Definition and methods for the carbon handprint of buildings

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1 Background

Assessment of climate impacts of buildings through life cycle assessment – or whole life carbon assessment - is gaining more attention in Europe. France has already implemented those requirements for new buildings and renovation through voluntary carbon-related labels. France will also publish soon an energy and carbon regulation for new buildings with LCA-based carbon thresholds (applicable from mid-2021). The Nordic Council of Ministers have initiated a work for Nordic harmonization of building regulations concerning climate emissions (Nordic co-operation, 2020). Finland is preparing new legislation to promote low-carbon building. The target is that life-cycle-based carbon footprint regulations are applicable by 2025. In May 2020, Denmark launched a voluntary sustainability class for buildings[1], which also has been announced to become obligatory requirements in the building code in 2022. The voluntary sustainability class includes requirements for conducting LCA, but still without reference values.

To inspire the construction industry for rapid product development, the opportunity to apply the carbon handprint concept alongside the footprint concept has also come up for discussion.

The first version of the Finnish “Method for the whole life carbon assessment of buildings” defines that carbon handprint refers to climate benefits that can be achieved during the life cycle of a building and could not be created without a construction project (Kuittinen, 2019). In Finland, the planned assessment method considers the potential benefits – called the carbon handprint - in addition to carbon footprint. The issue of carbon handprint has raised much discussion in Finland. However, it is not the case in the French context, excepted for exported energy, and the term of “handprint” is not known. The use of handprint has not as such been discussed either in relation to the definition of the Danish LCA methodology for buildings for the voluntary sustainability class. However, some of the subjects that could be covered by handprint are either partly included or some ideas for how to include them in the future have been discussed.

To apply the handprint approach, common definitions and clear rules for the assessment would be needed to ensure equal treatment of different building projects and correct comparison of alternatives. The carbon handprint should also be quantifiable, and its assessment should be possible in typical construction projects. The target of this study was to collect information about potential climate benefits and discuss the needs and usefulness of the handprint concept.

The need for the handprint approach has been argued by referring to needs for motivation. To motivate building professionals and building owners and investors to voluntarily search for and implement new and ambitious solutions, they may need information about the opportunities and understanding about the potentials of different alternatives regarding both carbon footprint and carbon handprint.

1 Vejledning om den frivillige bæredygtighedsklasse May 2020. Danish Transport, Construction and Housing Authority

In general, the importance of carbon handprint thinking increases also because of its close relation to the issue of carbon neutrality. Achieving the carbon neutrality targets will require extensive measures to lower emissions. However, it will also require taking care of natural carbon sinks and searching for opportunities for artificial carbon sinks (European Parliament, 2019). In addition, all possible positive incentives to encourage the reduction of emissions will be needed. The Finnish government of Prime Minister Sanna Marin (2019) is aiming towards carbon neutrality by 2035. One of the specific climate objectives in the government´s programme is “reducing the carbon footprint of construction and housing” (Finnish Government, 2019, p. 41). The entire European Union is aiming to carbon neutrality by 2050 (Directorate-General for Climate Action, 2019), and construction sector´s role in this quest has recently been brought into focus (von der Leyen, 2019) (European Commission, 2019).

The constituents of a carbon handprint can be categorised into standard-based approaches and a group of scientific and/or emerging approaches that may be difficult to quantify or to assess in practice. While the concept of an environmental footprint is already widely known and applied, the complementary concept of a handprint, which aims to promote actions to potentially compensate for environmental footprints, is still emerging (Guillaume, 2020). However, there is already an increasing body of scientific and professional literature on the topic. Dyllick and Hockerts (2002) introduced the idea of reporting positive sustainability impacts already in 2002. UNESCO´s 4th International Conference on Environmental Education was one of the first documented uses of the term “handprint" in 2007 (Centre for Environment Education, n.d.). Generally, the handprint emphasises an entity’s positive impacts, in contrast to the negative impacts considered by the footprint concept. The both indicators measure impacts or changes in impacts for which an actor is responsible by a chain of cause and effect (Norris, 2011).

Carbon handprint has been defined in different ways. However, definitions are not always compatible with each other; and there is still confusion, e.g. about the added value of a “handprint” over a “footprint reduction” (Grönman, 2019), (Jenu, 2020). However, from the viewpoint of wider perspective, assessing a handprint can be a challenging task when quantifying the positive impact attributable to a particular action (Vatanen, 2018). A handprint also carries ethical implications related to whether and what action should be taken, by whom, and why (Guillaume, 2020). Instead of being defined as a character of a product, handprint is often dealt from the viewpoint of activities of organisations or individual people (SITRA, 2020).

To define a consistent methods and rules for the assessment of carbon handprint, several viewpoints need to be studied and discussed. The problems to be solved are much related to the complicated methodological issues of life cycle assessment (LCA). Sala et al. (2013) say that LCA methodologies should be broadened to include also positive impacts. When looking benefits for other systems, the correct definition of system boundaries, definition of the baseline for handprint assessments, and allocation rules become important. Avoidance of double counting is important. In addition, the long-term perspective is challenging when assessing the global warming potential of building products, but it may be even more challenging in the connection of carbon handprint assessment. The expected benefit may depend on the potential avoidance of impacts that take place in the distant future.

When formulating rules for the assessment of low-carbon building, it is important to define, which or what kind of sinks, improvements and/or benefits for others are considered. Carbon handprint assessment includes studying different kinds of actions that help the reduction of others' footprints; some authors even emphasize this as the primary definition of carbon handprint (Vatanen, 2018). Thus, the inclusion of social causal influences and consideration of possible alternative decisions may be important (Guillaume, 2020). Methodological proposals for the use of handprint have been developed for assessing how businesses contribute to United Nations´ Sustainable Development Goals (Kühnen, et al., 2019).

Clear quantification methods and rules will be needed for the assessment of carbon handprint in the context of coming legislation for low-carbon buildings. It is also very important to prevent the use of the approach for any king of "green washing" and unjustified claims. However, independently on legislation, carbon handprint assessment methods may be useful, because the possibility to show positive impacts may encourage the building industry for powerful climate efforts. The construction practitioners are interested in using the concept of carbon handprint; for example within the test use of Level(s) indicators in Finland, some comments were given on the need to include additional indicators, such as adaptability of spatial design, the potential for circular economy of the materials, and reporting of the positive environmental "handprint" of the project (Venäläinen, 2019).

2 Objectives

The aims of the study are:

- to make a proposal for the definition of the carbon handprint and methodologies for quantifying it. The definition and methodology should be applicable in typical design and construction projects
- to make a recommendation of which of the possible and relevant constituents of the handprint can be quantified in building projects and which are still immature for robust building-level assessments
- to make a recommendation on applicable terms assessing the usability of “carbon handprint” against other possibilities such as “potential carbon benefit” or “potential climate benefit”.

The outcome should be compatible with national assessment schemes or their drafts, EN standards and the Level(s) framework. Relevant ISO standards were also considered.

3 Methods and execution of work

This study was executed in a joint development project, were nationally selected experts worked together in Finland, Denmark, and France. The work was supervised by the representatives of:

- Ministry of the Environment, Finland
- Danish Transport, Construction and Housing Authority

The research project aimed at achieving the targeted objectives with the help of the following tasks and methods.

Study of literature

The first task of the work was to make a review of literature focusing on journal articles and scientific reports worked out in research institutes during the 2010 – 2020. The study of literature collected and compared definitions for carbon handprint, reviewed different approaches for the assessment of carbon handprint, studied different issues addressed as specific problems or key aspects of the assessment methods, discussed the applicability of different approaches and solutions especially from the viewpoint of quantification. The study of literature also searched for possible case studies focusing on building products, buildings or other products that may have similar challenges in carbon handprint assessment as buildings.

The aim of the study of literature was also to pay attention to different issues that have been either recommended or not recommended to be considered as parts of carbon handprint assessment of building products or buildings.

Study of possible handprint cases for buildings

The literature study resulted in suggesting the following possible handprint cases for buildings:

- energy positivity
- offering space for systems that supply renewable energy for others
- recycling and reuse of components and elements
- easy disassembly enabling easy recycling or reuse of components and elements
- versatility and effective use of building area
- flexibility
- compensating actions
- different kinds of improvements that lower others' carbon footprint
- carbon uptake through photosynthesis by trees and vegetation
- accumulation of soil organic carbon
- carbon storage in building products and carbonation
- low-carbon innovations such as photobioreactors.

The cases were discussed from the viewpoint of possible calculation and quantification methods if they were to be chosen as possible quantitative handprints for buildings. In chapter 5 of the report, the cases are dealt with by discussing the following subjects:

- description of the benefit – what is the assumed handprint of the case
- time frame and related problematics
- example(s) of assessment results
- uncertainties of assessment and difficulties regarding modelling and calculating quantitative results
- who benefits from this handprint
- recommendations.

The preliminary results of the study were also introduced for external LCA experts, which all are participating in the IEA EBC Annex 72 - Assessing Life Cycle Related Environmental Impacts Caused by Buildings[2]. An inquiry was carried out to find out the views of these experts on the subject matter. The results are summarized in Section 6.

2 https://annex72.iea-ebc.org/

Finally, conclusions were made based on the study of literature about the methodological approaches, suggested solutions for carbon handprint, and applicability of the proposed assessment and quantification methods. The results of the study of literature are presented in Section 7. Section 7 presents the proposals and recommendations as follows:

- a proposal for the definition of the carbon handprint and methodologies for quantifying it
- a recommendation of which of the possible and relevant constituents of the handprint can be quantified in building projects and which are still immature for robust building-level assessments.

The initial requirements for the proposals were that those are applicable in typical design and construction projects. It was also required that the outcome is compatible with national assessment schemes or their drafts, relevant EN standards and the Level(s) framework.

Study of relevant standards

Several existing standards provide guidelines or rules for the calculation of carbon handprint or savings in carbon footprint.

The European standard ”Environmental product declarations - Core rules for the product category of construction products” (EN 15804, 2019) does not define handprint, but considers benefits and loads beyond the system boundary including reuse, recovery and/or recycling potentials, expressed as net impacts and benefits. In this standard, aggregation of modules A-C impacts (cradle to grave) and module D impacts (potential benefits outside the system boundary) is not allowed. Product related carbon storages are dealt with within the system boundary. The standard defines quantification procedures for the net benefits from the reuse, recycling or energy recovery of building products and materials at their end of life (for a study period from about 30 to 60 years in the future, including product renewal during this study period). In addition, there are other standards that define assessment rules for carbon uptake through carbonation (EN 16757, 2018), biogenic and sustainably sourced bio-based carbon stored in the products and materials over the lifecycle of the building (EN 16485, 2014), (EN 16449, 2014). Furthermore, it is possible to calculate the amount of surplus renewable energy that is exported from the building and can be uploaded into the grid (based on energy certificate calculations)[3].

The work also included a study of the existing relevant standards. On the basis of this, the study summarised the presented calculation methods and made conclusions about the availability, easiness, lacks and problems of the current quantification methods considering the conclusions made by the study of literature. These results are included in Section 4 and dealt with in the context of case studies when relevant.

3 Depending on the approach chosen this does not result in credits (Step A in ISO 52000-1: no credits, Step B: credits).

4 Study of literature

Definitions and approaches

Carbon handprint or from a more general viewpoint – environmental handprint - is often defined by comparing its meaning to carbon footprint. During the two past decades, carbon footprint has become one of the most important environmental indicators. Carbon footprint usually presents the amount of CO2 and other greenhouse gases (GHGs), emitted over the full life cycle of a process or product. Initially, the idea of footprint has also had a link to the use of land; in that case carbon footprint represents the land area required for the sequestration of fossil-fuel CO2 emissions from the atmosphere through afforestation (Cucek, et al., 2012). In accordance with ISO (ISO 14067, 2018), carbon footprint of a product is the sum of greenhouse gas emissions and removals in a product system, expressed as CO2 equivalent and based on a life cycle assessment. Carbon footprint – and correspondingly also carbon handprint – is often taken as an environmental key indicator. This is partly because the alarming nature of climate change but also because carbon footprint indicates to some extend the direction of some other environmental impacts. However, by investigating the correlations between the carbon footprint and 13 other impact scores, (Laurent, et al., 2012) show that some environmental impacts, notably those related to emissions of toxic substances, often are not parallel to greenhouse gases.

Handprint – or more specifically carbon handprint – has been defined by several researchers as shown in Table 1. All definitions and characterizations refer to positive impacts in contrast to negative impacts expressed with the help of the term footprint. However, the definitions slightly differ especially in approach to consider absolute or relative impacts and to consider positive impacts within the same system.

Table 1. Definitions, statements, and descriptions for handprint / carbon handprint.

Definition / characterization	Source	Comment
Handprint encourages actions with positive impacts, connects to analyses of footprint reductions, but adds value to them, and addresses the issue of what action should be taken.	*(Guillaume, 2020)*	The study focuses on water handprint
The environmental handprint refers to the good we do for the environment. The handprint emphasises an entity's positive impacts, in contrast to the negative impacts connoted by the footprint concept.	*(Biemer, et al., 2013)*	Not limited to carbon handprint
Carbon handprint means the reduction of the carbon footprint of another actor.	*(Vatanen, 2018)*	
Handprint serves as a measure of human contribution to sustai-nability at the individual, community, national and global level just as the footprint is a measure of unsustainable human action.	*(CEE Center for environment and education, 2020)*	Not limited to carbon handprint
Your Carbon Handprint is your contribution to the environment. If we think of your Carbon Footprint as the negative impact you have on the planet, your Handprint is a record of the positive steps you take.	*(CarbonHandprint.org, 2019)*	
Carbon handprint is an indicator of climate change mitigation potential. Describes the GHG emission reduction in a customer's activities that occurs when the customer replaces a baseline solution with a handprint solution.	*(Pajula, et al., 2018)*	
Handprint is an LCA-based metric that describes the potential positive environmental impacts of a customer's (or customers') activities achieved by replacing a baseline solution with a handprint solution.	*(Pajula, et al., 2018)*	The study focuses on water handprint.
The climate benefits of a product, process or service, i.e. the emission reduction potential for the user. It can be created by a state, a company, an association and an individual. For example, when a company produces a carbon handprint for its customer, the customer is able to lower its own carbon footprint.	*(SITRA, 2020)*	
Handprints are footprint-consistent estimates of positive change. If your handprint is larger than your footprints for a given impact category, then you are NetPositive for that impact category.	*(Norris, 2015)*	Not limited to carbon handprint.
Carbon handprint of a building is an absolute climate benefit that would not be achieved without the project.	*(Kuittinen, 2019)*	
The Direct Handprint is defined as the (absolute) positive impacts that a product can bring to its intended user, due to the product's functionality and/or due to the intervention flows. The Indirect Handprint is defined as the (absolute) positive impacts that a product can bring to unintendedly affected subjects, due to the product's functionality and/or due to the intervention flows. The Relative Handprint is defined as the (relative) positive impacts that a product can bring in comparison to a benchmark, for the intended user and/or unintendedly affected subject, due to the product's functionality and/or the intervention flows.	*(Alvarenga, et al., 2020)*	Wide scope. Not limited to carbon handprint.

Handprint thinking

(Guillaume, 2020) et al. propose three defining principles of what they call handprint thinking. First, they present that the primary focus of handprint thinking is to encourage actions with positive impacts. The second principle is that although handprint thinking is connected to footprint reduction analyses, it adds value to them. The added value can be based either on specifically considering doing good, or on giving greater attention to the action itself rather than its outcome. The third is that handprint thinking emphasises the type of actions that should be taken. Handprint assessment typically needs to consider ethical implications. Thus, it is important to consider the alternative decisions that could be made, and their different consequences as explained by (Lahtinen et al., 2017).

According to (Biemer, et al., 2013), a fundamental attribute of all handprint thinking is that, in principle, there is no limit to the good you can do. With regard to the footprint, ”the best you can do is no impact, and the closer you get to that ideal the harder it gets”. Though the concept of footprint is also widened if carbon sinks are considered as negative emissions. Regarding carbon handprint, there are no principal limitations to improve. (Biemer, et al., 2013) also say that another principal difference is the strength of the handprint based on the fact that positive energy of doing good is self-reinforcing. Also (Pajula, et al., 2018) emphasize the idea that with handprints there is essentially no limit to the positive impacts that can be achieved. They propose that the purpose of carbon handprint assessment is to calculate the beneficial greenhouse gas impacts of a product when used by a (potential) customer.

While the footprint concept and footprint assessments have been extremely useful in estimating the impact of human actions on various environmental measures, neither the concept nor indicator identifies whether a footprint is reasonable or if it can be reduced. Thus, also opposite approaches are needed (Amarasinghe & Smakhtin, 2014).

The ideas of handprint and footprint were summarised by (Behm, et al., 2016) following the ideas presented by (Biemer, et al., 2013) as follows:

Table 2. Basic features related to handprint and footprint thinking.

Handprint thinking	Footprint thinking
The good we do	The harm we do
Unlimited potential	Limited resources
Recover / Restore	Reduce, reuse, recycle
Influence, educate, inspire	Admonish
Count accomplishments	Measure quantities
Appreciate, celebrate	Calculate
Advocate protection	Resist destruction
Entrepreneurism	Problem solving

(Norris, 2015) introduced the concept of being NetPositive, which means that the handprint of a company is bigger than the footprint during the same period. Every organization and product have a footprint such as carbon footprint, and it needs to be continuously measured and reduced. One key scoping question relating to NetPositive accounting of an entity (e.g. an organization) is whether the reductions in its own footprint are credited in its handprint. Norris (2013, 2015a) concludes that there are two perspectives depending on whether the existence of some organization is considered to be a legitimate part of business as usual.

(Norris, 2015) lists a range of topics which arise as we formalize handprint based NetPositive assessment:

- who/what can be NetPositive?
- life cycle scope for NetPositive assessment
- ways to create Handprints
- does reducing our footprint count as a Handprint?
- handprints are for voluntary innovation
- change and the counter-factual: defining Business-as-usual
- causing a Handprint
- shared responsibility in foot printing, shared credit in hand printing
- handprint efficiency
- three orthogonal uses of time in NetPositive Assessment: NetPositive when, Handprint timing, Duration of influence
- modes of hand printing
- handprint gratitude.

Needs and barriers for the handprint concept

(Behm, et al., 2016) say that by using handprint estimations, companies can take a proactive role in striving for climate actions. They can demonstrate leadership in addressing climate change challenges, reduction of GHG emissions and promotion of carbon neutral or low-carbon products, solutions, and services. Companies can use handprints for voluntary innovation aiming at continuous improvement of their performance in this field and for demonstrating positive impacts of their actions.

According to an interview study by (Vatanen, et al., 2018), the benefits of hand printing were considered to be multiple and ideal for internal education or process management within the company. Handprints were also considered a source of attraction for new customers and those were incorporated into branding and marketing initiatives. Communicating the benefits was considered very important and, therefore, companies should strive to make them easy and simple to understand. ”Organizations can use carbon handprints for quantifying the greenhouse gas reductions their customers can achieve by utilizing the product. Thus, the carbon handprint can be a powerful tool in communications and marketing. By conducting carbon handprint assessments, a company can also find out how their product qualifies in comparison to baseline products. Therefore, carbon handprints can also support decision making and life long product design" (Grönman, 2019).

Zuo et al. have studied barriers for carbon neutral commercial buildings (Zuo, et al., 2012). Their results showed that the lack of a clear definition of carbon neutral building presents a significant barrier in pursuit of this goal. Key success factors highlighted in their study include market demand, material selection, facility manager's knowledge, government support, and leadership.

