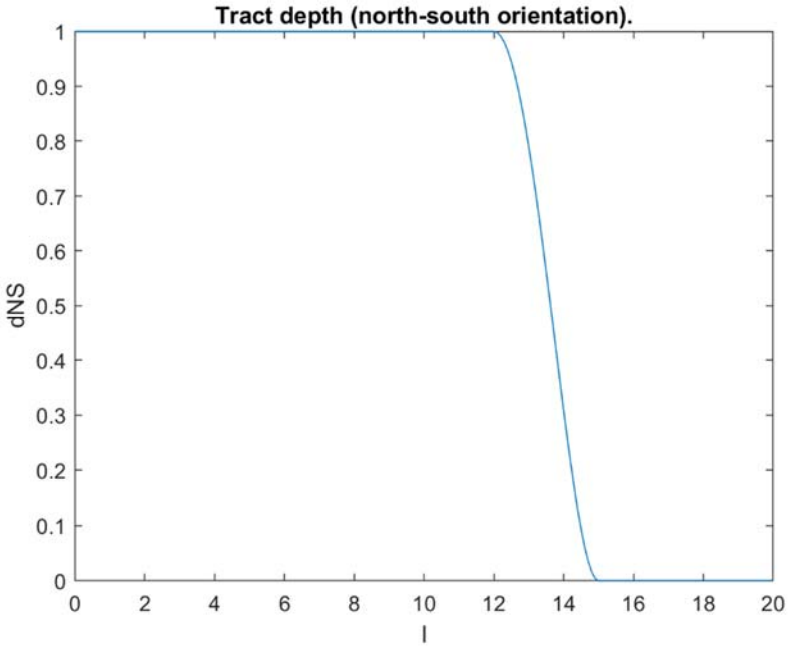

Adequate building height.
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Q2
0
1
2
3
4
5
6
7
8
nf

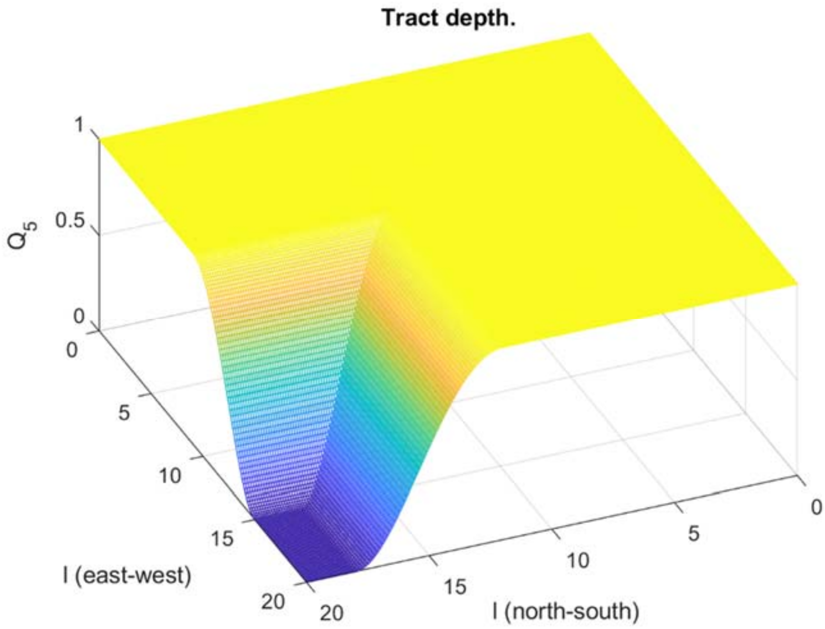

Manageable neighbourhood.
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Q3
0
20
40
60
80
100
120
rU


Development grid.
1
0.9
0.8
0.7
0.6
Q_4
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
l

Q4_195 = 0.6702


Tract depth (east-west orientation).
1
0.9
0.8
0.7
0.6
dEW
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
20
l