Measures that improve carbon handprint

There are two ways to create a handprint: Preventing/avoiding footprints that would otherwise have occurred (this includes reducing the magnitude of footprints that occur, relative to what their magnitude would otherwise have been) and creating positive benefits which would not otherwise have occurred. (Norris, 2015) says that it is helpful to use the shorthand term "business as usual" (abbreviated as "BAU") to refer to "what otherwise would have occurred. Using this, we can express the two ways for creating handprints as 1) Reducing total footprints relative to BAU, and 2) Creating positive benefits relative to BAU".

In principle, similar issues improve carbon handprint as decrease carbon footprint. These include especially the following (Pajula, et al., 2018):

- replacing non-renewable or GHG intensive materials
- avoiding material use or increasing material-use efficiency
- replacing non-renewable or GHG intensive energy and fuels
- avoiding energy / fuel use or Increasing energy efficiency
- lengthening the lifetime of a product
- enabling the performance improvement of a product
- reducing waste and losses
- contributing to recycling, reuse, and remanufacture.

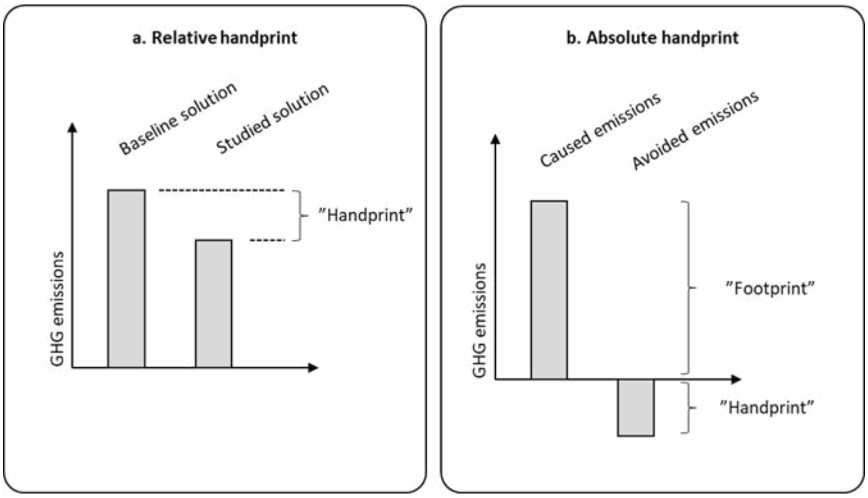
These benefits arise from replacing more harmful solutions with a less pollutive alternative. In principal, this can be done within the system/organization or for others.

In addition, carbon handprint can also be linked to absolute reduction of GHGs with the help of different kinds of carbon sinks. These include first of all carbon capture and storage that has been broadly recognised as having a significant potential in meeting climate change targets, delivering low carbon heat and power, decarbonising industry and, more recently, its ability to facilitate the net removal of CO2 from the atmosphere (Bui, 2018). In addition, as carbon harvest from forests and carbon storage in living forests have a significant potential for carbon capture and storage on a global scale (Ni, et al., 2016), the influencing actions can be treated as carbon handprints.

Absolute and relative carbon handprints, carbon neutrality and compensations

Handprints can be relative (reduction of emissions in comparison to a benchmark) or absolute (removals of carbon) (Kuittinen & Häkkinen, 2020).

Figure 1. Relative and absolute handprints.



In the current assessment method published by the Ministry of the Environment in Finland, the carbon handprint of buildings is defined/calculated as an absolute climate benefit that would not be achieved without the project. It is not a relative figure that indicates improvement in relation to market average or in relation to other benchmark value (Kuittinen, 2019). It also takes into account carbon storages and carbon sinks as issues of carbon handprint including the carbonation of concrete and biogenic carbon accumulated in wood products. As explained in Table 1, (Alvarenga, et al., 2020) also speak about direct and indirect handprints: the direct handprint is defined as the absolute positive impacts that a product can bring to its intended user, due to the product's functionality and/or due to the intervention flows while the Indirect handprint is defined as the absolute positive impacts that a product can bring to unintendedly affected subjects, due to the product's functionality and/or due to the intervention flows.

In this respect, the Finnish handprint method for buildings differs from proposals suggesting that a handprint would stand for the reduction of footprint in comparison to a baseline solution (Pajula, et al., 2018). They say that a carbon handprint can be created either by offering a solution with a lower carbon footprint than the baseline solution or by helping the customer to reduce the footprint of his processes, or both. This definition is applicable for organizations or companies that are actors that develop and offer low-carbon services and products for customers or others. However, this definition cannot be directly applied to individual buildings or building projects.

Handprint approaches are also close the approaches based on ecological compensations. Ecological compensation is a procedure whereby, for example, the disadvantage of construction to biodiversity is compensated by increasing natural values elsewhere. The addition of natural values may be, for example, the rehabilitation of traditional agricultural environments, the restoration of drained swamps or the addition of deadwood in forests. The compensation is carried out by restoring, renovating or by protecting habitats (SYKE, 2019). It is essential that the cost of compensation is paid by the actor who causes the harm to be compensated. Similarly, the term compensation could be used for actions that reduce greenhouse gases elsewhere to improve the carbon balance of an organization.

In accordance with the definition given by the European Parliament News (European Parliament, 2019) carbon neutrality means having a balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks. Removing carbon oxide from the atmosphere and then storing it is known as carbon sequestration. To achieve net zero emissions, all worldwide greenhouse gas emissions will have to be counterbalanced by carbon sequestration. Carbon sink is any system that absorbs more carbon than it emits. The main natural carbon sinks are soil, forests and oceans. According to estimates, natural sinks remove between 9.5 and 11 Gt of CO2 per year. Annual global CO2 emissions reached 37.1 Gt in 2017. Obviously, there is a need for artificial carbon sinks in addition to the utmost necessity to reduce emissions significantly.

Compensation means an emission removal unit that an operator acquires outside its own area of activity in order to offset greenhouse gas emissions from its own activities. Emission compensations are part of the mechanisms agreed in the Kyoto Climate Agreement. The EU emission trading system is an example of CO2 compensation. In the EU, the aim of the system is to ensure that emissions from the EU's emissions trading sectors (industry, energy, and European internal air traffic) maintain below the set emission limits. The system accounts for more than 40% of total EU emissions (and for example in Finland little less than 50% of all greenhouse gases) (Ministry of economic affairs, 2020). There are also voluntary mechanisms for compensating actions. Thus, these may also be dealt with as alternative ways of making carbon handprints for manufacturers and other enterprises.

In addition to many enterprises, also many cities, like the city of Helsinki, has committed to significantly reducing carbon emissions through various climate measures and achieve carbon neutrality by 2035. For instance, Copenhagen is aiming at carbon neutrality by 2025 (City of Copenhage, 2020), and Helsinki is aiming at 80 % reduction by 2035. As a general, it has been the practice in Finland to define the achieving of carbon neutrality by reducing at least 80 per cent of emissions in the urban area and then compensating, i.e. by producing the rest of the emission reductions elsewhere (Helsinki, 2018). Renewable energy policies are in central role for achieving carbon neutrality. Cities have many opportunities to adopt various energy policy measures, including small-scale renewable energy production in building premises, renewable energy integration to district heating, demand-side solutions for energy utilization, and increasing budgets and subsidies to renewable energy production and enhancement of the social acceptance of renewable energy. Such additional policies are needed to reach carbon neutrality (Dahal, et al., 2018). Handprint thinking may become important also in this context for example regarding (seasonal) surplus energy supplied by buildings or regarding energy positive buildings.

Calculation methods and assessment approaches

Although the significance of carbon footprint calculation result becomes understandable only by comparing the result with alternative products, services or processes, the calculation as such does not require the definition of alternatives. In contrary, to calculate the relative carbon handprint (when carbon sequestration is not dealt with), it is necessary to compare. According to (Pajula, et al., 2018), the carbon handprint of a product is achieved by comparing the carbon footprint of the baseline solution with that of the carbon handprint solution when used by a customer.

For example (Jenu, 2020) assesses the climate impacts of lithium ion batteries by considering the emissions savings caused by the potential use of the batteries together with PV panels by customers. The used baseline situation for customers climate impact was the use of electricity from grid. The carbon handprint is re-presented as the difference between the impact of the baseline scenario “Electricity from grid” and the alternative scenario “Solar electricity”. They assessed that there was a high potential for significant carbon handprint in those counties where the use of coal accounts for ca. 40–45% of electricity output.

According (Norris, 2015) ”There are two ways to create a handprint. In the first place we can speak about preventing or avoiding footprints that would otherwise have occurred (this includes reducing the magnitude of footprints that occur, relative to what their magnitude would otherwise have been)”. The other way is to create positive benefits which would not otherwise have occurred. With the help of this concept, it is possible to define two ways for creating handprints as follows:

- reducing total footprints relative to BAU (business as usual)
- creating positive benefits relative to BAU.

Handprint encourages actions with positive impacts, connects to analyses of footprint reductions, but adds value to them, and addresses the issue of what action should be taken.

One important question regarding to handprint is whether reducing your own footprint should be counted as a handprint. (Norris, 2015) looks the assessment of an organization’s handprint and gives the following answer:

> *”One scoping question for NetPositive accounting is whether or not an entity should get handprint credit for reductions it makes in its own footprint. Put simply, do we get credit for cleaning up our own mess? Two perspectives on this question are possible and defensible. It all depends on whether we consider the existence of the person or organization to be a legitimate part of business-as-usual.*
>
> *If we take the entity's existence as a given, then reductions to any negative impacts are a benefit for all, whether they occur within the scope of the entity's footprint or not. NetPositive from this perspective means giving more than you take or doing more good than harm.*

A second way to define NetPositive is making the world better off with you than without you. In this case, one scenario has you (or your organization) absent from the earth, while the other has you present, both polluting and making reductions in the footprints of others. If you didn't exist, then you'd have no footprint at all. So from this second perspective, you don't count reductions in your footprint as part of your handprint."

Norris (2015) accepts both perspectives as possibilities. Companies can introduce new products to the market or try to influence the demand for one of their existing products at the expense of other products on the market. In both cases the base case is a forecast of market demand and market shares, and the life cycle impacts of the products sold on that market in the years of assessment. Assessing an organization's footprint or handprint also requires that a time frame is selected. The most common time frame for assessing an organization's footprint is annual. Thus, Norris (2015) adopts this same convention in assessing the handprints of organizations and other actors. Finally, there is the question of the duration over which the influence of a change persists, in relation to business as usual. Regarding this question, Norris (2015) suggests an innovation-relevant rime horizon. The proper value for this will vary by product type and will be shorter for product types for which innovation cycle times are shorter.

Regarding to product relative handprints Norris (2015) suggests that handprints can be created by a combination of product-related factors, including:

- improving the life cycle performance of an existing product through innovation, so that demand for the product is met by an improved solution
- introducing a new product which performs better than other product(s) on the market whose demand it displaces
- increasing demand for an existing product at the expense of demand for other product(s) on the market which perform worse than the subject existing product.

The drawback of this approach is the difficulty to define clear rules for considering possible simultaneous changes in consumers' behaviour, if for example energy-saving lighting causes a rebound effect and consumers start to pay less attention to the lighting hours.

Development of collective handprints is possible through energy and environmental design (Biemer, et al., 2013). Examples are the development of wind power technologies and solar cookers. Collective handprints mean major accomplishments that have been influenced by several actors within a long period of time.

The concept of ”avoided emissions” has sometimes been used instead of handprint but rather in similar way. (Behm, et al., 2016) list criteria based on the baseline against which the avoided emissions are calculated. These include that the compared solutions must for example:

- be at the same level in the value chain
- deliver the same function to the user
- be used in the same application.

Concluding remarks for Section 4

Based on the study of literature, the concept of carbon handprint is typically associated with organizations' activities. Unlike for example carbon footprint, handprint is seldom directly associated with products or described as a characteristic of a product or service.

By searching scientific articles in Google Scholar with using terms "handprint" and "building", only few articles were found. For example (Poudyal, 2014) speaks about architect firm's creative handprint as designers can have a significant impact on buildings' GHG emissions. Research about handprint approach has focused on the description and discussion of the concept. There are only few case-specific studies available, but some of these present cases that are linked to buildings. An example of the few published case studies is written by (Vatanen, et al., 2018). They introduce examples of innovations – such as new kinds of elevators and waste management solutions - that offer potentials for their customers to decrease environmental impacts, and they deal with these as handprint creating activities.

An essential question raised is whether internal benefits can be considered as handprints or should we only consider benefits caused to others. On the other hand, carbon handprint concept is close to the concept of carbon neutrality, because there it is necessary to consider both emissions and carbon sinks.

Anyway, building projects can create carbon benefits while simultaneously inducing greenhouse gas emissions. Among these benefits are:

- "negative emissions" and carbon storage caused by carbon sequestration in trees and carbon storage in long-lasting timber products
- building's surplus energy generated with the help of decentralised renewable energy systems and supplied to grid
- external benefits that can be utilised outside the system boundary of the building project such as recycling of metals and other demolished products and simultaneous savings in carbon emissions of primary production
- benefits that can be utilised within the system boundary, if the system is enlarged, such as versatility of a building and arising opportunity to build less space and save emissions
- specific compensations - such as reforestation - covered by the project budget to improve the carbon footprint of the project.

These are more closely studied in the next section.

Rules for the consideration of sequestered carbon are defined by CEN standards. A definition is also given in the current version of the assessment method published by the Ministry of the Environment. In accordance with (EN 16485, 2014) for all product systems over the wood chain biogenic carbon balance over life cycle is zero, and contribution of biogenic CO2 to GWP over life cycle is roughly zero. The stored carbon is transferred to the next system. In accordance with (EN 16757, 2017) carbonation of concrete can be taken into account as carbon sequestration if appropriate data is available.

As the design of net zero, zero and plus energy buildings becomes more common, it also raises the question of surplus energy and alternative ways to deal with it in LCA and carbon footprint calculations. For example (Deng, et al., 2014) and (Vares, et al., 2019) discuss the application of LCA in NZEB evaluation. The European standard (EN 15798, 2011) is being revised, and the consideration of surplus energy has aroused much discussion also in this context. Different approaches have been proposed as introduced in Section 5.

The next section deals with different kinds of climate benefits that are/can be relevant for buildings. Section 5 also discusses the possibilities or needs to apply the handprint concept in the context of these benefits.

5 Alternatives for climate benefits regarding buildings

This Section presents alternative ways of doing climate benefits that would not be achieved without the project.

The alternatives which are presented and analysed here are as follows:

- carbon sequestration and long-term storage in wooden products
- carbonation of concrete
- carbon capture in the manufacture of building products
- carbon uptake through photosynthesis by trees and vegetation and accumulation of soil organic carbon
- surplus energy / energy positivity
- offering space for systems that supply renewable energy for others + surplus heat +
- versatility
- flexibility
- easy disassembly enabling easy recycling or reuse of components and elements
- recycling and reuse of components and elements
- new technologies - Photobioreactors (artificial or enhanced photosynthesis) and DAC systems
- different kinds of improvements that lower others' carbon footprint
- compensating actions.

Carbon sequestration and long-term storage in wooden products

The carbon storage because of sequestered biogenic carbon in wooden products calculated as CO2 can be considered as carbon handprint (negative CO2 emission) during the building life cycle. Eventually, this storage is either released or it continues in the next product system in the end of life. According to the standards, carbon sequestration can be considered for wood from the forests, which are operated in accordance with the certification schemes for sustainable forest management, and new growth replaces taken materials. (EN 15804, 2019) says that:

> *Biogenic global warming potential (GWP-biogenic) accounts for GWP from removals of CO2 into biomass from all sources except native forests, as transfer of carbon, sequestered by living biomass, from nature into the product system declared as GWP-biogenic.*
>
> *All carbon exchanges through the lifecycle (modules A to modules C) relating to biogenic carbon content in biomass from native forests shall be modelled under GWP-luluc ac-*

cording to the latest available version of PEF Guidance document. NOTE: Native forests exclude short term forests, degraded forests, managed forest, and forests with short-term or long-term rotations.

Removals of biogenic CO2 into biomass (with the exclusion of biomass of native forests) and transfers from previous product systems shall be characterised in the LCIA as –1 kg CO2 eq./kg CO2 when entering the product system. Emissions of biogenic CO2 from biomass and transfers of biomass into subsequent product systems (with the exclusion of biomass of native forests) shall be characterized as +1 kg CO2 eq./kg CO2 of biogenic carbon. NOTE: The amount of CO2 taken up in biomass and the equivalent amount of CO2 emissions from the biomass at the point of complete oxidation results in zero net CO2 emissions when biomass carbon is not converted into methane, non-methane volatile organic compounds (NMVOC) or other precursor gases.

In accordance with (EN 15804, 2019), information on biogenic carbon content shall be included in the EPDs of products. The biogenic carbon content quantifies the amount of biogenic carbon in a construction product leaving the factory gate, and it shall be separately declared for the product and for any accompanying packaging (EN 15804, 2019). It is expressed in terms of carbon (C) in kg[4].

The consideration of carbon storage as carbon handprint is specifically stated in the Finnish assessment method published by the Ministry of the Environment (Kuittinen, 2019). Carbon storage (expressed as negative CO2 emissions) in buildings is reported as carbon handprint while carbon footprint includes the CO2 emissions from non-renewable materials.

(Alvarenga, et al., 2020) say that in LCAs, some beneficial effects are already counter-balanced with adverse effects as it typically happens with the carbon footprint. For example, biogenic carbon dioxide sequestration is accounted for and counter-balanced with adverse effects such as fossil carbon dioxide emissions. They call this as Net Indirect Handprint, if it has a negative sign, which means a net beneficial result.

The quantity of carbon storage can be significant compared to the CO2 emissions of phases A1-A5 (life cycle phases from extraction of raw materials to building construction) (Table 3).

4 The product category rules of different operators allow the application of the older version of the standard still for some years. This means that there will probably be EPDs and data bases which include data based on the older standard version for several years.

Table 3. Carbon storage calculated for a case building (Vares, et al., 2017).
Case building: Finnish residential building (block of flats) with four floors (including the ground floor). Gross area 1922 m², net area 1402 m²). Load bearing structures in each floor either timber or concrete. Walls between flats are load-bearing. Ground floor concrete slab. The alternative buildings meet the same essential building regulations (U-value < 0,17 W/m²K, R'w > 55 dB). For exterior walls and fire separation walls in wood buildings, fire class is REI 60 (fire resistance time 60 minutes) and protecting covering meets the requirements of K210/EI15. The fire resistance time is longer (90 minutes) in the concrete building where the interior layer of exterior wall element is load bearing (150 mm). Design solutions of wood buildings are mainly based on RunkoPes2 (PuuInfo, 2020) guideline structures; concrete building design solutions are based on RT guidelines.

	Structural design solution	Carbon storage in wood products		Carbon footprint	
		t CO2e	kg CO2e/ br-m²	t CO2e	kg CO2e/ br-m²
Timber	Columns and beams	287	149	325	169
Timber	CLT-based large elements	543	283	321	167
Timber	Frame structured box unit	345	179	301	156
Timber	Frame structured large element	338	176	326	170
Timber	CLT-based box unit	574	298	310	161
Concrete	Concrete element	77	40	542	282

Also (Darby, et al., 2013) have assessed the embodied carbon using whole life cycle assessment (LCA) on a CLT building and on a more conventional reinforced concrete frame option for comparison. Regarding the assessment method, they point out that the debate is largely about timescales regarding the consideration of sequestered carbon and whether the timber resource is replaced.

Carbon can also be sequestrated in other organic products than timber such as in bamboo, straw, lake reed, cord, and hemp. (Sodagar, et al., 2010) have studied the significance of straw with using an estimate of 1.35 kg CO2 per kg straw with the moisture content of 10%. They assessed embodied and operational GHG emissions in a UK social housing project and estimated that over 15 tonnes of CO2 may be stored in biotic materials of each of the semi-detached houses, of which around 6 tonnes are sequestered by straw and the remaining by wood and wood products. They estimated that the carbon lock-up potential of renewable construction materials was capable of reducing the case study house's whole-life CO2 emissions over its 60-year design life by roughly 60% when compared with the case without sequestration.

In accordance to (Darby, et al., 2013), if forests are sustainably managed, the carbon store can be maintained at a constant level, whilst the trees removed and converted to timber products can form an additional long term carbon store. Therefore, the total carbon store in the forest and the associated ‘wood chain’ can be increased over time.

(Peñaloza, et al., 2016) have studied the effect of increased use of biobased materials in Swedish buildings using traditional and dynamic LCA. Dynamic method calculates the radiative forcing impact caused by each pulse emission on a yearly basis within a defined time window. This defines the period of time from year zero to the final year, for which the cumulated radiative forcing impact is calculated. The method treats fossil and biogenic carbon dioxide emissions and sequestration equally with the same characterization factors, as the method aims to differentiate carbon dioxide exchanges with the atmosphere according to their timing instead of source. Three alternative designs were analysed: one without biobased material content, a CLT building and an alternative timber design with increased wood content. Different scenario setups compare the sensitivity to key assumptions such as the building’s service life, end-of-life scenario, setting of forest sequestration before (growth) or after (regrowth) harvesting, and time horizon of the dynamic LCA. The study does not consider no-harvesting scenario as a reference situation – as have been suggested by (Soimakallio, et al., 2015) -, which would have been interesting because the effect of felling on growth is one of the key issues. In accordance with the results, increasing the biobased material content in a building reduces its climate impact when biogenic sequestration and emissions are accounted with using traditional or dynamic LCA in all studied scenarios. The result is sensitive to the end-of-life scenario, timing of the forest growth or regrowth and the time horizon of the integrated global warming impact in a dynamic LCA. Further climate impact reductions can be obtained by keeping the biogenic carbon dioxide stored after end-of-life or by extending the building’s service life.

The consideration of carbon sequestration as carbon handprint in building related assessment has also been criticised. (Kurnitski & Seppälä, 16.6.2020) say in their statement for the Finnish calculation method (Kuittinen, 2019) that the carbon stock of wood construction is now taken into account as a compensatory issue without taking into account the loss of carbon sink caused by the harvesting of construction wood. The idea followed in the Finnish calculation method is that new similar stands will grow into the forest, which is why the carbon storage of wood in the building is additional from an atmospheric point of view. However, the issue is rather complicated. The modelling results of the climate panel (Kalliokoski, et al., 2019) indicated that wood corresponding to one tonne of carbon would cause an average carbon loss of 1.7 tons in the forest over a period of 45 years. There is no certainty about the situation over a hundred years. The result in all cases depends, among other things, on the age structure of trees and felling methods of the stands. Kurnitski and Seppälä say that further development of models would be needed before the carbon stock credit for wood structures can be unambiguously brought into the guidelines for the assessment of low-carbon buildings.

Indeed, the essential question is, how harvesting of wood for long-term use and storage in buildings affects the carbon balance of forest and future growth of wood. The study of literature by (Häkkinen & Appu, 2013) summarises that from the viewpoint of a short time perspective covering the coming decades, the sequestration of carbon into logs used for long-lived building products is less important than the effect of harvesting on the carbon balance of forests. The positive impacts take place in situations in which the use of logs from forests causes a short-term minimum disturbance to the carbon uptake of forests and the harvesting takes place by methods and in phases, which actually enable further growth and sequestration of carbon.

(Zubizarreta-Gerendiain, et al., 2016) assessed the effects of different wood harvesting and utilisation policies on the carbon balance and economic profitability of forestry under the current and changing climate in two Finnish boreal case study areas. They considered changes in the carbon pools of living forest biomass, dead organic matter and wood products, carbon releases of harvesting, transporting and manufacturing, and reduced carbon emissions due to the use of construction wood and forest biomass-based fuels instead of fossil-intensive materials and fuels. In accordance with the study by (Zubizarreta-Gerendiain, et al., 2016) changes in the carbon pools of growing stock (living above- and below-ground forest biomass), dead organic matter (soil carbon), and wood-based products, as well as the energy consumption of wood harvesting, transporting and product manufacturing should all be taken into account, when analysing the carbon balance of forestry. (Zubizarreta-Gerendiain, et al., 2016) conclude that:

- the carbon pools of forest biomass are affected by regeneration, growth and mortality of trees
- the carbon pools of soil organic matter are affected by the mortality of trees, litter production, residuals of harvested trees and decomposition of organic materials
- the carbon pools of wood products (including fuel feedstock) depend on harvested assortments, releases of harvesting, transporting and manufacturing and life cycles of products
- the carbon balance of forestry may be improved for instance by increasing the carbon stocks of forest ecosystems and wood-based products through modifying forest management and utilisation of wood
- it is also possible to reduce carbon releases of forest industries by decreasing the capacity of energy-intensive mechanical pulping (grinding or refining) and by increasing the use of construction wood to substitute concrete and steel
- the use of thinning from above[5] instead of thinning from below has been shown to improve the carbon balance of forestry because it increases the share of saw logs in removed volume
- increasing the use of pulpwood and especially spruce pulpwood as fuel feedstock instead of pulping also improves the carbon balance of Finnish forestry.

5 Wikipedia: Thinning / Harvesting above: this crown thinning removes all of the trees that impact crown wise on other trees.

According to the results of (Zubizarreta-Gerendiain, et al., 2016), harvesting alternatives with thinning from above had considerably higher carbon balance than those with thinning from below. The first alternative led to positive carbon balance (carbon ton per hectare and year) in pine-dominated forest in current and changing climate and in spruce-dominated forest in changing climate, when carbon of wood products was not considered. In addition, the effect of wood products on carbon balance was strong. However, it is notable that substitution effect was considered by assuming a substitution rate 0.4 for sawn wood and plywood and 0.8 for biofuel meaning, for example, that the use of biofuel decreases the releases from fossil fuels by an amount which is equal to 0.8 times the carbon content of wood. Their study indicated that carbon balance of forestry is maximised by harvesting only saw log and fuel feedstock.

In accordance with (Gustavsson, et al., 2017), active forest management with high harvest levels and efficient forest product utilization will provide more climate benefit, compared to reducing harvest and storing more carbon in the forest. They claim that the climate benefit of forest carbon storage decreases with time, since net forest growth declines in aging forests, leading to diminishing removals of carbon dioxide (CO2) from the atmosphere. In contrast, the supply of forest biomass for the substitution of fossil energy and carbon intensive materials provide a continuing long term climate benefit, but with a lower average carbon stock in the forest. They analysed how Swedish national forest resources can contribute to reducing climate impact based on different options for forest management and harvest utilization. Separate simulations were made of Swedish productive forests according to three forest management scenarios: Business as usual (BAU), Set-aside (characterised especially by increase of protected areas), and Production (characterised especially by the use of faster growing trees). The current harvest level was used as reference for all scenarios. In addition, an increased harvest of forest residues was studied. They used the scenario, which estimates an increase of the mean temperature during the growing season by about 2 °C by 2100, and in the simulations this resulted in an increased forest growth of 5% after 15 years and 21% after 100 years compared to no-climate-change scenario. Forestry was modelled on the basis of growth, mortality and ingrowth. Soil carbon stock changes were also considered. Life-cycle building CO2 emissions were based on case studies of a multi-story apartment buildings constructed in Sweden. The main building alternatives were reinforced concrete frame or cross laminated timber (CLT) construction. Substitution effect was considered which somewhat complicates the understanding of the conclusions from the viewpoint of the significance of carbon storage.

(Hildén, et al., 2019) discuss carbon storages of wooden products in the context of compensation actions. They deal with it as one possible model to increase forests related carbon storage by growing wood for the use as raw material for wooden products. The way of forestry would, however, be changed by giving up clear-cutting and by increasing the volume of stand thus keeping the level of harvest continuously smaller than the total growth. Thus, the amount of sequestrated carbon increases and the forest acts as carbon sink. The model is useful, but the increase of carbon storage is naturally slower than in the context of protection of forests. The advantage compared to basic ways of forestry is also based on stopping the decrease of soil carbon storage. In the context of clear cuttings part of soil carbon is released into the air with each harvest cycle.

The so-called displacement factor has been used to describe the amount of reduced GHG emissions because of wood use, when producing a functionally equivalent product or fuel. The factor considers life-cycle GHG emissions, but it does not cover the impacts of wood harvesting on the carbon stocks of forests. (Seppälä, et al., 2019) have developed a methodology to assess the required displacement factor for all wood products and bioenergy manufactured and harvested to achieve overall zero CO2e emissions from increased forest utilization in comparison with a selected baseline harvesting scenario. The simulation of the use of domestic round wood by the Finnish forest industry indicated that planned increased wood harvesting during coming 100 years would lead to a high required displacement factor (2.4 tC/tC). According (Seppälä, et al., 2019) the average displacement factor of wood-based construction products in Finland is 1.45 tC/tC. However, they also take into account the utilization of wood residues in production and construction stages in combustion replacing fossil fuels with a factor of 0.8 tC/tC, and additionally consider the decrease of energy sector emissions by 2050 due to climate change mitigation requirements. For this reason, wood-based construction products with long time spans (over 30 years) can be assumed to have a lower end-of-life displacement effect regarding combustion in the future. Finally, they make an estimate of 1.33 tC/tC for products used in construction. They say that the results indicate that the increased harvesting intensity from the current situation would represent a challenge for the Finnish forest-based bioeconomy from the viewpoint of climate change mitigation. They conclude that further research is urgently needed to improve modelling and confirm best ways to proceed.

Regarding carbon sequestration, an interesting question is also whether the concept of carbon handprint is necessary. Basically, there is no absolute need for the use of the separate carbon handprint concept because carbon uptake and release can be dealt with as negative and positive emissions. However, the need of the carbon handprint concept may arise, when there is a specific desire to describe the availability of stored carbon in timber products to be reused/recycled in the next systems and to express that this is enabled by the building project in question. In that case, the benefit caused outside the system boundary can be calculated by comparing with a baseline that will be replaced with the help of the reuse/recycling the wooden product. As mentioned above, also (EN 15804, 2019) requires the reporting of carbon storage in environmental product declarations. However, it is expressed in terms of carbon (C) in kg.

The following table summarises the chosen perspectives of the review for carbon storage.

Table 4. Viewpoints for CARBON SEQUESTRATION AND STORAGE as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	The benefit is the uptake of carbon through the growth of wood and the possibility to store the carbon of harvested wood in building structures. An essential issue that affects the justification for the consideration of carbon uptake and storage as a benefit is connected to the effect of wood use on further growth and carbon uptake of forests. Research results indicate that the process may open opportunities for renewal of forests and enable climate benefits: "Active forest management with high harvest levels and efficient forest product utilization will provide more climate benefit, compared to reducing harvest and storing more carbon in the forest." (Gustavsson, et al., 2017). Research results by (Zubizarreta-Gerendiain, et al., 2016) indicate that carbon balance of forestry is maximised by harvesting only saw log and fuel feedstock. However, concerns about the effects of increased harvesting have also presented. Modelling results also show that from a shorter-term viewpoint, harvesting of wood causes a bigger carbon loss in the forest than is the carbon content of wood (Kalliokoski, et al., 2019). The effect of harvesting on the carbon balance of forests is essential. Current standards make a difference between native forests and other, but more attention should also be paid on methods of forestry that enable further carbon uptake and growth as soon as possible after harvesting.
Time frame and related problematics	Carbon uptake happens slowly during several decades and long before the life cycle of the building (before the building or even its plan exists). On the other hand, it is possible to store carbon for decades (or even centuries) in building structures. The significance of positive impact is sensitive to expected time frame and end-of-life scenarios.
Example(s) of assessment results	Significance of biogenic CO2 uptake compared to CO2 emissions have been assessed by several researchers. An example of assessment results by (Vares, et al., 2017) is given in Table 3. Biogenic carbon storage typically dominates the GWP value when both uptake and emissions are added up and when only phase A is considered. Many studies consider the so-called substitution effect when assessing the benefits of wood building and carbon balances. However, the consideration of the substitution effect complicates the clarity of the results as the method may exaggerate the coming benefits. This is – for instance – if the calculation does not consider the probable coming advances in cement and concrete technology which may significantly affect the global warming potential of concrete products.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	Rules for assessing and reporting GWP biogenic and carbon storage in environmental declarations have been agreed upon and standardised. However, research results show that more complicated approach and consideration of time dependences could be reasonable.
Who benefits from this handprint	Carbon storage can be calculated on product level and building level. The benefit can be allocated to the building under scrutiny.
Recommendations	There is evidence about the benefits of carbon storage in timber buildings for climate impacts. However, clearer justification based on scientific results is needed. The consideration of carbon storage as separate handprint indicator is not necessary because it can also be considered as balancing negative emissions within the concept of carbon footprint along the life cycle. However, because of different time horizon and because of shown benefits of carbon storage, separate reporting is strongly recommended.

Carbonation of concrete

According to (EN 15804, 2019), the elementary flows related to material inherent properties, such as the potential to carbonate, are considered completely and consistently in EPDs of building products.

The consideration of carbonation of concrete as carbon storage (negative emissions) and as carbon handprint is also specifically stated in the Finnish method (Kuittinen, 2019). It requires that carbonation is calculated in accordance with the rules given in (EN 16757, 2017) and its appendix BB. The environmental conditions and the type of concrete and its surface must be considered in the assessment of carbonation. The Finnish method defines the following rules for time scales: Before use (phase A), maximum 1 year; during use (phase B), design life or 50 years; after use (phase C), in accordance with applied scenarios, maximum 3 years; outside the system boundary (phase D), in accordance with the applied scenarios and Finnish legislation.

Carbonation of concrete happens as a chemical reaction of hardened cement in concrete with carbon dioxide of atmosphere during the life cycle of building and after the demolition, waste treatment and final disposal such as landfilling. Carbonation is a chemical reaction of calcium dioxide with the hydration products forming calcium carbonate. In general, carbonation is a natural chemical reaction process which occurs between atmospheric CO2 dissolved in water and the cement hydration products (e.g. calcium hydroxide, calcium silicate hydrate, and calcium aluminate hydrate, to form calcium carbonate (Kaliyavaradhan & Ling, 2017). The rate of carbonation depends on both interior and exterior factors. The interior factors include cement content, concrete strength, water-cement ratio, pore structure and degree of water saturation in the pore structure, whereas the exterior parameters include ambient temperature, relative humidity, and CO2 concentration in the atmosphere.

Carbonation leads to the decrease of pH thus reducing the chemical protection provided by the cement gel for the reinforcement. The binding of CO2 is permanent in nature as high temperatures would be required for CO2 to re-enter the gas phase. Carbonation of concrete is also a relatively slow process, which takes place over many years and gradually slowing down, because of simultaneous compaction of the pore structure of cement stone. The CO2 uptake during use stage and end-of-life can amount to 10–15 % of the weight of concrete corresponding total annual emissions from production of cement (Andersson, et al., 2019). In principle, it can replace the CO2 emissions because of the decomposition of limestone but not the CO2 emissions because of the combustion of coal to heat the cement clinker.

According to Xi, et al. (2017) calcination of carbonate rocks during the manufacture of cement produced 5% of global CO2 emissions from all industrial process and fossil-fuel combustion in 2013. Xi, et al. (2017) claim that while considerable attention has been paid to quantify these industrial process emissions from cement production, the natural reversal of the process – carbonation - has received little attention. They used new and existing data on cement materials during concrete service life, demolition, and secondary use of concrete waste to estimate regional and global CO2 uptake between 1930 and 2013 using an analytical model describing carbonation chemistry. They modelled the global atmospheric CO2 uptake by four different cement materials - concrete, mortar, construction waste, and cement kiln dust - between 1930 and 2013 in four regions (China, the U.S., Europe, and the rest of the world). Their results indicate that carbonation of cement materials over their life cycle represents a large and growing net sink of CO2. They estimate that the cumulative amount of CO2 sequestered in carbonating cement materials from 1930 to 2013 corresponds to 43% of the CO2 emissions from production of cement over the same period, when not including emissions associated with fossil use during cement production. Mortar cement sequestered the most carbon, even though only ~30% of cement is used in mortar. This is because mortar is frequently applied in thin decorative layers to the exterior of building structures, with higher exposure surface areas to atmospheric CO2 and thus higher carbonation rate coefficients. Xi, et al. (2017) also estimate that the global carbon uptake by carbonating cement materials in 2013 was approximately 2.5% of the global CO2 emissions from all industrial processes and fossil fuel combustion in the same year.

Active carbonation usually occurs under an accelerated controlled environment. With a high concentration of CO2 condition, the reaction between CO2 and calcium bearing phases of fresh concrete can occur within a few minutes to shorten the time of curing. Through active carbonation certain properties of concrete can be improved such as higher early strength and strong surface hardness, reduced the porosity and enhanced the durability of concrete (Kaliyavaradhan & Ling, 2017).

Kaliyavaradhan and Ling (Kaliyavaradhan & Ling, 2017) have studied active carbonation techniques adopted for crushed concrete aggregate and waste cement derived from the construction and demolition waste. CO2 sequestration effectiveness is affected by the original quality of concrete, particle size, and moisture content of recycled concrete aggregate, as well as the CO2 pressure, CO2 concentration and curing time applied to concrete aggregate. The potential for carbon sequestration significantly increases when the particle size decreases. Engelsen, et al. (2005) found that 60-80% of the CO2 release during calcination is reabsorbed to concrete sample with water cement ration 0.6 or higher for the grain sizes 1 – 8 mm within 20-35 days exposure. Also, the effect of carbonated recycled concrete aggregate on the mechanical properties and durability of new concrete has been reported in various studies. Kaliyavaradhan & Ling (2017) conclude that - compared to non-carbonated recycled aggregate – carbonated recycled concrete aggregate can improve the strength and durability performance of concrete. They say that recycled concrete aggregate and waste cement have been identified as potential material to sequestrate CO2 by applying an active carbonation. In addition, applying accelerated carbonation technology already in the concrete blocks industry is technically feasible because of many reasons: CO2 curing chamber can be set up in concrete block production plant, CO2 curing is preferably conducted right after demoulding of freshly pressed blocks, pressed blocks easily absorb CO2 due to their highly porous structure, and blocks are concrete products without any reinforced steel bars. For example, El-Hassan & Shao (2014) have tested that one 200-mm concrete block weighing 15 kg with 13% cement can absorb 0.47 kg of CO2.

There are different legislations regarding the use of recycled concrete aggregates. E.g. in Finland, the norms allow its use in certain limited applications, but in majority of cases the material needs to be covered with soil. This decreases or even prevents carbonation.

Carbonation during a concrete products' life cycle can be considered within the GWP values of concrete products and thus also within the GWP of the building built with the help of these products. The question of the real need of a separate handprint value arises only when looking the carbonation that happens after building's life for example during the carbonation of crushed concrete used in noise fences, concrete blocks etc. In this case the crushed concrete exists only because of the existence of the former building but the negative emissions arise outside the system boundary and can thus be allocated to the noise fence's life cycle emissions. However, there is no necessary need for the use of a baseline to calculate the benefit.