Tab = 6×7 table

	dGFZ	nf	rU	L	LEW	LNS	RQd
1	0.5000	1	1	150	15	12	1.0000
2	0.7500	3	1	150	15	12	0.8878
3	0.7500	3	80	200	15	12	0.6844
4	0.7500	3	1	150	17	14	0.7792
5	0.7500	3	80	200	17	14	0.5362
6	1.0000	7	100	300	18	15	0

4.11 GENDER+ AND DIVERSITY ASPECTS OF BUILT AND OPEN SPACE STRUCTURES ON THE PLOT

Preparatory considerations

Creation of equal conditions for all people, taking into account their differences resulting from their gender, cultural background, religious affiliation, age, care work, extent of employment, possible disability, living conditions and interests. The consideration of the gender+ and diversity sensitivity of temporary housing forms aims to ensure that the location, embedding, room layout and equipment of the housing project provide structures suitable for everyday use for all user groups. Structures suitable for everyday use support the users in coping with their everyday life. They are characterized by the fact that they are usable, variable in use, adaptable and allow temporary appropriation.

This success factor is based on other indicators. It is important in order to be able to make general statements about the gender+ and diversity sensitivity of the form of housing.

Proposal for the evaluation of this success factor:

[homogeneous function]

8. Effective area per person (private)
9. FacilityCategory
11. Effective Area per person (community)
12. Spaces conducive to communication
13. Barrier-free accessible rooms
14. Changeability of the apartment size and layout
35. Active mobility on the plot
37. Proximity to use-specific objects and facilities
45. Private Open Space
46. Communal open spaces
51. Residential quality in the district

Definition $\boldsymbol{GD_P}$ (Gender and diversity ... on the plot)

$v \coloneqq \left(Ea_{P_P}, F_C, Ea_{P_C}, S_{CC}, BF_{AR}, C_{SL}, AM_P, P_{OF}, OS_P, OS_C, RQ_D\right)$ ... Vector of used indicators.

$GD_P \coloneqq \frac{\|v\|_p}{\|1\|_p}$

$p = 2$

4.12 EMPOWERMENT AND TYPE OF PARTICIPATION

Consideration

From the outset, i.e. depending on the concept, our models offer different numbers of opportunities in different categories for the participation of the residents. Life Sharing to Go, for example, is strongly designed for participation, whereas Beat the Heat is much less so. Beat the Heat has more of a service character. These different conceptual starting points should not, however, have a negative impact on the measurement of the indicator.

Therefore: Assessment/measurement should only be carried out if a category (see below) actually applies, i.e. if participation in this category is possible and reasonable.

Measurement

1. does the category apply (possible & useful)? yes/no
2. only then is the extent of participation within this category determined.

This procedure should lead to a standardization of the results. This means that a model that can only offer participation in one or two categories should be able to achieve values between 0 and 1, as should a model that is evaluated in all five categories.

Assessment

Participation in:

Category 1: Construction of buildings (construction, reconstruction, dismantling, recycling)

- Does the category apply? Y/N

If Y:

- Construction Y/N (for Y +0.6) + Self assembly possible Y/N (for Y +0.4).
- Reconstruction Y/N (for Y +0.5) + Self assembly possible Y/N (for Y +0.2).
- Dismantling Y/N (at Y +0.3).
- Participation in the recycling process possible Y/N (at Y +0.1).

Category 2: (Political) participation in day-to-day operations (internally: administration, expression of opinion, self-administration)

- Does the category apply? Y/N

If Y:

-
- Information + Intensity range: nothing (+0.0) to complete (+0.5).
- Exchange (feedback, advice, consultation) + Intensity range: nothing (+0.0) to complete (+0.3).
- Decision-making options (e.g. residents have voting rights on the board) + Intensity range: nothing (+0.0) to complete (+0.2).

Category 3: Integration/inclusion activities in ongoing operations (cultural activities, music, games, sports, groups for mutual exchange, language courses, etc.)