Table 5. Viewpoints for CONCRETE CARBONATION as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	The benefit is the uptake of CO2 – or part of the CO2 – that was released in the calcination of Portland cement. The sequestration happens during concrete service life and it continues after the end of life of concrete products.
Time frame and related problematics	The process depends on concrete properties and the ambient environment, and the process is normally very slow. The process is also normally unwanted for reinforced concrete structures because of the simultaneous impair the protection capacity provided by concrete for steel reinforcement. However, specific actions could be taken to increase the used on crushed recycled concrete rubble. Also, active methods of carbonation could be utilised to increase the carbon sequestration potential of concrete after end of life.
Example(s) of assessment results	Several studies have reported assessment and test results regarding the sequestration capacity of concrete and crushed aggregates made of demolished concrete structures. Even high potentials have been reported.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	Carbonation of concrete is very well-known process and there are generally used models for the quantitative assessment of carbonation and its effects.
Who benefits from this handprint	The carbon sequestration of concrete benefits concrete products as negative emissions during service life. When the carbonation happens after end-of-life, the sequestration of CO2 gives climate benefits for the products that utilise recycled concrete aggregates.
Recommendations	Carbonation itself is a well-known process which can be modelled with the help of generally accepted models. However, methods for active utilisation of the phenomenon are still rare. This makes it difficult to achieve reliable results when assessing the effects that take place outside the product life cycle.

Carbon capture in the manufacture of building products

Carbon capture and storage technologies involve the capture of carbon dioxide from fuel combustion or industrial processes (IEA, 2020). The most mature separation method in the oil and chemical industries involves absorption by chemical or physical solvents (Al-Mamoori, et al., 2017).

Carbon capture and utilisation is a broad term that covers all established and innovative industrial processes that aim at capturing CO2 – either from industrial point sources or directly from the air – and at transforming the captured CO2 into a variety of value-added products such as chemical building blocks, food/feed, synthetic fuels or materials (in particular for the building sector). Most reactions to transform the CO2 molecule require an additional energy input, which must come from a renewable low carbon source (CO2 value Europe, 2020).

Although carbon capture and storage technologies are recognised as having the potential to play a key role in decarbonising industry, broad consensus and its technical maturity, the scale of deployment is low. However, it may play an important role in the rather near future especially in the decarbonation of iron, steel and cement industry (Bui, 2018).

Norcem and Heidelberg Cement Group have established a small-scale test centre for studying and comparing various post-combustion CO2 capture technologies and determining their suitability for implementation in modern cement kiln systems. Carbon capture is energy demanding and one of the essential criterions for comparison of technologies is the energy use per ton CO2 captured. At Norcem, a considerable quantity of waste heat could be made available, therefore the capture technology's capability of utilizing this waste heat was of special interest. In addition to the energy demand, important focus areas are the capture rate, performance impact from flue gas impurities, all cost aspects and space requirement among others (Bjerge & Brevik, 2014). Also, other projects have reported results related to cement production and concrete technology. For example, a team of five companies led by CarbonCure Technologies has demonstrated integrated CO2 capture and utilisation from a cement plant kiln for subsequent use in concrete production. CO2 was captured using cryogenic CO2 capture technology. The concrete manufactured with the waste CO2 was then used in a local construction project in the Atlanta area (World Cement, 2018). Dalmia Cement has reported about a large-scale carbon capture unit in India. The project explores how CO2 from the plant can be used, including direct sales to other industries, and using the CO2 as a precursor in manufacturing chemicals (Global cement, 2020).

CO2 can be permanently bound in materials in the form of minerals through carbonation or mineralisation. This process happens in nature over geological times as seen with the formation of limestone over millions of years. CCU processes use the same basic principle as natural processes but in an accelerated manner, when CO2 is combined with calcium-rich materials to produce calcium-carbonate (CaCO3) which can be used as building material either directly (e.g. as aggregate) or after being further processed into cement. Mineral waste such as slags and ashes from the power and steel sectors or concrete from the demolition of old buildings are abundant sources of calcium that can be carbonated by captured CO2 to produce building materials, thereby reducing the need to extract fresh mineral resources from quarries (CO2 value Europe, 2020).

From the viewpoint of carbon handprint, the influence of carbon capture and storage would be included as negative emissions in the global warming potential (GWP) values of steel and concrete. Thus. there is no necessary need to bring this information as separate handprint data in the context of building level data. When the decrease of GWP is exceptional compared to a baseline, the manufacture makes a handprint with a specific and significant improvement that lowers others' carbon footprint.

Table 6. Viewpoints for CARBON CAPTURE as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	When the manufacturer is able to bring into the market exceptionally beneficial products because of CCS and thus significantly lower others' carbon footprint, results of CCS efforts can be seen as manufacturer's handprint. This requires the definition of the base case towards which the benefit is compared.
Time frame and related problematics	Carbon capture takes place in phase A1 of the building's life cycle. There are no time related problems in considering the benefit in the assessment from the viewpoint of the building's life cycle inventories. However, from the viewpoint of the actual handprint – the good done by the manufacturer – time and the change of the baseline in course of time needs to be considered. The handprint loses its significance when the solution will become more in the market.
Example(s) of assessment results	Large scale testing plans and results have been reported but the technologies are not in general use. The potentials and benefits have been assessed.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	There is no broad consensus about the maturity of the technology. However, regarding the assessment method, there are no specific problems.
Who benefits from this handprint	The carbon footprint of the product (steel or concrete) will be lower and correspondingly the carbon footprint of the building using these products. This would be the "good" induced by the handprint.
Recommendations	The recommendation is not to generally consider achievements of CCS as building level handprint as the benefit is visible in low carbon footprint result. However, in transition phases, when significantly higher investment could be required to utilize for example zero carbon concrete based on CCS, separate reporting is supported, if that helps to promote for example the use of zero carbon concrete.

Carbon uptake through photosynthesis by trees and vegetation and accumulation of soil organic carbon

According to Rackley (2017), terrestrial ecosystems play an important part in the global carbon cycle. Changes in carbon inventory and related fluxes as a result of human activity have also been a major contributor to the atmospheric [CO2] increase during industrial times. On the other hand, there is the possibility of enhancing the carbon inventory in terrestrial ecosystems as a sequestration measure. Basically, carbon storage in terrestrial ecosystems can be enhanced by increasing the flux of CO2 from the atmospheric into long-lived terrestrial carbon pools, either in or derived from plant biomass, or by reducing the rate of CO2 emissions from carbon pools in terrestrial ecosystems back into the atmosphere. Changing land use to ecosystems that sustain higher soil carbon stocks belongs to approaches to increasing soil carbon stocks.

Trees and plants bind carbon dioxide from the atmosphere through chemical connection. Carbon dioxide is stored in wood biomass as carbon compounds. About half of the dry weight of the wood is carbon sequestered from the atmosphere. In sustainable forest management, more wood grows during the year than it is being harvested. When the growth of the stands binds more carbon than felling and deforestation releases, the forest acts as a carbon sink. In Finland, it has been estimated that trees are able to uptake 4400 kg of CO_2 per hectare and per year, excluding the undergrowth (Kooijmans, et al., 2019).

Both aboveground and belowground carbon allocation take place. Up to 50% of the mono- and disaccharides (e.g., glucose and sucrose, respectively) produced by plants are delivered to the root system, where they are used to build root biomass, exuded and accessed by soil microbes. Carbon typically represents 57% by weight of organic matter incorporated into soils (Rackley, 2017).

When a forest is converted into construction land, the carbon sink of vegetation is lost. At the same time, the carbon cycle of the soil changes and part of the organic carbon in the soil can be released into the atmosphere. The conversion of arable land or meadow into a built-up area also changes the carbon stocks and carbon circulation of the soil. In Finland, the forest is converted into built land or fields approximately by 0.1 % per year (Maa- ja metsätalousministeriö, 2019). Although the low number, the issue is important because the carbon sink of forests and soil should be protected and increased in the pursuit of a carbon-neutral society. Forests are the most efficient and affordable means of carbon sequestration so far, and the international need to increase the forest sector is significant (Bastin, et al., 2019). Finland's forests sequester in average 34 million tons of CO_2 (Lehtonen, et al., 2016). In comparison to this, it has been estimated that carbon storage of the overall built environment in Finland is 83.7 million tons CO_2e which corresponds to net growth of forests during 2–2.5 years. Roughly one third of this carbon storage is in detached buildings (Vares, et al., 2017).

On the other hand, also soils in urban areas can uptake significant amounts of carbon. As cities are responsible for roughly 75% of global anthropogenic carbon dioxide emissions, this is an interesting research topic and it is important to quantify and understand the role of conserving or increasing carbon stored within urban areas in offsetting anthropogenic CO_2 emissions generated from cities (Tang, et al., 2016). According to Tang, et al. (2016), the carbon sequestration of street trees per unit area in Beijing is roughly equal to that of non-urban forests, though the annual net carbon sequestration in urban street trees across the entirety of Beijing's urban districts is equal to only 0.2% of its annual CO_2-equivalent emissions from total energy consumption. It is notable that current assessments typically consider only the carbon accumulated by trees and usually neglect the contribution from soil respiration and the emissions associated with greenery management.

According to Nowak, et al. (2013) urban trees and forests affect climate change, but are often disregarded because their ecosystem services are not well understood or quantified. The estimated rate of carbon storage per square meter of urban tree cover has been estimated to be 7.69 kg C per m^2. Storage rates per square meter of tree cover in urban areas were estimated to be slightly larger than those found within forestlands. Studies suggest that urban forests may represent an important carbon reservoir. On the other hand, Velasco, et al. (2016) claim that climate change mitigation policies based on promoting tree-planting, preservation of green spaces, and green architecture may also overestimate their GHG reduction goals if the complete biogenic component (vegetation and soil) and its associated maintenance activities are not properly considered.

Carbon footprint approach was used to assess the level of sequestration of a green belt in Leipzig, Germany. The green belt is 2.16 hectares in area, and it is partly planted with dense blocks of trees and partly open land. Also this study did not include the carbon stored below-ground. Emissions from construction were estimated to account for 4.8 tonnes of CO2 per hectare. Emissions from maintenance after 50 years ranged between 2.57 tonnes of CO2 per hectare and 4.71 tonnes of CO2 per hectare. The carbon stored in trees varies with growth and mortality, but maximum growth with low mortality stores large amounts of carbon - 226 tonnes of CO2 per hectare - while only 38 tonnes of CO2 per hectare were stored with minimum assessed growth and high mortality. However, the significance of these kinds of measures is limited because of the lack of space in urban areas. Mitigation of all emissions from residents in Leipzig for 50 years would require a total area of 14,800 hectares, which is roughly 50% of the city area (Strohbach, et al., 2012).

Carbon uptake and accumulation of soil carbon can be an important issue regarding building projects' carbon benefits / carbon handprints. Basically, this can be considered, when looking neighbourhoods or blocks of buildings. Planting trees and vegetation can affect positively (causing negative emissions) in cases when the system boundary covers the whole building site/sites and when industrial wastelands are being redeveloped.

Regarding building projects, carbon uptake by trees and vegetation can also occur as a carbon handprint or negative emissions, when forestation is done/supported as a compensating action in another place (see "Compensating actions" sivulla 80).

Regarding LCA approaches for product-scale assessment, (EN 15804, 2019) introduces an indicator Land use and land use change global warming potential (GWP-luluc):

> *"This indicator accounts for GHG emissions and removals (CO2, CO and CH4) originating from changes in the defined carbon stocks caused by land use and land use changes associated with the declared/functional unit. This indicator includes biogenic carbon exchanges resulting e.g. from deforestation or other soil activities (including soil carbon emissions). Calculation rules for GWP-luluc shall follow the latest available version of PEF Guidance document. For native forests, all related CO2 emissions are included and modelled under this sub-category (including connected soil emissions, products derived from native forest and residues). CO2 uptake related to the carbon content of biomass entering the product system from native forests is set to zero. Impacts are declared in the modules where they occur. Any biomass-based net increase in carbon stocks, including soil carbon uptake (accumulation), shall not be considered in GWP-luluc, and is set to zero. Soil carbon storage may be included as additional environmental information when proof is provided.*
>
> *NOTE: For example proof of soil carbon storage is provided when legislation provides modelling requirements for the sector such as the EU greenhouse gas accounting rules from 2013 (Decision 529/2013/EU), which indicate carbon stock accounting. GWP-luluc shall be included in GWP-total. If the contribution of GWP-luluc is < 5 % of GWP-total over the declared modules excluding module D, GWP-luluc may be provided as indicator not declared."*

Table 7. Viewpoints for photosynthesis and accumulation of soil organic carbon as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	The assumed benefit is the sequestration of carbon into growing trees and vegetation and accumulation of soil carbon.
Time frame and related problematics	The sequestration happens slowly during decades. Regarding new areas, the construction causes emissions in the beginning. The carbon uptake can vary considerable depending on environmental and management issues leading to different kind of growth and mortality.
Example(s) of assessment results	Examples are given above.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	The assessment of soil carbon accumulation is typically not considered because of lack of knowledge and methods.
Who benefits from this handprint	The benefit can be considered building/project specifically. The benefit can take place either on building site or as a compensating action elsewhere.
Recommendations	Basically, carbon sequestration can be considered within the GWP / carbon footprint concept by adding up carbon uptake (“negative emissions”) and emissions. However, separate handprint approach is recommended because of significant differences in time frames to be considered and because of differences in the level of development of assessment methods.

Surplus energy / energy positivity

In the future, there may be energy positive buildings that supply surplus energy to grid for the use of others. This is already the case for a small number of recent buildings in Europe, efficiently designed, located in a temperate climate, and having a high potential in producing renewable energy, due to favourable contextual factors. This supply of surplus energy would not exist without the building project in question. However, although the surplus energy can be considered as ”negative energy” when looking the energy balance of the building, the surplus energy does not have ”negative emissions” and probably it is neither zero-carbon energy, but it also has a carbon footprint based on the embodied carbon footprint of - for example - PV installations if solar energy is the source of surplus energy. The surplus energy becomes CO2 negative only when it is compared to a chosen baseline such as average carbon footprint of electricity generation.

Vares, et al. (2019) compared the carbon footprint of different renewable energy systems used in Finland throughout life cycle in relation to the reduction in the carbon footprint of the operation of the building achieved through the systems. Energy simulations were made for southern Finland residential building. The comparison included the following renewable energy systems: Solar panels (thin film and polycrystalline silicon), solar collectors (flat collector, pipe collector and vacuum pipe collector), geothermal heat and batteries for the storage of electricity or water boiler heat.

By combining these systems, three different options were created: a grid-connected net zero-energy house, a grid-independent off-grid house with its own energy storage, and a grid-connected house powered by solar energy alone. A very large variation was observed in the comparison of the different options. The manufacture of a battery-powered off-grid house system caused very high emissions. The smallest carbon footprint (approximately 40 t) was in the grid-connected net zero energy house whose energy was generated by thin-film solar panels and solar collectors. Although some of the buildings were self-sufficient in energy production, none reached zero in terms of carbon footprint.

In general, the biggest drawback regarding the exploitation of renewable energy is represented by the mismatch between their production and users' consumption. "The storage would be a possible solution, but its viability consists of economic sustainability and energy process efficiency as well. The cutting-edge technologies of batteries have not still solved these issues at the same time. So, a paradigm shift towards the identification of an energy carrier as storage option, the so-called Power-to-Gas, could be the viable solution. From viability to feasibility, a mandatory step is required: the opportunity to integrate the new solution in the proven infrastructures system. Thus, the recent studies on Hydrogen (H2) enrichment in Natural Gas, demonstrating a lower environmental impact and an increase in energy performance, are the base to build the hydrogen transition in the urban environment." (Nastasi, 2015)

Wang, et al. (2017) describe future buildings so that:

- future buildings will be tied to the local ecosystems and supplies and constantly monitor their environmental impact.
- future buildings will rely on centralized and decentralized utility networks and can operate in low-resource situations.
- future buildings will adapt to function or condition changes and being connected by a multimodal transportation network.
- future building will learn occupant behaviour and provide personalized environment with minimum resource consumption.
- future buildings will consist of modular, interoperable components and embrace dynamic envelope to provide complex functions.

In order to reach a necessary matching of generation and consumption in net zero energy buildings under real time dynamic conditions, the application of intelligent predictive control schemes may be necessary. These would be based on just enough accurate simulation models and supported by easy installation, commission monitoring and networking schemes (Deng, et al., 2014).

The consideration of surplus energy as carbon handprint of the building that supplies this energy is specifically stated in the Finnish method (Kuittinen, 2019) although it is relative in nature. Basically, the CO2 benefit of the surplus energy could also be simultaneously considered in the assessment of another building project if the energy was not supplied to grid but directly to another user. Also – at least in theory – a significant amount of low carbon surplus energy supplied to grid could have an effect on the average carbon footprint of electricity which would then benefit the carbon footprint of all users of grid electricity.

In the framework of the revision of EN 15978 under CEN TC350, in 2019 and 2020, two visions of how to deal with exported energy in building LCA emerged [6].

One of the visions is supported by certain experts, mainly the representants of the construction industry. They consider that 100% of the LCA impacts of the energy producing system has to be supported by the building and that exported energy is free of impact. This is very close to the existing/previous EN 15978.

Another vision is supported by some other experts who argue that exported energy must share a part of the LCA impacts of the energy producing system, in proportion of the percentage of exported energy compared to the total production of renewable energy. The building supports the LCA impacts of the system in proportion of the renewable energy that is self-consumed [7]. A benefit may appear in module D when comparing exported energy to the substituted energy carrier. This approach is the methodology used in France, both in the energy-carbon experiment and related label (E+C-) and to the coming regulation (RE2020).

As a consequence, because no consensus was reached after discussion, the 2 visions are available in the EN 15978 draft for enquiry, the first one as a default approach, because close to the pre-existing one, and the second one as an optional approach, in an annex. This is the situation in November 2020.

Thus, in terms of benefits, both for the building on which is installed the energy supplying system and for other buildings able to use the exported energy, the LCA calculation is different, for the building LCA and for the module D. That means that handprint may be understood in 2 ways.

The exported energy used by another building or more generally another “system” can be considered as a climate benefit or handprint. This is the case where no impact is associated to exported energy. For the other approach, it is the case only if the GWP impact of on-site energy system (embodied kg CO2e per kWh produced) is lower than the GWP impact of the electricity grid. Depending on the GHG factor of the electricity grid in each country, this benefit can be negligible or high. With the decarbonation of electricity grids in the perspective of carbon neutrality in 2050, this benefit will decrease versus time.

6 The 2 documents developing arguments (from CEN TC350) are not free of dissemination.

7 Of course, the sum of these two proportions makes 100%.

A precise calculation relies on realistic assumptions:

- an hourly based simulation (for the calculation of self-consumed energy and exported one)
- a good knowledge of the technical choices regarding energy producing system and related complementary elements, compared to a building without this equipment
- specific EPDs of systems producing on-site renewable energy (e.g. PV panels) with their service life.

If correctly designed and managed, it may reduce the intensity of energy (electricity) drawn from the grid during peak hours. This system may be associated to building-related strategies of energy systems ”flexibility” or ”demand-response” adjustment, so as to limit the power drawn from the grid or to optimize a smart-grid.

Regarding this topic of surplus energy, we suggest the following indicators:

- quantity of exported energy /year
- GHG emissions associated (considering embodied carbon of system LCA)
- avoided GHG emissions when using this renewable energy instead of the electricity grid (per kWh)
- difference / balance between exported energy and imported energy from the grid, (hourly based simulation, precise rules taken from standardisation or harmonised EU method, a positive result corresponding to an energy positive building or plus-energy building.

Table 8. Viewpoints for SURPLUS ENERGY as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	A building can be an energy producer and not only an energy consumer. With new technologies, a building can produce more energy than it consumes, and can export part of the produced energy when production does not match with its needs. Renewable energy production systems can be integrated or associated to buildings and the produced energy can be split into self-consumed and exported. Without a building equipped with such systems, no energy could be exported If correctly designed and manged, it may reduce the intensity of energy (electricity) drawn from the grid during peak hours.
Time frame and related problematics	The lifetime of decentralized energy system is lower than the lifetime of the building, but if the building can offer space / roof area for supporting this system, energy can be exported.
Example(s) of assessment results	A quantitative exercise was performed under the revision work of EN 15978. Two different approaches were developed and quantified, because of contrasted opinions on which entity has to support the LCA impacts (embodied carbon) of the energy system.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	Uncertainties are linked to the calculation of the amount of exported energy (an hourly-based modelling and simulation is necessary at least). Some countries prefer an annual balance for the calculation of exported energy, that does not represent the physical reality of exported energy. An important question is also whether to allocate (or not) the embodied carbon of the system to exported energy in proportion of the ratio of exported energy / total produced energy.
Who benefits from this handprint	The receiver of the surplus energy may be a close building, a close public infrastructure, the neighbourhood, the local territory or the national grid. Regarding the studied handprint (consideration of saved emissions based on surplus energy), the climate benefit goes to the building that provides the surplus, by reducing its carbon footprint. However, for the building using this energy surplus, the benefit may be low or high according to the difference between the embodied GWP impact of the on-site energy system and GWP impact of the substituted energy (electricity grid, gas, or heat network…). Rules are needed for the calculation of the related “negative” emissions (or rather “avoided emissions”). The embodied emissions of the supplied surplus energy could be shared between the initial investor of the building and potential external users of the exported energy. From a financial point of view, the investor can be progressively reimbursed by the revenues generated by the selling of exported energy. The financial and carbon logics should be similar.
Recommendations	Basically, the recommendation is to apply the future renewed harmonized methodology (EN 15978). Here it is recommended that the saved emissions are calculated on the basis of the emissions of the substituted energy. In addition, it is recommended that the embodied emissions are allocated to energy that goes for own use and exported energy on the basis of the assessed shares.

Offering space for systems that supply renewable energy for others

In dense urban areas, where there is often lack of space for installing renewable energy production systems, available space that can be offered for use is a precious resource.

Certain building types can offer large roofs or car park areas convenient to install solar / PV panels or possibly small wind turbines: retail supermarkets, commercial centres (malls), logistic buildings, schools, gymnasiums, etc. Some of these buildings have limited needs of heat or electricity, so a large part of produced energy may be exported to close buildings or to the electricity grid (or to the district heat network). An energy loop (of electricity or heat) may be installed at the neighbourhood or city block scale to collect, manage, regulate, store, optimise and distribute this energy.

The idea behind this topic of offering space is that the neighbourhood or city block scale is often much more relevant for the production and management of local energy than the building scale. Thus, we may have plus energy neighbourhood instead of several non-interconnected plus energy buildings, leading to a carbon handprint that is maximised and optimised at the neighbourhood or city block scale. This is a strong idea supported by Alain Maugard, ex-president of CSTB, in his book "Le BEPOS[8] pour tous" (Maugard, 2015). In 2005, he created the idea of plus energy buildings, and he has promoted this concept since that date.

There are 2 ways of considering this topic of "offering space":

- The owner (or developer) of the building under study, or an external energy operator, may install more renewable energy equipment compared to what would be normally designed for this building, because there is available space for installing more, leading to a mutualisation of energy sources at the neighbourhood scale,
- The building under study is for instance a residential high-rise building with limited roof area. If there exists in the vicinity an existing building having available space, roof, or land, that may be used for installing a renewable energy system (producing electricity or heat), this is relevant to install such an extra-system on this close existing roof and connect it to the building under study, allowing also export of energy to other buildings nearly or to the grid. This kind of urban opportunity is promoted by (Maugard, 2015).

Some barriers may exist that form an obstacle to such solutions and local energy mutualisation: inadequate urban regulation, legal limits, contractual difficulties, not adapted business model, implementation of a new actors' organisation. Generally technical issues are not the main barrier. Creating a renewable energy system and related management organisation at a small urban scale, with interconnections and smart-grid implementation, must be encouraged and facilitated by municipalities and energy operators (classical operators or local smart-grid ones).

It is important to develop incentives measures and legal adaptations to trigger extra investment, by the building owner or by a third party renting the space and selling produced energy.

8 BEPOS : French acronym for POSitive Energy Building

The implementation of these solutions leads to more energy locally produced and shared and constitutes a carbon handprint because some buildings have offered available space to produce renewable energy for others.

In addition, if the local energy network is correctly designed and managed, it may reduce the intensity of energy (electricity) drawn from the grid during peak hours. This system may be associated to strategies of systems' "flexibility", so as to limit the power drawn from the grid.

As space is a rare resource in dense urban zones, it is important to avoid use conflict regarding roof or land spaces, by preserving biodiversity, water cycle and other functions. It may be done for example by mixing solar panels and vegetation, or by offering shadow to accessible terraces, car parks, playgrounds, etc. The presence of the energy system should not contribute to the urban heat island effect. One of the solutions studied by the French research projet "PROOF" (as photovoltaic and green roof [9]) is a combined system mixing PV panels and green roof, sometimes called "bio-solar roof". Through modelling and full-scale experiment, several assumptions will be checked, for example a good evapotranspiration effect from the plants, coupled with an improved efficiency of PV panels due to refreshed air. So, the stake will be to preserve both biodiversity (with related ecosystem functions) and energy efficiency, while not increasing the urban heat island effect. Another example of such a bio-solar roof is in place since 2014 in Switzerland on the very large roof of the Beaulieu South Halls in Lausanne.

In order to assess the carbon or climate benefits of renewable energy systems installed on various roofs of a neighbourhood, associated with a local energy loop or smart grid, it is necessary to think at the neighbourhood scale and to integrate all the relevant interactions and optimisation factors in a urban zone modelling. Calculation methods should be compliant with energy-related and LCA-related standardisation, but standardised methods need to enlarge their scope to deal with the neighbourhood scale. A detailed hourly or infra-hourly simulation is necessary to correctly estimate the production, regulation, possible storage, and distribution of energy in the connected buildings. Logically, the embodied carbon of the energy systems should be allocated to the buildings using the produced energy, per kWh. The surplus of local energy, if any, may be transferred to the grid.

Regarding this topic of offering space for renewable energy systems, we suggest the following indicators:

- potential quantity of exported energy /year (per allowed energy system if several technologies are possible)
- GHG emissions associated (considering embodied carbon of system LCA, per energy system) (handprint if kg eqCO_2 / kWh is lower than grid)
- avoided GHG emissions if this on-site or nearby energy is used instead of the grid or network (per kWh or per year)
- indicators may be calculated at the building scale, or at the neighbourhood scale if a local energy network is created, where buildings are inter-connected.

9 PROOF is an ongoing ANR project led by CEREMA with 7 other partners: https://www.cerema.fr/fr/innovation-recherche/recherche/projets/photovoltaic-and-greenroof-proof

Table 9. Viewpoints for OFFERING SPACE as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	What is often missing in dense urban areas is space (mainly roof or land area) for installing renewable energy production systems, so available space is a precious resource. Maximizing the installation of renewable energy systems on the large roofs offered by certain types of buildings of the vicinity (new or existing) leads to a greater amount of energy locally produced, that can be used by the surrounding buildings or exported to the rest of the city or territory. The building offering space for energy systems can export more energy. An energy loop (of electricity, heat or cold) may be installed at the neighbourhood or city block scale to collect, manage, regulate, store, optimise and distribute this energy. The idea behind this topic of offering space is that the neighbourhood scale is often much more relevant for local energy production and management than the building scale. So, we may have plus energy neighbourhood instead of several non-interconnected plus energy buildings, leading to a carbon handprint maximised and optimized at the neighbourhood scale. Without a building with available area equipped with renewable energy system, less energy could be exported. If correctly designed and managed, the decentralised energy system may reduce the intensity of energy (electricity) drawn from the grid during peak hours. This system may be associated to strategies of systems' flexibility, to limit the power drawn from the grid. In this case, the beneficiary is the grid, with a lower CO2 contents per kWh during peak hours, because additional fossil sources can be avoided or limited during this time.
Time frame and related problematics	The lifetime of decentralized energy system is lower than the lifetime of the building, but if the building can offer space / roof area for supporting this system, energy can be exported.
Example(s) of assessment results	Calculation method will be drawn from energy standards and LCA standards (EN 15978 under revision). A hourly calculation method is necessary to correctly estimate the actual shares of self-consumed and exported energy.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	Uncertainties may be linked to the calculation of the amount of exported energy. Difficulties in modelling may be the integration of the modes of energy management and regulation of the local network at the neighbourhood scale, need of a model at this scale. A detailed hourly or infra-hourly simulation at the urban zone scale is necessary to correctly estimate the production, regulation, possible storage. and distribution of renewable energy in the connected buildings, in connection to energy imported from the classical grid. Modelling choices: defining perimeters of the mutualised sub-systems, allocation of embodied carbon of systems to users' entities, avoiding double-counting and omissions.
Who benefits from this handprint	The beneficiaries are all the buildings connected via the local energy network, especially those suffering from a lack of space for installing renewable energy systems. If a surplus of renewable energy exists at the local scale, it may be exported to the grid. This exported energy out of the neighbourhood scale is a handprint for the city or territory. Win/win process: share of embodied carbon (and of money) between initial investors and the created "energy local community" using the energy produced.
Recommendations	To develop, promote and spread energy and environmental urban models including all the energy and built environment of a neighbourhood, coupled with an urban information modelling. It is logical that exported energy includes its proportion of embodied carbon of the energy system, as for all types of energy systems in general. To develop incentives measures and legal adaptations to trigger extra investment, by the building owner or by a third party (renewable energy operator), and to allow local mutualisation of renewable energy systems. To avoid use conflict regarding roof or land spaces, by preserving biodiversity, water cycle and other functions by mixing solar panels and vegetation, or by offering shadow to accessible terraces, car parks, playgrounds, etc. The presence of the energy system should not contribute to increase the urban heat island effect.

Versatility

In accordance with (ISO 20887, 2020) versatility is an ability to accommodate different functions with minor system changes. ISO 20887 also says that versatile structures and spaces facilitate continuous alternative uses with minor system changes. In designing for versatility for specific adaptation, it is important to consider the needs of the targeted users. Having one space that accommodates many uses can reduce the overall building footprint, required floor area, costs, and resources. Regarding versatility, it is also possible to look beyond the boundaries of the current user or owner to seek potential partnerships and users that could use the space at times when it would otherwise be unused. This would save costs and reduce the need to construct more single-use structures and spaces. This kind of versatility can result in measurable benefits by increasing building utilization (ISO 20887, 2020).

Tarpio (2015) speaks about variation in room use, meaning frequent changes in use at different times of the day or on different days of the week. When changes need to be made frequently, it is important that they can be made quickly and easily. The requirement of ease can be reacted to by means of a space, for example by sizing the room to such an extent that it is suitable for a wide range of different furniture for different uses, so that you do not have to move them. You can also react to it with special furnishings. Such furniture may consist, for example, of multi-purpose furniture, which are suitable for different purposes as such. Furniture can also consist of light furniture that is easy to move or furniture that can be folded and stored in a small space when they are out of use. The furniture can also consist partly of furniture integrated into the structures of the space, sliding under tables or which can be lifted on a wall or closet and quickly stored when not in use.

Tarpio describes alternative basic solutions for versatility regarding residential buildings. These include the Open Space logic and Hall and Rooms logic. When following the Hall and Rooms logic, the premises of the apartment are divided into a traffic space (hall) and separate rooms suitable for many uses, all of which are accessible from the traffic space and are designed and sized to be furnished in a wide range of ways. Room connection variation creates different uses within the apartment in different ways by combining or closing connection with the help of doors or sliding walls (Tarpio, 2015).

Benefits of versatility are much emphasized regarding office buildings, schools, blocks of service flats, libraries, and sports and exercise buildings. The importance of versatility for profitability and economic benefits is particularly related to increasing utilization rate. The utilization rate and at the same time profitability can improve significantly when the space serves different uses at different times of the day and allows for higher user numbers (De Paris S.R., 2018).

Profitability of real estate investment depends, for example, on the economic utilization rate of the premises. The generally used definitions of utilization are therefore related to the economic utilization rate and are not intended to assess multi-purpose or dual use. For example, Occupation Rate is the percentage of the premises in use as a percentage of the total in a given sub-market. This is often used as a key figure to characterize the property portfolio of an owner or a group of owners (KTI, 2019).

However, if we were to deal with actual utilization rates, we should take into account all hours of the day and the number of users in terms of hours of use in relation to the potential number of users. On building level, significant real improvements in the utilization of spaces – and thus also carbon benefits - can only be achieved in different types of buildings through multi-purpose or dual use (Häkkinen & Alakotila, 2019). The utilization rates are much lower than what is typically reported as occupation rates. For example in Helsinki metropolitan area the utilization rate of office buildings (on the basis of working hours) has been estimated to be 50% (Kauppalehti, 2014) while the occupation rate is roughly 95%.

Multi-purpose facilities may have different customers at different times of the day. For example, the City of Helsinki has sought to increase the versatility of the premises and sought opportunities for co-operation with various administrations. Different activities can be organised to happen in one premise including uses such as library, adult education centre, youth centre, sports room etc. (Jäske & Kähkönen, 2017).

The versatility of a building reduces the environmental impact if the multiple use improves the actual utilization rate of the building and if, as a result, the need to build the premises elsewhere is reduced. In addition, the combination of, for example, school and leisure facilities or accommodation and business facilities can reduce mobility needs and thus reduce traffic emissions (Häkkinen & Alakotila, 2019).

The quantitative assessment and consideration of the benefits of versatility for sustainable building is somewhat problematic. For example, the energy performance of a building is traditionally calculated in terms of the annual energy consumption per surface area (commonly kWh/m^2, a). This meter is useful especially at the design stage of the building when assessing the impact of the design parameters on energy consumption. Similarly, the carbon footprint of a building is often assessed and reported using the unit kg CO_2e/m^2 or kg CO_2e/m^2,a. These units do not take into account the utilization rate. However, new indicators that better consider versatility have also been proposed. Sekki, et al. (2015) compared the following indicators for the assessment of energy efficiency:

- specific energy consumption (kWh/m^2, a)
- energy-intensity of use (kWh/number of users or kWh/hours of use, a)
- specific energy efficiency weighted by the number of users (kWh/m^2, o), where o is the relation between the actual hours of use to maximum possible)
- specific energy consumption weighted with use and space efficiency (kWh/m^2, u) where u = ntka/((A/aref)*tref) where n is the actual number of users, tka is the mean time of use per user, A is surface area, aref is surface area per user and tref is normal hours of use.

The first of these indicators can be accurately calculated and measured and it is well suited for comparing design options. However, when using this indicator, a higher utilization rate leads to a lower energy efficiency. This is because the use has an impact on energy consumption, both based on the number of users and as the operating time may increase at the same time, and at least if the building's technical systems react, for example, to the growing need for ventilation. The energy-specific indicators of use reward the efficient use of the building in terms of the time or number of users, but do not take into account the surface area of the building. The problem of energy efficiency weighted with the number of users, is that it does not consider the actual use of the building. Sekki, et al. (2016) propose the use of the indicator ” Specific energy consumption weighted with use and space efficiency”, because it fits well together with the ideas of cost efficiency. At present, the use of this indicator is difficult, but it will become easier, when the use of sensors that are able to monitor the actual use of building spaces.

Sekki, et al. (2016) have dealt with the consideration of space efficiency from the viewpoint of energy performance, but similar ideas are important also regarding climate impacts. However, the methods suggested by Sekki et al. are problematic because of the complexity of the calculation formula. One option might be to consider impacts calculated in proportion to space and user-hours in parallel. Versatility may become on important aspect as the requirements for circular economy become more and more important. Thus, also much more experience will be needed in the use of calculation methods that enable to consideration of its benefits.

Similar new approaches would be needed to assess and monitor the impacts on the scale of building stock. In addition to economic occupancy rates, it should be possible to look at the needed volumes of space that meet, for example, accommodation needs, workspace needs and school needs from the point of view of environmental efficiency. Many cities, such as Helsinki in Finland, are working to increase the utilization of facilities, which means increasing space efficiency and extending use times. Indicators are also needed to support these efforts both in planning and monitoring phases.

Table 10. Viewpoints for VERSATILITY as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	The potential benefit of versatility is the decreased need of space, related decreased need for the use of resources and thus also reduced emissions. Versatility can also reduce mobility needs and thus also traffic emissions when different activities can be organised in one premise.
Time frame and related problematics	There are no specific time related problems, when assessing the effect of versatility on building level for GHGs regarding the number of users or hours of occupation. However, when estimating the saved emissions because of saved spaces, the assessment becomes more complicated. This is because the potential savings happen during a long time period and because there is much uncertainty in scenarios.
Example(s) of assessment results	There is lack of evidence based on quantitative assessment. however, its benefits regarding sustainable building have been recognised; a new international standard and new research have been published.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	New reference units, calculation formulas and possibly also new monitoring methods should be taken in use to assess and show the climate benefits of versatility. Benefits become visible only when utilization rate is considered on calculations. When assessing the benefits of a new versatile building, there is a need to formulate scenarios about “saved spaces”, which may be difficult.
Who benefits from this handprint	Versatility is one method to reduce both cost and GHG emissions which interests cities and other big building owners. Also, investors are interested in showing the carbon footprint benefits of versatile buildings.
Recommendations	There is a growing interest towards versatility. Versatility may become even much more important performance aspect of buildings in parallel with increasing requirements for circular economies. Thus, it would be important to further develop and get experience in the use of new indicators and monitoring methods that would enable the quantitative assessment and follow-up of its benefits.

Flexibility / Adaptability

The flexibility[10] of buildings aims to adapt to changes in purpose or changes in external conditions, such as climate change, and the resulting needs to make changes in the building or its systems. Flexibility can help to prepare for either known needs for change or possible unknown needs for change (ISO 20887, 2020). Flexibility also means that the space can be converted to suit the new purpose by carrying out construction work by changing structures and/or supplementary equipment.

Flexibility refers to the ability to adapt to an essential change in the user's needs through changes in spaces. Flexibility is close to multifunctionality, but flexibility is used to prepare for future changes in user needs. Durmisevic (Durmisevic, 2019) talks about a design strategy that takes change into account. Our needs and requirements for the built environment are constantly changing; the aim is to create buildings that support change efficiently and effectively.

According to Tarpio (2015), needs to make changes in the use of room in residential buildings are rare. The need to change the use of living rooms may arise, for example, as family size changes, ways of working or hobbies change, thus the intervals of changes in the use of room space is measured mainly in years. To make changes possible, there are requirements for both rooms and the entire layout.

In general, the basic principle of flexibility design is the design of structures, in particular load-bearing structures, so that it allows for varying interior plans, both in terms of space and the placement of systems, equipment, appliances, and furniture. From a structural point of view, long spans and pillar structures are advantageous for flexibility. Galle & De Temmerman (2013) also talk about partial flexibility, highlighting the flexibility of building services systems, furniture and surface materials, as well as flooring.