- Does the category apply? Y/N

If Y:

Number of activities that are in principle possible/planned.

- Of which in each case: irregular/rare(0.5) to regular/frequent (1).
- Of which each: Residents must organise the offer themselves (0.5) until the offer is organised (1).

Category 4: Work in ongoing operations (repairs, cooking, organisation, cleaning work, etc.)

- Does the category apply? Y/N

If Y:

Number of possible forms of participation .

- Of which each: How many people can participate (potential participants divided by all residents).
- Of which each: residents are paid (money or other or other gratuities) or not.

Category 5: work, income opportunities and contact with "the outside world" (production, sales, storage space rental, cultural initiatives, neighbourhood initiatives, repair cafe etc.)

- Does the category apply? Y/N

If Y:

Number of possible forms of participation .

- Of which each: How many people can participate (potential participants divided by all residents).
- Of which each: residents are paid (money or other gratuities) or not. (1+paid portion)/2

Definition P_R (Participation residents)

$I_j := \begin{cases} 0, & p_j \notin T \\ 1, & p_j \in T \end{cases}$ … Characteristic Funktion. T … set of services offered

Category types

1. Discreet values with bonus: $C_i := \frac{\min\left(\sum_{j=1}^{N} I_j \cdot \omega_j + \sum_{k=1}^{M} I_k \cdot \omega_k, \sum_{j=1}^{N} \omega_j\right)}{\sum_{j=1}^{N} \omega_j}$. $\omega_j \cdots$ weighting for possible services. $N \cdots$ total number of possible services. $\omega_k \cdots$ weighting for possible bonus. $M \cdots$ total number of possible bonuses.
2. Discreet values: $C_i := \frac{\sum_{j=1}^{N} I_j \cdot \omega_j}{\sum_{j=1}^{N} \omega_j}$. $\omega_j \ldots$ weighting for possible services. $N \ldots$ total number of possible services.
3. Goodness of the realization: $C_i := \frac{\sum_{j=1}^{N} g_j \cdot \omega_j}{\sum_{j=1}^{N} \omega_j}$. $\omega_j \ldots$ weighting for possible services. $N \ldots$ total number of possible services. $g_j \in [0,1] \ldots$ goodnessfactor.

Merge:

- $C_i \ldots$ i-th Categiry.
- $H \in \mathbb{N}_0 \ldots$ Number of categories.
- $p \ldots$ degree of influence of categories not satisfied.

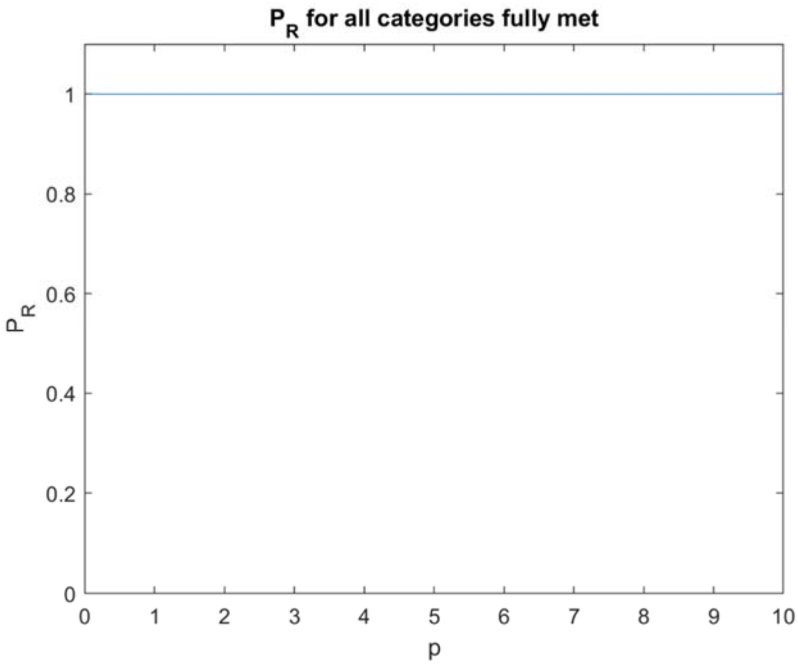
$$P_R := \begin{cases} 1 & H = 0 \\ \frac{\left(\sum_{i=1}^{H} C_i^p\right)^{1/p}}{\left(\sum_{i=1}^{H} 1\right)^{1/p}} & H \in \mathbb{N} \end{cases}$$