Slaughter (2001) defines the design principles of the building to be modified, emphasizing the reduction of interaction of parts, accessibility, zoning, phasing, simplification, and predictability. The principles of flexibility design are defined as: 1) physical separation of the main construction systems (and their sub-systems) so that modifications can be made without affecting the need to modify other parts, 2) premanufacturing of the most important parts, which may improve flexibility, and 3) design for overcapacity for certain systems so that changes can be made afterwards without changing the performance of these systems. The proposed design strategies include, for example, reducing interactions within and between systems, using replaceable components in systems and enabling step-by-step disassembly, improving physical access to targets and zoning of different systems.

10 France makes a distinguish between flexibility and adaptability for a change of use (e.g. from office to dwelling). ISO 20887 uses the generic term of ”adaptability” in its title, and also in the standard the term ”convertibility” for substantial changes. We note that ”flexibility” appears only once in this standard. So Adaptability seems the generic term. In BAMB reports, they often use ”reversible” and ”reversibility” terms.

On the long term, flexibility saves the use of energy and material resources regarding both building products and the use of buildings, and thus also resulting greenhouse gases whenever flexibility can reduce the need to build new. On the other hand, there is always a risk of loss and overcapacity if the expected need for future changes.

Flexibility improves the environmental impact of a building based on the following issues (Moffatt & Russell, 2001):

- more efficient use of space – flexible buildings are likely to use facilities and materials more efficiently during the life cycle than other buildings
- long service life – adaptability increases the total service life of the building and
- improved functionality – the building to be converted can be improved and optimised during the service life, for example, regarding energy use.

The real environmental benefits of flexibility and easy disassembly depend not only on their successful design and implementation, but also on the circular economy market. The market for repair, recycling and reuse should work well at all levels. There should be viable business models in the market for (ISO 20887, 2020).

- reuse and repair of demolition products
- repair of products
- the use of recycled products in construction and
- recycling of products.

These are all helped by compliance with the principles of simplicity and standardisation in the design. Simplicity includes, for example, favouring moderately homogeneous solutions over very multi-layered, or multi-material products. Compliance with standards can apply to dimensions, components, joints, modularity, and so on.

The documentation of design, construction and repair and the instructions for maintenance, repair and disassembly are of considerable importance for the implementation of planned flexibility, and easy dismantling, and subsequent reuse or recycling. Digitalization of data, data transfer and guidance, as well as ensuring data maintenance, are all important in order to put into practice ideas of flexibility.

The European BAMB project[11] (Buildings As Material Banks) has dealt with this issue and circular economy of construction products. Reversibility and disassembly have been deeply developed, and their potential on a given building has been assessed. An assessment methodology was finalised in summer 2020. (Durmisevic, 2019).

11 BAMB website : https://www.bamb2020.eu/

Rob Geraedts and Hilde Remøy, from the Delft University of Technology, have worked for several years on practical instruments to assess the adaptive capacity of buildings. (Rob, 5–7 October 2016) (Geraedts, 2017).

Table 11. Viewpoints for FLEXIBITY as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	The benefit is on the long term. By this ability to adapt to new needs and/or new uses, with limited works and investment, the service life of the building is prolonged, the obsolescence avoided. This results in a better service provided to occupants when reducing carbon footprint due to deconstruction then construction of a new building. Generally, at least the bearing structure does not need to be modified.
Time frame and related problematics	Future is unknown, but future has to be prepared. Flexibility and adaptability to future uses allows to adapt the strategy to the market needs that we don't know at present.
Example(s) of assessment results	Most of well-known certification reference frameworks deal with flexibility or adaptability, as BREEAM, DGNB, HQE, LEED.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	Assumptions are necessary because future is unknown.
Who benefits from this handprint	The owner of the building is the main beneficiary, from an environmental and financial point of view. His building remains attractive for occupants. Carbon handprint on the long term is reduced. Occupants can work or live in a functional and comfortable building.
Recommendations	To anticipate future changes since the brief phase, including changes of use (from office use to residential use for example). To respect architectural and technical design principles, to be developed all along the design phases, from general dimensions to details as reversible connections or modular components. To use a semi qualitative/quantitative assessment method (some exists, to be adapted to the building type and the national context, or to develop a new one).

Easy disassembly enabling easy recycling or reuse of components and elements

The idea behind Design for Disassembly (DfD) for buildings is to design and produce a building component or element that can be removed without damaging the component itself as well as the rest of the building. Secondly, that the component or element preferably can keep its value through multiple cycles and thus be reused again – or recycled with higher value by the use of DfD approach.

Due to intensive focus on circular economy and resource efficiency, DfD has recently gained more focus. According to a literature study on circular building design and construction strategies (Eberhardt , et al., 2020), assembly/disassembly was the most encountered strategy in the study. The reason why DfD has developed and gained foothold in the building industry for the past 10 years can be explained by expectations that it can in the future enable high-quality reuse of recovered materials beyond end-of-pipe solutions (Geldermans, 2016).

The potential environmental benefits of applying DfD will occur in the future, when the building component will be removed from the building assessed, and applied in another building or elsewhere, and hopefully more than two use-cycles. However, there are many challenges associated with the assessment of the potential quantitative benefits of applying DfD. The challenges are associated with the uncertainties related to if, how and how often the component will be reused in the future and the magnitude of the environmental load of the avoided product in the future.

The standards applied for building LCA are not properly prepared for multiple cycles, as intended in the circular thinking. The current version of the EN 15978 and EN 15804, handle multi-functionality through system expansion where benefits and burdens of the secondary function are reported separately in module D (Eberhardt, 2020). The Product Environmental Footprint (PEF) developed later by the European Commission suggests a Circular Footprint Formula (CFF) (Allacker, et al., 2017), which enables assessment of end of life scenarios possible and includes allocation approaches for products with two or more cycles. It is not clear how the CFF formula will be included in building LCAs following the EN 15978. Other allocation approaches than used in the CFF exist, which in some cases better facilitates multiple cycles than the CFF (Eberhardt, 2020). Concepts of more appropriate allocation principles for DfD that could better comply with the circular economy thinking have been further developed by Leonora et al. (2020b) and tested in LCA calculations for circular design strategies. It is however not clear how these different allocation methods will be accepted by the EN 15978, and if circular initiatives will only be considered in the module D.

All of those allocation methods mentioned above distribute the emissions taking place today for the production of the DfD-product over two or more cycles, which challenges the focus on the importance of reducing the emissions happening in today. This is not representing the timing of the physical flow of emissions. This can also, if intended, lead to a misuse of the concept of DfD for greenwashing products that are not realistic to be reused or by choosing more use-cycles than realistic. On the other hand, incentives for circular strategies are needed in order to accelerate circular approaches in the built environment.

Table 12. Viewpoints for EASY DISASSEMBLY as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	A building can consist of building components that can be disassembled and reused again in another building or other systems/sectors. This reduces construction waste after the endo of life of the product and avoids production of new materials in the future. As LCA is performed today, benefits of Design-for-Disassembly solutions for building components in buildings are not included within the calculation of phase A - C. Therefore, there is within LCA limited possibilities to include benefits of choosing DfD solutions. Building with DfD solutions might even have higher load within phase A-C due to additional material use for joints etc. Potential benefits of the second use-cycle can be included in module D, but it is not possible to show additional benefits if the product/component has three or more use-cycles. Another way of estimating the potential benefits in LCA is through allocation of impacts over the expected use-cycles by the CFF formula or linear digression. The handprint can be: • The potential benefit calculated in module D (for one additional use-cycle). This is then subtracted from the environmental load of the production. This is similar to module D. • The potential benefit of the additional use cycles calculated by CFF, linear digression or similar. This is then subtracted from the environmental load of the production. The potential benefits (or handprint) might be higher than the solution above if the material/component has more than two use-cycles.
Time frame and related problematics	The physical flow of the emissions related to production of the materials/components take place today (when built). The potential benefit will happen after the end of life of the material/component if it is reused as intended with the DfD solution. • It is unknown if the material/component will be reused/recycled ad intended. • The product the component will replace will have lower environmental impacts in the future and real avoided load expressed by the handprint (or module D) will therefore be lower (due to future energy production and production improvements). This is usually not included in the current LCA calculations. • In addition, clear criteria for DfD are needed.
Example(s) of assessment results	Eberhardt with co-authors has several publications where inclusions of the potential benefits of DfD in LCA calculations has been developed. Therefore, several versions of the calculation methods exist. • Figure 2 shows the results for an office building built with DfD concrete beams and the module D when the DfD concrete beams have 2 or 3 use-cycles. • Figure 3 shows the results for concrete beams with or without DfD for 2 use-cycles. Similar results are available for a window. • (Rasmussen, et al., 2019) has also worked with development of methods for assessing DfD strategies in LCA. • Figure 4 shows an example of a building with DfD (orange) and the timing of the loads and benefits.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	Due to extreme long timeframe for buildings and most building components, realistic calculation of the benefits of DfD scenarios is difficult to conduct. There are several uncertainties as mentioned above related to if and how often the components will be reused, what is the impact of the avoided product in the future.
Who benefits from this handprint	A producer that produces DfD components/solutions. Building LCAs with buildings that include DfD components.

Table 12. (Continued).

Aspect	Comment
Recommendations	It is uncertain if the component will be reused in the future. Therefore, it is recommended that a careful approach is chosen for how to let the DfD lower the results of the building LCAs. It could be by giving a certain percentage "discount" for the production impacts (such as 10% as used in the Norwegian Future build projects). This would then not reflect the actual potential benefits, but still could give incentives for using DfD for buildings. Module D could be used to show the potential benefit (outside the system boundary) that could reflect the expected benefits based on different assumptions (amount of use cycles, different allocation approaches etc.) The methods developed by Leonora Eberhardt (different publications) and (Rasmussen, et al., 2019) should be further developed.

Figure 2. Example of calculating the benefits of DfD with one and two use-cycles as potential benefit in module D. Example from (Eberhardt, et al., 2019) showing use of module D.

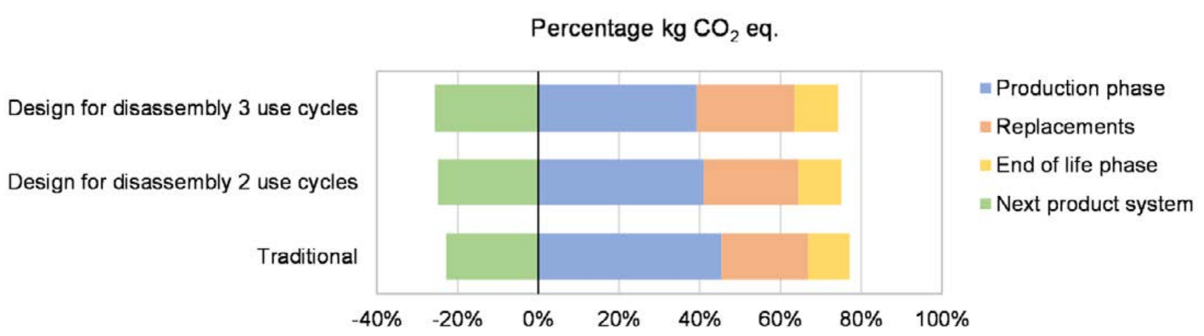


Figure 3. Example of calculating the benefits of DfD solution for concrete beams by showing the timing of the benefits (Eberhardt, et al., 2019).

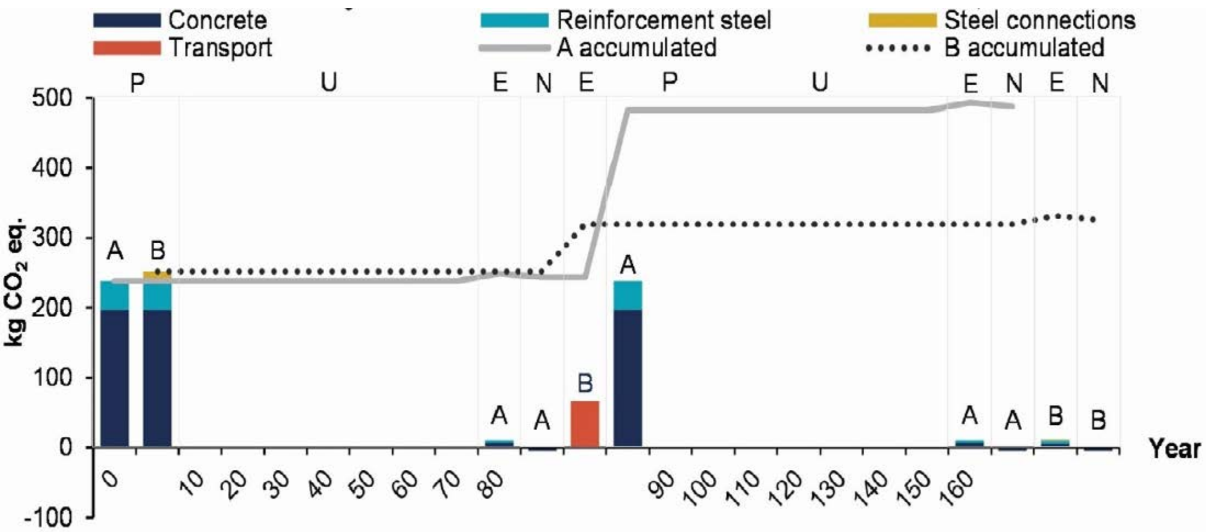
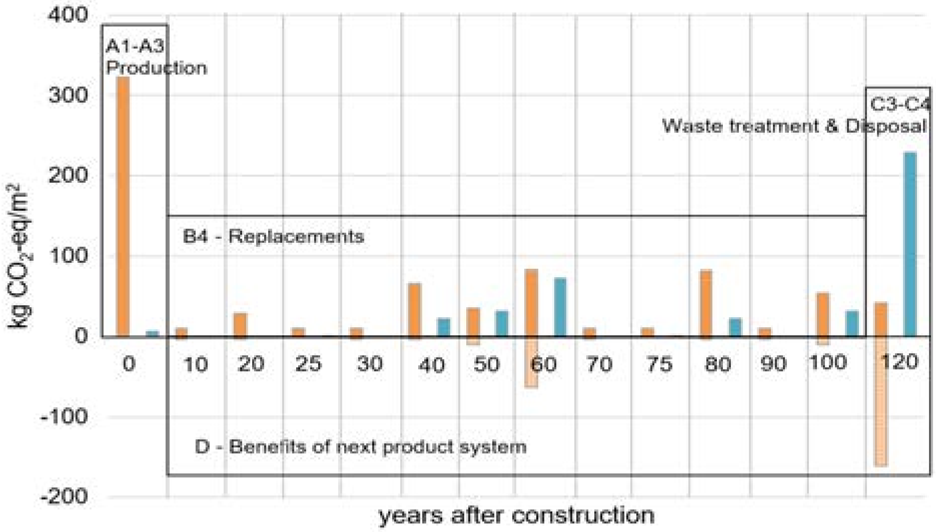


Figure 4. Example of calculating the potential benefits of two circular approaches, DfD (orange) and reuse (blue), according the timing of the loads and benefits (Rasmussen, et al., 2019).



Recycling and reuse of components and elements

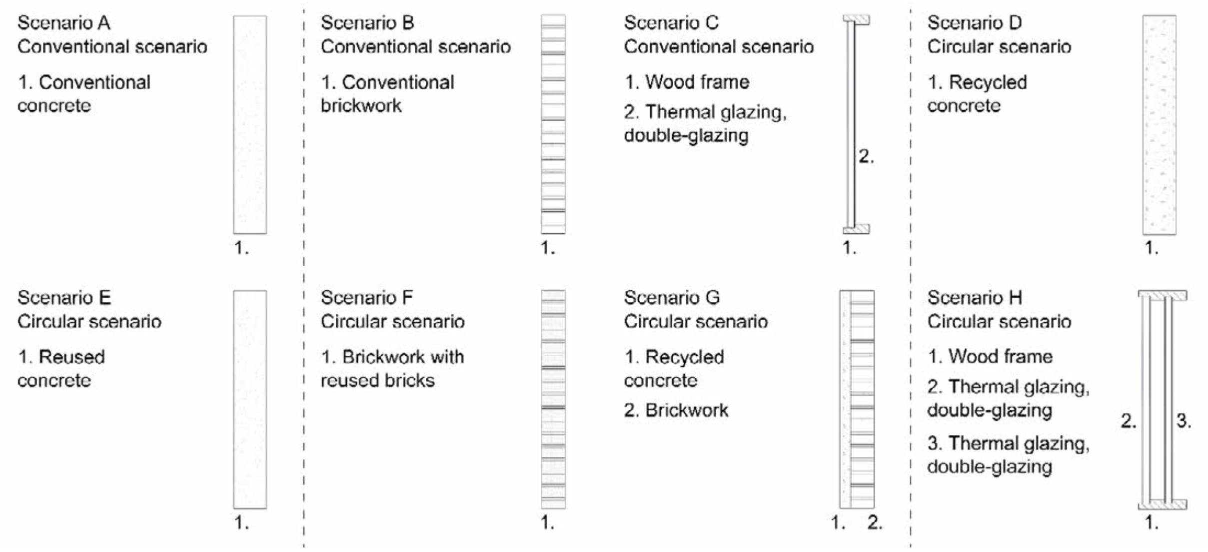
Construction and demolition waste are usually far the largest waste fraction. Minimizing the generation of this waste fraction, e.g. by avoiding demolition of a building or by using DfD solutions, is the preferred action to avoid impacts, followed by reuse and recycling. There is already considerable high recycling rate within production of many building materials. Recycling of gypsum in gypsum production and steel for reinforcement steel are good examples. But there is still possible to make significant improvements and changes within reuse and recycling of construction waste to obtain reuse/recycling with the highest potential of benefits.

As for DfD, with intensive focus on circular economy and resource efficiency, reuse and recycling with higher potential has recently gained more focus. In order to take reuse and recycling into account in LCA of buildings, data for the different solutions has to be available. Data for common recycling scenarios, such as recycling of gypsum, is already included in the EPDs for the production of gypsum. Therefore, handprint approach is already there although it is not called as a handprint but potential benefit beyond the system boundaries.

For handprints, it is important to distinguish between the state of the art of reuse and recycling of construction waste, and how handprint can be used to make improvements that give incentives to go above current methods. On the other hand, direct reuse of components from the building sector is now gaining more attention due to significantly higher potential for reduction compared to the state-o- the-art recycling solutions. Some newly used Danish examples are given in figure 5. These are as an example:

- reuse of glass from old windows in new windows (instead of crushing the glass for potential recycling)
- reuse of brick-façade elements with cement mortar (instead of crushing and using as fill material in e.g. road construction).

Figure 5. Composition of conventional and circular scenarios A–H (Andersen, et al., 2020).



In order to include the benefits of reuse in building LCA, data for those solutions is needed. Andersen, et al. (2020) includes examples of development of LCA data for the above mentioned solutions. According to the EN 15804, cut-off approach is used for allocation, which means that the reused material is almost burden free. Andersen, et al. (2020) only includes few examples, and intensive focus on development of data is required if the majority of building components and materials should be represented by available datasets.

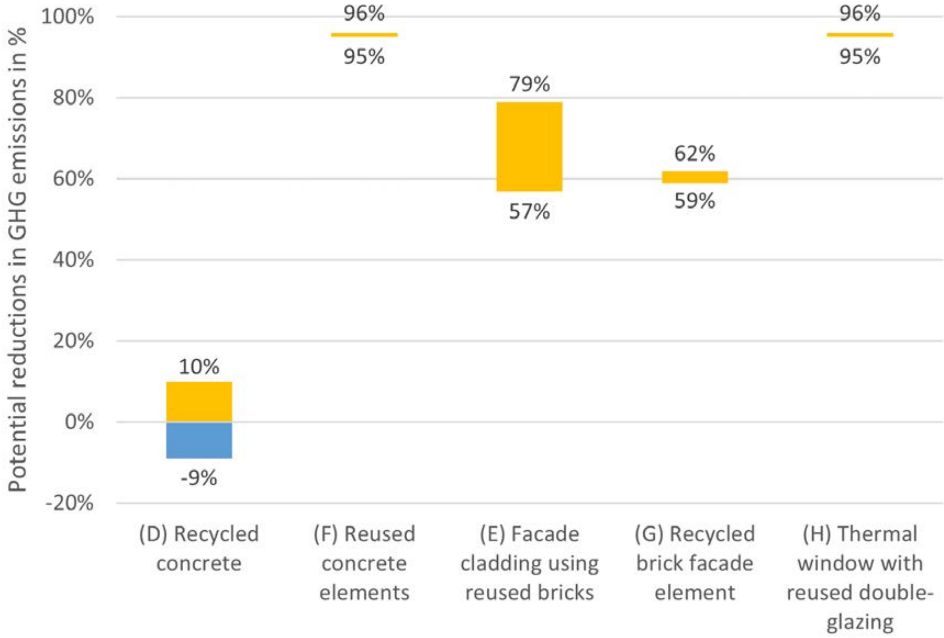
Recycling of certain construction waste fractions into new materials is already included in LCA data for the respective materials (such as gypsum, plywood and reinforcement steel). And the potential impacts of reuse of certain building components can be calculated in LCA, as mentioned above. However, generally data is lacking, especially for reuse of building components, and perhaps also for some innovative recycling scenarios. A reason for emphasising the D phase benefits with the help of the term handprint could be to create an incentive with "temporal handprints" to accelerate some innovative choices within the building sector. And when those solutions become common choices, they could be replaced with other new innovative temporal handprints.

On building level, the exceptional utilization of recycled products can also be dealt with as designers' / investor's handprint when the result is an extraordinary low-carbon building.

Table 13. Viewpoints for REUSE AND RECYCLCCING POTENTIAL as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	Use of materials with innovative recycling or reuse solutions that lower the carbon footprint can be regarded as handprint by comparing them with building as usual. The handprint can therefore be the savings compared to building as usual. Increased use of products with high recycling rate or reused materials will in many cases lower the upfront-embodied impact.
Time frame and related problematics	The potential benefit is lowered upfront-embodied impact, so actual savings that take place in the beginning of a building life cycle (phase A). There is a risk of double counting the benefits, if the previous product also reports and incorporates the potential benefits of the end of life solutions (in module D).
Example(s) of assessment results	Figure 5 above shows an example of different recycling and reuse solutions for selected materials/waste fractions. Figure 6 below shows the potential benefits of reuse compared to commonly used waste treatment methods. Figure 4 above shows the potential benefits on a building level for use of upcycled materials (orange) and in a timeline.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	There is a quite good experience with recycling of construction waste in the production of new materials, and also within modelling and calculating quantitative results. But reuse/upcycling of different components in building projects is mostly on experience level – and therefore is still immature. There are therefore several types of uncertainties in relation to the calculation of the quantitative results, such as how much can be upcycled, what is the service life of the upcycled component compared to virgin component, what is the extent of failures in relation to the source of the upcycled component from the building being demolished etc.
Who benefits from this handprint	The user of a reused product or a product with a high recycling rate.
Recommendations	Consider if "temporal handprints" can be used to create an incentive for acceleration of circular solutions (see discussion in the text above).

Figure 6. Potential reduction of greenhouse gas (GHG) emissions (%) when comparing five circular scenarios with three corresponding conventional scenarios from Andersen, et al. (2020).



New technologies - Photobioreactors (artificial or enhanced photosynthesis) and DAC systems

Compared with the more recognized plant-based green façades, microalgae-incorporated photobioreactor façades are raising attention in urban built environment because of the potential to take a chance in the decreasing of CO2 emissions. (Oncel, et al., 2020), (Oncel, et al., 2016). Microalgae may be able to offer a new renewable resource to be applied in buildings on the basis of their potential to absorb CO2, recycle wastewater, and release O2. According to Talebi, et al. (2020) algal photobioreactors act as closed bioreactors driven by light energy and might appear in different shapes. They have to meet specific requirements for algal growth; i.e., conditions such as sunlight, nutrients, pH, CO2 supply, and temperature directly determine the final productivity of these algal systems and therefore, should be taken into account during buildings design and construction.

There is still very limited experience regarding building-integrated microalgae photobioreactors (PBRs). Elrayies (2018) has investigated the potential suitable types of PBRs for integration with buildings, the overall bioprocess and the design considerations regarding PBRs and their technical requirements, the environmental and energetic performance of PBRs, their challenges, and their prospects. The environmental potential benefits of building-integrated PBRs are energy savings; GHG emissions reduction; oxygen and hydrogen release; biofuel production; and wastewater treatment. However, there are still many challenges including the biorefinery infrastructure, the provision of a source of CO2, and the high initial cost. He says that: “One of the most profound challenges of establishing the bio-façades system is the provision of a biorefinery infrastructure. The system includes the efficient supply of nutrients, water, light, and CO2 along with microalgae harvesting and extraction system that should be done on site to prevent energy loss during transportation. Furthermore, microalgae-powered buildings should be equipped with their own biogas plants to produce methane from their produced algal biomass, which could be subsequently processed by anaerobic digestion to generate its own electricity. The inability to provide a biogas plant on the building site will be faced with the need of providing a source of CO2. Integrating CO2 capturing, sequestering, and storing systems are well known in the industry. However, the integration of these systems into buildings represents a big challenge so far. However, the unique CO2 scrubbing plant with the humidity swing technique will surpass this issue if its cost-effectiveness and applicability are proven."

According to Talebi, et al. (2020) algal cells are able to convert sunlight, CO2, and inexpensive nutrients into products of photosynthesis such as carbohydrates, proteins, lipids, etc. These products could serve as raw materials for the production of bioenergy, biofertilizers, etc. Microalgae have a relatively high surface area-to-volume ratio, allowing them to absorb nutrients and CO2 much faster than agricultural plants. Smart green buildings integrated with microalgal cultivation systems could have a potential to create clean renewable fuels and but also remediate wastewater. Input parameters include natural luminosity and artificial luminosity, temperatures, O2 and CO2 available in air inside buildings and these factors determine the final productivity of the systems. Flat plate photo-bioreactor panels installed on buildings surfaces could efficiently absorb the UV light and other thermal light rays and generate heat the same way a solar thermal unit does. The captured energy is either directly used for hot water supplementation or stored in the ground using boreholes. Sunlight energy could also be fixed within biochemical compounds accumulated in algal biomass. Talebi, et al. (2020) tell that, for instance, it has been reported that the harvested biomass in façade elements showed a productivity of on average 15 g/d. This was equivalent to 150 kWh/m^2 thermal energy (equal to 30 kWh/m^2 biomass) and caused the building CO2 emission to reduce by 6 tons annually.

Köktürk & Anıl (2018) claim that the integration of renewable energy systems into buildings is made possible by the use of a closed-loop photobioreactor. This system can be used to grow microalgae and cyanobacteria, living photosynthetic microorganisms that can capture carbon dioxide, release oxygen, filter air and water, and produce nutrients and various resource materials. Its integration with buildings as a facade element can help with energy efficiency, energy production, and CO2 sequestration in the built environment. Building-integrated PBRs are state-of-the-art elements that may offer diverse opportunities for use, yet their control is a critical issue for reaching the desired benefits. Köktürk & Anıl (2018) present a programmable logic controller designed to control environmental conditions such as temperature; liquid level; pH; fluid velocity; quantity of CO2, bicarbonate, nitrogen, and some ions inside the PBR; valves for product harvesting and cooling, etc. They say that more interdisciplinary research is necessary for energy efficiency in building applications.

(Talebi, et al., 2020) have summarized information about the parameters that affect the operation of PBRs as follows: CO2 concentration has a direct impact on the pH of the bioreactor, because microalgae needs CO2 for growth. CO2 can be supplied by the atmospheric air but the concentration is too low to support high productivities. In an ideal situation, atmospheric air can be captured, and CO2 can be filtered and concentrated for use in photobioreactors.

Temperature in reactors also affects algal growth and needs to be maintained in an appropriate range for the algal species to be cultivated. Too high temperature values could cause cell death while too low temperature values could freeze cell growth. It is also known that the rate of photosynthesis depends on the amount of dissolved oxygen removed from reactors. It is recommended that the partial pressure of oxygen (pO2) be maintained at less than 100% of air saturation. Algae growth is inhibited when the pO2 rises beyond 400% of air saturation. Thus, measures should be taken to reduce the pO2 without damaging the cells using an excessive supply of volumetric power. The faster growing microalgae species and the consequent more concentrated biomass produced will block more sunlight from entering buildings and at the same time, more energy can be harvested per surface area. It should be noted that all these parameters are usually predefined and running and operations are not usually performed based on real-time data and daily variations. Application of the concept of Internet of Things to monitor the algae growth could be beneficial.

Table 14. Viewpoints for PHOTOBIOREACTORS as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	Algal cells are able to convert sunlight, CO2, and inexpensive nutrients into products of photosynthesis. The assumed benefit is that the integration with buildings as a facade element can help with renewable energy production and CO2 sequestration in the built environment.
Time frame and related problematics	No specific time related problematics.
Example(s) of assessment results	PBRs represent a new and possibly potential technology for building integrated renewable energy systems. There is lack of information about real functionality. Thus, also the quantitative assessment results are still uncertain. No research about the applicability in Northern European environments was found.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	The main problem is the lack of knowledge and experience regarding applicability and reliable operation. When functional systems would be available and when there is knowledge about operation and durability in different kinds of environment, the quantitative calculation with LCA methodology should not be a problem.
Who benefits from this handprint	When the PBR is applied and used in buildings, its effect on GHGs can be taken into account in the building level LCA. However, as the PBRs currently represent only a potential – but challenging – solutions for sustainable buildings, the commercial innovations could also be dealt with as handprints of developer organizations. In that case a baseline would be needed to assess the benefit. In addition, a proper time frame should be defined.
Recommendations	The consideration of PBRs as specific carbon handprint issues is not recommended at this stage. However, the technology as such is interesting, and more information would be needed.

In addition to photobioreactors there are other technologies that may provide new solutions for carbon sequestration. Carbon uptake through direct air capturing (DAC) is a largely theoretical technique in which CO2 (and potentially other greenhouse gases) are removed directly from the atmosphere. In accordance to Geoengineering monitor (2018) the current technique uses large fans that move ambient air through a filter, using a chemical adsorbent to produce a pure CO2 stream that could be stored. To have any significant effect on global CO2 concentrations, DAC would need to be rolled out on a vast scale, raising questions about the energy it requires, the levels of water usage for particular technologies, and the toxicity impacts from the chemical sorbents used. In addition, safe and long-term CO2 storage cannot be guaranteed, either in geological formations where leakage is a risk or in products using CO2, where carbon is likely to end up back in the atmosphere one way or another.

Despite technical advances in the past decade, there are still misconceptions about DAC's current and long-term costs as well as energy, water, and area demand. However, according to Fasihi, et al. (2019) large-scale CO2 DAC systems would be needed to meet the climate goals even in a world with high levels of de-fossilisation. It is estimated that DAC capacities of 3, 470, 4798 and 15 402 MtCO2 are needed by 2020, 2030, 2040 and 2050, respectively. According to de Jong, et al. (2019) direct air capture of carbon dioxide (CO2) from ambient air has the potential to combat climate change. DAC systems capture CO2 using a sorbent material and compress it for storage. In their study, they calculated the life cycle carbon efficiency of a DAC system which equals the net amount of carbon stored per amount of carbon captured from capture to geological storage. They included greenhouse gas (GHG) emissions during construction of the necessary facilities as well as GHG emissions from energy, water and chemicals needed during operations. The system analysed includes a hydroxide solution as sorbent material and utilizes the pelletized variant of the Kraft process to regenerate the sorbent and separate the CO2. Using the baseline scenario, they obtained a positive carbon efficiency of 62%. For the optimistic and pessimistic scenarios, they found a carbon efficiency of 93% and 10%, respectively. Potentials and risks have also been described for example in Evans (2019).

Different kinds of improvements that lower others' carbon footprint

Green building certification schemes can be considered as an example of already existing socially accepted and collectively developed form of handprint schemes in the construction sector (Biemer, et al., 2013). The establishment of certification schemes has enabled the competition with sustainability issues and increased willingness to invest on sustainable / low-carbon solutions. From the viewpoint of an investor – for instance – the investment on office buildings certified as low-carbon/sustainable buildings would improve the carbon footprint of the actors that rent the premises. However, the certification schemes cannot be accounted as handprint solutions on the level of an individual building or a building project.

Product development that remarkably improves building projects carbon footprint compared to the best available / normally applied technology can be dealt with as handprint issue from the viewpoint of product developing industry. This kind of product development does good for others by making efforts and providing carbon saving solutions into the market. However, the development normally happens in the context and level of products – not in the level or context of building design or the development of house concepts. Thus, these handprints – good that is done for others – are advantages of manufacturers rather than investors. Examples of these kinds of handprints are given in the literature.

The new kind of elevator, called as MonoSpace, developed by the Finnish company KONE, was studied as an example of these kinds of handprints by Vatanen, et al. (2018). They present the example by defining the base case and by assessing the carbon handprint. The assessment is based on the idea that carbon handprint can only be based on savings enabled for others:

The KONE MonoSpace® 500 elevator is designed for passenger transport in residential and office buildings regarding both new and existing buildings with need for refurbishment. The potential customers range widely from housing companies and building owners to global real estate investors. The MonoSpace 500 uses innovative and energy efficient technologies for lifting, lighting and stand-by operations and thus has a potential handprint. It is an electric elevator, with a gearless traction drive system.

The challenge in this case study is to define the baseline solution, i.e., alternative reference elevator against which the KONE MonoSpace 500 could be compared. Elevator types range a lot from hydraulic to gearless and geared traction with different speeds, travel heights and loads, and manufactured from different materials in many locations by different manufacturers. However, as elevators are products with a long service life and energy is used for their operation, their use stage is the most important life cycle stage when carbon footprint is considered. The international standard (ISO 25745-2, 2015) defines energy efficiency classes for elevators, from A to G, depending on the energy consumption level per day. The energy efficiency classes depend on the specific running energy for the average running cycle. If the rated load, number of trips per day, average running distance and the non-running time per day are kept constant, the energy efficiency of different elevators can be compared based on these specific running energy consumptions. A simplified approach is to consider that the rest of the life cycle remains the same as that of the KONE MonoSpace. Thus, the energy consumption of the KONE MonoSpace 500 can be compared to these other energy efficiency classes and the handprint of the KONE MonoSpace 500 can be estimated.

(Vatanen, et al., 2018) also presents an example regarding renewable diesel produced by Neste. In this case aslo the base case amust be defined to assess carbon handprint. Again, the assessment is based on the idea that carbon handprint can only be based on savings enabled for others:

The fuel is produced from used cooking oil. Neste's customers have the potential to reduce their traffic-related greenhouse gas emissions by using the diesel produced from renewable and waste-based raw materials. According to (EC Directive, 2009) waste and residue-based raw materials have zero lifecycle greenhouse gas emissions up to the process of collection of those materials. In this case, the biogenic carbon intake equals the number of released biogenic carbon emissions, resulting in zero net biogenic CO2 emissions. The *renewable diesel needs to be compared to fuel(s) that similarly provide motive power for diesel engines. When considering consumers as the customers, they have a vast number of possible fuels to choose; thus, no specific baseline product can be defined for comparison. Therefore, the average diesel fuel sold and used in Finland during the previous full year (2016) was selected as the baseline fuel, consisting of a mix of fossil diesel and 12% bio-based diesel (LIPASTO, 2017). Annual statistics of market-area-specific fuel consumption are likewise well suited to be used as a baseline.*

Regarding all these improvements that lower carbon footprint of others, the danger for double-counting is obvious. When an organisation that has invested on low-carbon innovations/ solutions, they will make use of the result by assessing quantitatively "the good they have done for others". At the same the organisations that rent innovative low-carbon premises or build a low-carbon building with using low-carbon innovations also want to make use of the low-carbon advantages in marketing and competition in the market. One solution could be that these kinds of handprints are only allowed for organisations while at the same time the benefit is also considered as reduced emissions in LCA calculations of buildings (without calling these benefits as handprints).

One possibility for doing good is also by investing for example for local renewable energy project and thus promote the availability of renewable energy. However, this comes close to the compensating actions that are dealt with in the next Section.

As shown in previous Sections, versatility, recyclability, offering space for renewable energy supply are also issues that can considered as handprints. These are building scale performance issues that may help to reduce the carbon footprint of other buildings or units:

- with the help of versatility, it may be possible to avoid new building and offer an existing space for multiple use (see Section Versatility)
- with the help of offering space for renewable energy supply it may be possible to enable the use of renewable energy in near-by buildings and thus reduce their emissions (see Section Offering space for renewable energy)
- with the help of supplying surplus energy, it may be possible to reduce the need for electricity generation (see Section Surplus energy).

Table 15. Viewpoints for CARBON FOOTPRINT IMPROVEMENTS FOR OTHERS as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	When considering "doing good for others" as a carbon handprint, the benefit is the assessed saving that takes place because of this improvement compared to a defined baseline.
Time frame and related problematics	A timeframe needs to be defined because the exceptional nature of any excellent innovation ends at some point when others have also been able to improve their services or products. Defining a right time frame is difficult. One alternative is to calculate only on annual basis considering one year at a time.
Example(s) of assessment results	Some examples have been studied and reported with quantitative results.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	The biggest difficulty is to define the baseline correctly. In many cases (as also shown in above examples) it is problematic to define a good reference point, because lack of comprehensive information.
Who benefits from this handprint	The benefit goes to the provider of the improvement. There is a true risk for considering the benefit twice. However, when looking at "green" innovations, the handprint – doing good for others - belongs to an organisation or actor, while the low GHG impact because of the innovation goes for the product (building) in which the innovation is used. Organizations' handprints and buildings' footprints are probably not calculated together.
Recommendations	The recommendation is to support the use of the handprint approach in the sense of "doing good for others". It may give significant motivation for doing low-carbon product development if there is an accepted procedure to report the significance of the innovation and use this information in developer organization's communication. However, organizations' handprint approach is not the focus of this report. Regarding buildings, all low-carbon innovations must also be considered on building level calculations. There is no real risk for overlapping calculations because the GHG impacts of buildings and different actors are hardly added up. The recommendation is not to call these as handprints as those are not either negative emissions, but just smaller emissions compared to other projects that may use more conventional solutions[12].

12 The draft for GBC Finland's report for carbon neutral building currently defines so that occupation related electricity consumption is not considered in calculations (as it is calculated in the context of energy certificates with the help of default values and as the building project itself has minor possibilities to affect). However, investment on low-energy/low-carbon domestic appliances can be considered as negative emissions calculated on the basis of the difference compared to typical.

Compensating actions

Emission compensation means eliminating one's climate impact or part of it by reducing the corresponding amount of emissions elsewhere. In practice, compensation means an emission removal unit that an operator acquires outside its own area of activity in order to offset greenhouse gas emissions from its own activities.

In addition to the mandatory emission compensations, many voluntary compensation services are available in the market. There are several forms and service providers for voluntary emission compensations. The main mechanisms by which compensation is carried out are the prevention of emissions and the removal of CO2 from the atmosphere. Emissions somewhere else can be prevented, for example, by purchasing EU emission allowance certificates or by financing renewable energy production that replaces the use of fossil fuels or by removing carbon dioxide from the atmosphere with the help of carbon sinks.