Example for choosing p

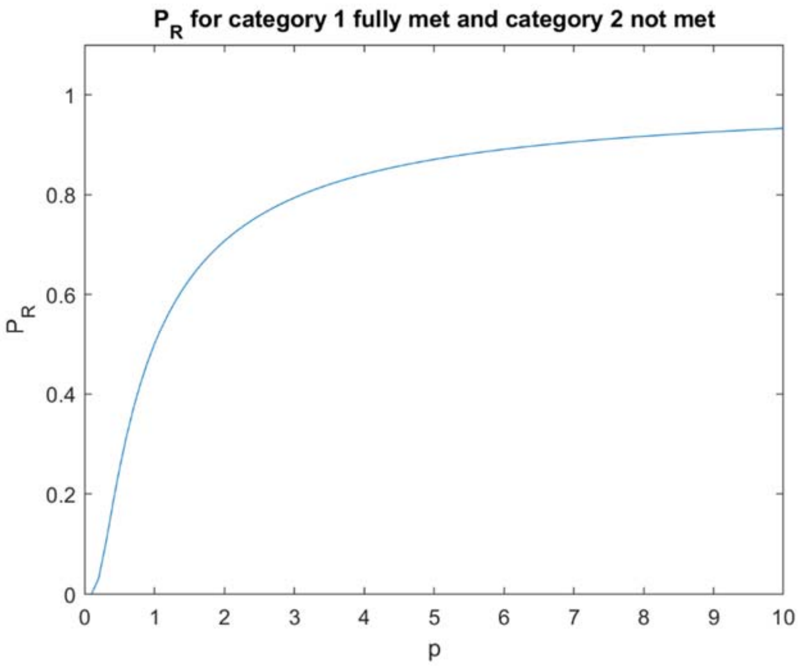
H=2, $\omega_1 := [0.6, 0.5, 0.3, 0.1]$, $\omega_2 := [0.5, 0.3, 0.2]$, I1=[1,1,1,1], g1=[1,1,1]

P = 1×100

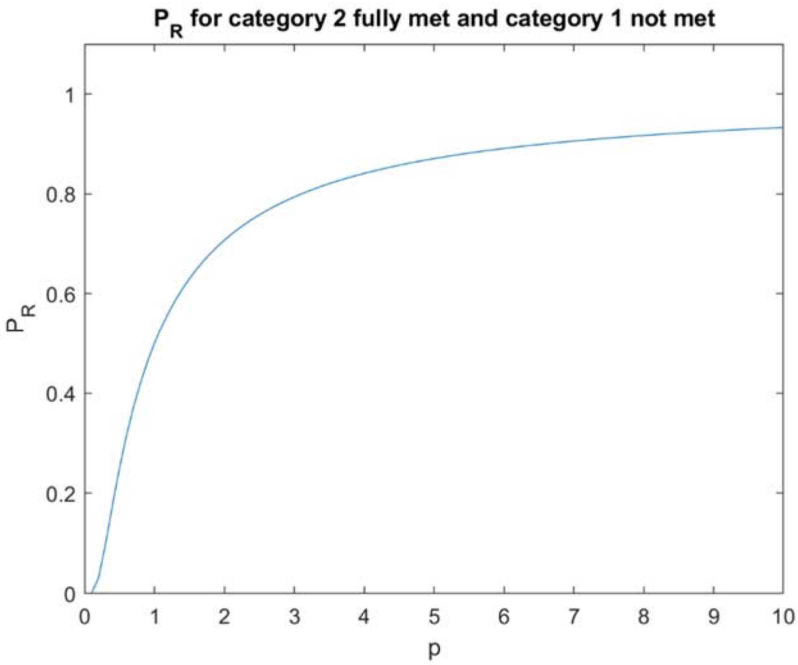
0.1000 0.2000 0.3000 0.4000 0.5000 0.6000 0.7000 ···



g1=[0,0,0]



I1=[0,0,0,0]



Example with p=2

H=2, $\omega_1 := [0.6, 0.5, 0.3, 0.1]$, $\omega_2 := [0.5, 0.3, 0.2]$, I1=[1,0,1,0], g1=[0.5,0.8,1]

PR = 0.6466

I1=[1,1,1,0], g1=[0.8,0.8,1]

PR = 0.8879

I1=[0,0,0,0], g1=[0,0,0]

PR = 0

I1=[1,0,0,0], g1=[0,0,0]

PR = 0.2828

I1=[0,0,0,0], g1=[1,0,0]

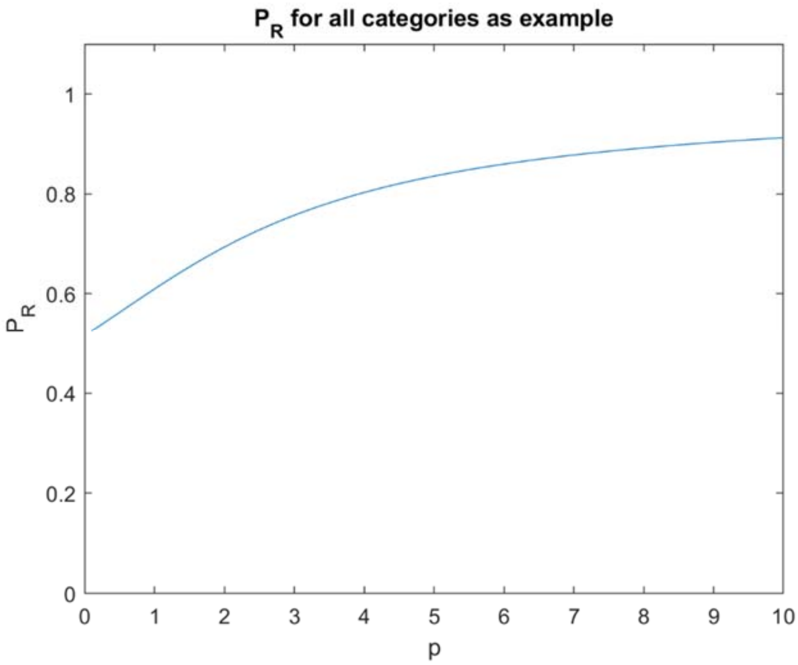
PR = 0.3536

Example

H=5, $\omega_1 := [0.6, 0.5, 0.3, 0.1]$, I1=[1,1,1,1], Ik=[0,0], $\omega_k := [0.4, 0.2]$, M=2, $\omega_2 := [0.5, 0.3, 0.2]$, $g_2 := [0.3, 0.2, 0.1]$, $\omega_3 := [1, 0.5]$, g3=[1,1], $\omega_4 := [1, 1, 1]$, g4=[1*0.5=0.5,0.5*0.5=0.25,0.2*1=0.2], $\omega_5 := [1]$, g5=[0.5*1]

g3 = 1×2

1 1



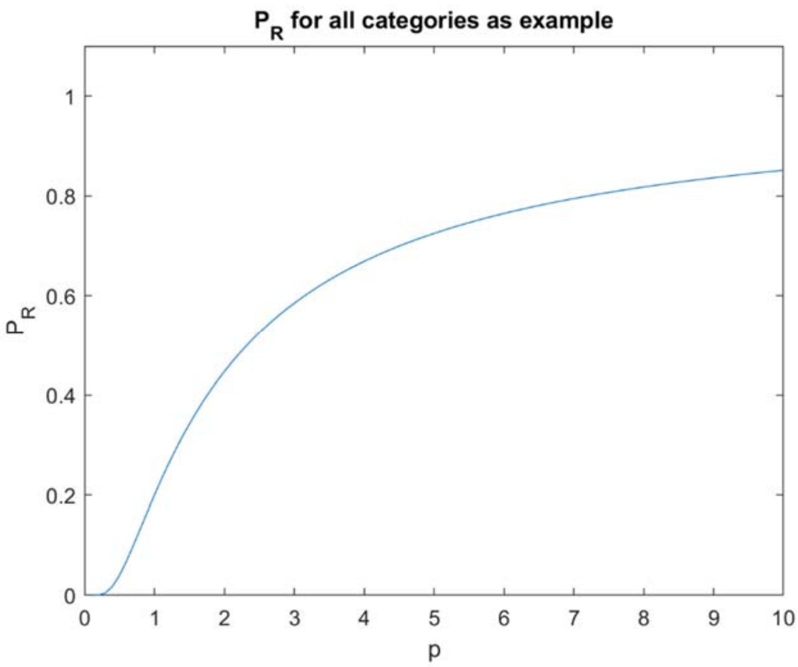
for p=2

PR = 0.6933

Example

H=5, $\omega_1 := [0.6, 0.5, 0.3, 0.1]$, I1=[1,1,1,1], Ik=[0,0], $\omega_k := [0.4, 0.2]$, M=2, $\omega_2 := [0.5, 0.3, 0.2]$, $g_2 := [0, 0, 0]$, $\omega_3 := [1, 0.5]$, g3=[0,0], $\omega_4 := [1, 1, 1]$, g4=[0,0,0], $\omega_5 := [1]$, g5=[0]

```
g3 = 1×2
     0     0
```

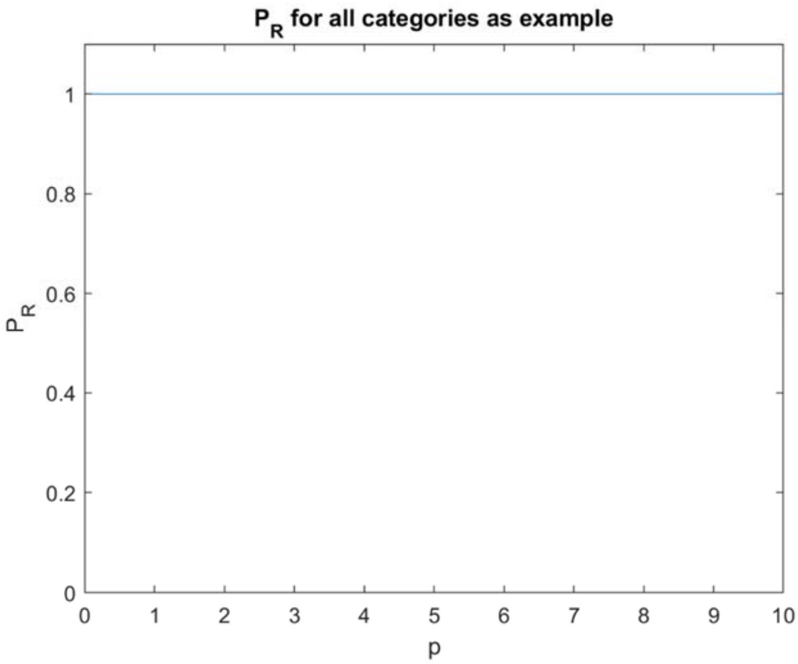


for p=2

PR = 0.4472

Example

H=1, $\omega_1 := [0.6, 0.5, 0.3, 0.1]$, I1=[1,1,1,1], Ik=[0,0], $\omega_k := [0.4, 0.2]$, M=2



for p=2

PR = 1