Usually, compensating actions mean buying and cancelling carbon credits or carbon offsets through a service provider. Emission units are produced in developing countries by projects that, for example, build renewable energy, protect forests from deforestation, afforest new areas, switch to more energy-efficient stoves or collect methane released from landfills. Projects are certified with the help of controls made by a third party against some standard and the reduction of emissions produced are calculated and defined with the standard methods. Once the emission reductions have been produced and verified, the allowances issued are numbered and added to the register where their ownership is recorded. When a unit is sold for compensation, it is cancelled in the register (Landström, 2020).

Natural carbon sequestration, which takes place without human intervention, should not be counted as compensation at all. Acceptable measures should restore or recreate an otherwise inoperable natural process and at the same time ensure that the natural process can continue for a long period - at least 100 years. Similarly, the maintenance of carbon stock in a situation where normal operation would release it into the atmosphere can be considered as compensation. An interview study carried out in Finland showed that reforestation, the restoration of swamps, and carbon sequestration of soil were considered as the most valid methods for compensation measures (Hildén, et al., 2019). Forestation is seen as one of the most important measures; the following list summarises benefits and problems related to forestation as a compensation measure:

- the main problems are unsure stability and longevity
- misuse of the measure may happen in countries like Finland where forestation regarding woodlands is required by law
- the risks for short life of the investment are especially big in developing countries.
- the protection of forests maintains the carbon storages when fires do not happen. For example, in Finland the amounts of wood in natural-state forests may be 500–600 tons per square hectare while the amount of wood in economically exploitable forests is roughly 100 tons/ha. The carbon storage of soil in coniferous forests may increase during hundreds or even thousands of years. Thus, protection may create a permanent sink.

Protection may, on the other hand, create pressures to harvest timber in other areas. However, as harvesting volumes have been continuously increasing, protection is eventually an important method for carbon sinks and storages.

There are several standards and services for compensation measures. A list of well-known services is given in Hildén, et al. (2019, p 32). For example, the Golden Standard is a non-profit organization that evaluates and verifies emission reductions. It is claimed that only projects of high quality from the point of view of renewable energy or energy efficiency are awarded. "Karbonautti" is a Finnish emission reduction broker that only accepts Gold Standard-certified projects as bases.

Similar criteria than those applied for mandatory systems have also been suggested for voluntary systems. These include the conformity of the project with a chosen standard or programme, verification of emissions reductions of the project by external verification, follow-up, and registration of the emissions reductions with the help of units, which are removed from the register and transferred to the new owner when those have been used as compensations. Based on the results of the Finnish interview study (Hildén, et al., 2019), the criteria for credible compensations can be summarised as follows:

- scientific basis
- effectiveness and clear added value
- adequate and demonstratable/assessable impact,
- permanence, and consideration of risks for instability
- external verification
- transparency and openness.

From the viewpoint of building projects – or actually, any kinds of projects -, the idea of offsets or compensations have aroused interest because of high emphasis on carbon neutrality goals and because of extensive difficulties in true and ambitious development of carbon neutral solutions. However – as carbon neutrality really is the final and necessary target, reducing project's and processes' emissions with the help of renewable energy, energy efficiency, carbon capture and storage is always a priority. Possibilities for compensation action should never reduce the interest to make efforts for own carbon reductions.

NollCO2 (Sweden Green Building Council, 2020) is a Swedish extension for building certification published by the Sweden GBC in accordance with systems Miljöbyggnad, BREEAM-SE, LEED and the Nordic Ecolabel. It aims to achieve a net-zero climate impact of a new building and allows the consideration of compensations. The description of the extension is at present available as a draft version (Sweden GBC, 2020) for the manual NollCO2 for New building. Regarding compensations, the manual says as follows:

Climate compensation takes place through the purchase of climate credits corresponding to one tonne of carbon dioxide equivalent (tCO2e). The climate credits are generated from projects and activities where greenhouse gas emissions are either avoided, reduced, or stored.

According to ISO 14021: 2017, climate compensation is defined as: a mechanism for compensating for a product climate footprint by preventing, decreasing of, or removal of, an equivalent amount of GHG emissions in a process outside the limits of the product system. For a climate compensation project to be accepted in NollCO2 must first be validated against the following requirements environmental integrity: Additionality, Durability, Measurability, Traceability and exclusivity, and Contribution to economic and social added value. NollCO2 projects can choose one of the listed climate compensation projects that meet the criteria for environmental integrity.

The Green Building Council Finland is currently preparing a definition for carbon neutral building. They say that the definition is urgently needed as several organizations have already set a goal for carbon neutrality. In accordance with the current definition, a building is carbon neutral when the sum of life cycle GHG emissions minus the potential benefits and compensations is zero (Bruce-Hyrkäs, et al., 2020). Regarding compensations, also considered are investments on renewable energy projects that enable and promote the availability of renewable energy. Examples of such arrangements include investment on the construction of a windmill farm or solar power plant outside the building project.

The Greenhouse Gas (GHG) Protocol is a partnership with multiple stakeholders (e.g. business, governments, and non-governmental organizations). The GHG Protocol develops internationally accepted GHG accounting and reporting standards and tools. These standards support organizations on how to measure, manage and report greenhouse gas emissions. The GHG Protocol is the most widely used international accounting tool for government and business leaders to understand, quantify and manage GHG emissions (Behm, et al., 2016). If avoided emissions are to be estimated, a project accounting method is required, using e.g. accounts for GHG reductions by quantifying impacts from individual GHG mitigation projects relative to a baseline (Behm, et al., 2016).

The BSI PAS 2060 Carbon Neutrality (2016) standard includes requirements for achieving and demonstrating carbon neutrality encompassing guidance on the measurement of carbon footprint (in accordance with ISO 14064 or GHG Corporate Protocol), carbon management plan for emission reductions, offsetting of emissions (carbon credits), disclosure of documentation covering emission reductions and offsets and final verification process (Behm, et al., 2016).

In accordance with EN 15804, a carbon offset is a reduction in emissions of carbon dioxide or other greenhouse gases made in order to compensate for an emission elsewhere. In accordance with (EN 15804, 2019) carbon offset processes are not part of the product system under study. Thus, carbon offset cannot be included in the calculation of the GWP. In addition, the effect of temporary carbon storage and delayed emissions, i.e. the discounting of emissions and removals, shall not be included in the calculation of the GWP. Neither the effect of permanent biogenic carbon storage can be included (embedded) in the calculation of the GWP.

Table 16. Viewpoints for COMPENSATING ACTIONS as a measure to create carbon handprint.

Aspect	Comment
Description of the benefit – what is the assumed handprint of the case	The benefit is the possibility to compensate own GHG emissions by supporting other projects that are able to cause emission reductions. These projects should create added value and cause adequate, solid, and assessable reductions. The credibility and value should be ensured with the help of verification and registration processes. The handprint is taken into account on the basis of the units defined and registered by a system provider.
Time frame and related problematics	Time problems are related to projects that should enable permanent sinks but the stability of which cannot be ensured. For example, forestation projects should be very long-term projects – at least 100 years.
Example(s) of assessment results	Not found.
Uncertainties of assessment; difficulties regarding modelling and calculating quantitative results	The difficulties are related to the assessment of the emission reduction caused the compensating actions and especially to actions that are not covered by verified programmes. In principle, the greenhouse gas impacts of any projects can be quantitatively assessed, but in practice problems may occur in the modelling of saving potentials (such as saving potentials because of an investment on windmill farm).
Who benefits from this handprint	Allowing the consideration of compensations in the calculation of climate impacts of buildings lower the overall carbon footprint of a building under scrutiny. Thus, the benefit goes for the building and indirectly also the actors that consider the building related impacts in the assessment of their own emissions. There is a risk for double counting when both buyer of the building and seller of the building (or its part)/the buyer of the carbon offset units consider the compensating actions.
Recommendations	Recommendation is to approve compensations as handprints in the assessment of climate impacts of buildings. Clear rules for building scale calculation are needed. In addition to rules, also practical calculation examples are needed to clarify and concretize. As there are many possibilities to utilize the benefits by compensating actions, not on building level, but also on organizational level, allocation principles are needed.

6 Viewpoints from LCA experts

The preliminary results of the study were introduced for the following three external LCA experts with the inquiry to ask about their views on the subject matter:

- Dr. Tove Malmqvist, KTH Royal Institute of Technology, Sweden (TM)
- Prof. Thomas Lützkendorf, KIT Karlsruhe Institute of Technology, Germany (TL)
- Dr. Rolf Frischknecht, treeze, Switzerland (RF).

All three participants have been involved in the development of the LCA methodology for buildings for over 20 years, both nationally and internationally. All three experts are participating in the IEA EBC Annex 72 - Assessing Life Cycle Related Environmental Impacts Caused by Buildings. Their views presented here are their personal views, and not representing the view of IEA EBC Annex 72 as a whole.

The experts received a short introduction of the handprint concept and a list of the handprints that were being investigated in this project. It must be noted that the experts did not get access to the draft report with detailed description of each handprint and the findings and recommendations. But as it can be seen from the expert comments and recommendations that they agree well with the general findings of this report and therefore there is a certain overlap in the experts' comments and the discussion and recommendations in Chapter 7.

The experts were asked to reflect on the following two questions:

1. Are you familiar with the idea of handprint, and if you are, what is the benefit of bringing the handprint into the greenhouse gas assessment of buildings?
2. Look at the list of handprints in discussion in our project:

- Can you give pros and cons for the use of those / some of the handprints selected.
- Please consider this in relation to the ongoing standardization work (EN and ISO) on LCA of buildings. Please consider positive and negative things with the use of handprints in relation to other declarations than LCA (e.g. building certification, carbon neutrality of buildings etc.).

The interview was on online meeting and lasted about 45 minutes. The experts got the opportunity to deliver written feedback after the interview.

General feedback on the concept of handprint

All three experts were familiar with the idea of handprint. However, the concept was relatively new to at least two of the experts, and they became familiar with it through the inclusion of it in the Finnish method for evaluation of the climate impacts of buildings. The following benefits and possible challenges or drawbacks were specifically mentioned:

1. Benefits:
    - structured discussion on “product-based” real net zero emission solutions
    - opportunity to implement two separate and binding targets: minimize footprint (not above X), maximize handprint (not below Y)
    - motivation for using approach as handprint: An addition to a footprint
    - good to see the potential in D or handprint, but not a part of the overall calculation.
2. Challenges/Drawback:
    - misuse of handprints for easy but only apparent net zero emission solutions
    - hiding emissions which need to be borne by third parties (utilities purchasing fed in electricity, future generations using recycled building materials)
    - needs to be a clear definition of what is the purpose, what is to be measured?
    - is it thought for motivation? Be careful of the use for greenwashing.
    - risk with quantification, how it will affect the limit value in legislation
    - risk of high footprint solutions covered by uncertain handprints.

Additional reflections were about what we really want to show with a handprint? All three experts raised the question if we want to have a footprint and a handprint in parallel? Here RF would like to keep them separate and define separate and legally binding benchmarks. TL mentioned a similar example of including both loads and benefits of the same “subject” is the evaluation of thermal comfort for people as it is included in sustainable building certifications (such as the German approach in DGNB and NBNB certifications). Here there are both minimum requirements for thermal comfort, and it is encouraged to be reached with lowest possible energy consumption.

The experts were also hesitant in using the handprint to show some benefits of the load in carbon performance. There were reflections about if it could be used as additional information, as we have for module D in LCA. It was considered if handprint can be a compromise for module D. Handprint can be a way to communicate it, because many dislike the idea of module D. But it needs to be an additional information (as it is now for module D) and not a part of the LCA calculation of the building.

TL highlighted the benefits or arguments for using the handprint approach if a national assessment system is limited to only including the loads. But this will be not in line with a full sustainability assessment. From his point of view (TL), we will see only a D2 to express avoided impacts in other places and systems as additional information (and you can call this "handprint"), but it is impossible to compare a carbon footprint with a carbon handprint (real impacts compared with additional information on possible effects elsewhere?

TM considers if the use of the concept of a handprint could be more motivating than the module D. The use of a handprint could be motivating for some actors in the industry. It could be motivating for organizations if some "positive things" can be declared – and here handprint can be used for this. And RF added to this that a care has to be taken so the concept will not be used for greenwashing products, and in this case, the building.

Specific feedback on the list of handprints

The experts were asked to give pros and cons to the list of the handprints, as well as to the concept as a whole. They were asked to consider this in relation to the ongoing standardization work (EN and ISO) on LCA of buildings as well as in relation to other declarations than LCA (e.g. building certification, carbon neutrality of buildings etc.).

A general reflection from the experts were that the list of handprints is long, and that there is no general consensus on how to quantify them all. It is an increasing demand that "everything" should be measured by LCA, and there are still many aspects to be improved for the aspects that usually are included in LCA. Therefore, by increasing the "subjects to be included in an LCA" requires far more research to be done.

Another reflection is that there is a big difference in what can be included in voluntary certification and what can be included in legislation. There is much more freedom within voluntary certification to use and test different indicators and change them after testing.

RF outlined three general recommendations, which were supported by the other experts:

1. Keep requirements on footprints and handprints of buildings separate; do not mix the two and refrain from a requirement which relates to the sum of the two. Footprints shall be minimized, handprints shall be maximized.
2. Classify the handprints listed according to:
   - NB: net balance approaches (LCA balancing “tricks”)
   - EC: economical compensation (CO2 certificates)
   - TR technical reductions (investments in (permanent) negative emission technologies).
3. Technical reductions, i.e. the investment in negative emission technologies, is considered to be the way to go. This is not the cheapest nor the easiest way. Technical reductions really contribute to net zero. The others are emission shifting measures and thus more of a “communication measure”. This is tentative but not helpful for reaching net zero CO2 emissions globally. And the technical reduction measures should be paid by those causing the emissions, not by society.

Since it was not regarded important to indicate specifically how each expert commented on the handprints and the questions, the comments from the experts to each handprint are anonymously listed in Table 17 below. However, some of the answers can indicate from which expert they origin from. For some handprints, RF classifies them according to his three recommendations above. For the report on the Swedish roadmap for development of legislation from 2027, the authors were asked to reflect on whether Sweden would also go for a handprint approach similarly to the Finnish proposal. TL, therefore highlights the handprints that were either suggested or not suggested to become handprint.

Table 17. Experts comments to the list of handprints.

Carbon sequestration and long-term storage in wooden product	• only temporal storage (postponing biogenic CO2 emissions) • the "carbon content" will become an additional information for products – so it will become possible to calculate the "carbon content" of a building as additional information. Carbon storage was excluded from the standards, but there is still an ongoing discussion. But if there is a carbon content of bio-based products, what about products made from coal and oil? • information that could be of importance for the sector to understand. Comparison of using the wood in building or incinerate for carbon fuels. Important to show that this delays the emissions. • propose to have as additional information on this topic in the Swedish roadmap for development of the legislation, from 2027[13].
Carbonation of concrete	• potential is small or negligible. Carbonation is undesirable in construction because of corrosion of reinforcing steel. Only post-consumer treatment of concrete may reveal a certain percentage. • not suggested as handprint in Swedish roadmap for development of the legislation, from 2027.
Carbon capture in the manufacture of building products	• this is not a handprint but an emission reduction technology (end of pipe solution) which leads to lower GHG emissions per ton of construction material. • questionable if this can be regarded as a handprint (this lowers the emissions in A1-A3, so why handprint?). But off course an important issue.
Carbon uptake through photosynthesis by trees and vegetation and accumulation of soil organic carbon	• natural carbon cycle, uptake not attributable to building • no connection to buildings, perhaps this can motivate investors to have more trees on the site • could be of interest if it can save already existing trees and vegetation on site (if that is meant by the handprint).
Surplus energy / energy positivity	• this kind of handprints are derived from the (virtual) difference of footprints of grid mix and (most often) PV electricity. Such handprints require an off-setting footprint. The footprint is on the PV electricity exported from the building and purchased by the utility. It equals the footprint of the avoided electricity (used to determine the handprint of exported electricity) • energy positivity does not contribute to the net zero emission situation of a country/region. It simply reallocates emissions to reach net zero buildings • surplus energy / energy positivity does not necessarily lead to potential benefits (only if system expansion is applied). Attributing the share of emissions to the exported energy does not create "benefits" • first of all, we have to define system boundaries (with/without user and use related energy demand) to check "surplus energy" /exported energy. Today there is a higher priority for a high self-consumption • in Germany, in some systems we have this as additional indicator "delivered energy to third parties" and as "negative cost/income" in LCC • in the Swedish roadmap, PV energy is included in the handprint since LCA for the Swedish requirements only include A1-A5. However, the Swedish roadmap proposed to include a voluntary "handprint" on the amount of exported energy (in an energy unit) – not any calculation of avoided GHG emissions or similar • classification "NB" according to recommendations above.

13 https://www.boverket.se/sv/om-boverket/publicerat-av-boverket/publikationer/2020/utveckling-av-regler-om-klimatdeklaration-av-byggnader/

Table 17. (Continued).

Offering space for systems that supply renewable energy for others + surplus heat	• this kind of handprints are derived from the (virtual) difference of footprints of grid mix and (most often) PV electricity. Such handprints require an off-setting footprint (see graph below). The footprint is on the PV electricity exported from the building and purchased by the utility. It equals the footprint of the avoided electricity (used to determine the handprint of exported electricity) • energy positivity does not contribute to the net zero emission situation of a country/region. It simply reallocates emissions to reach net zero buildings • surplus energy / energy positivity does not necessarily lead to potential benefits (only if system expansion is applied). Attributing the share of emissions to the exported energy does not create "benefits • this is a business case if you allow third parties to use the roof for BIPV, so you can create income and you can contribute (indirectly) to a cleaner energy mix. You can call this a "contribution of the building" – but as additional information. You can think about an indicator "usable area for BIPV and type a level of usage" as additional information, but not for performance based approach! • classification "NB" according to recommendations above.
Versatility	
Flexibility	
Easy disassembly enabling easy recycling or reuse of components and elements	• recycling may give rise to benefits (and loads) beyond the system boundary. Such handprints require an off-setting footprint. This footprint is shifted to the secondary materials made out of materials recycled. It equals the footprint of the avoided primary production (used to determine the handprint of recycled material) • this was always the idea of "design for deconstruction" and the main purpose for module D. Deconstructability is a technical characteristic • classification "NB" according to recommendations above.
Recycling and reuse of components and elements	• recycling may give rise to benefits (and loads) beyond the system boundary. Such handprints require an off-setting footprint (see graph below). This footprint is on the secondary materials made out of materials recycled. It equals the footprint of the avoided primary production (used to determine the handprint of recycled material) • during design this is an assumption/a forecast and not a fact. It is a potential – and this was the idea of Module D = recycling potential • classification "NB" according to recommendations above.
Reflectivity of building and its surfaces	• this is a technical characteristic. The effect is expressed e.g. in higher thermal comfort in the cooling period and a lower energy demand for cooling – there is no need for such information in a performance based approach.
Waste-based biogas supply	• if there is such a system in place in the building – using the waste of the users – this will reduce the energy consumption of non renewable resources/fossile fuels, but think about the emissions to local air.
Different kinds of improvements that lower others' carbon footprint	• if there is any kind of compensation in place this will reduce the calculated carbon footprint but not create additional benefits • classification "NB" according to recommendations above.
Compensating actions	• if this means purchase of CO2 certificates: Only 50% reduction is achievable, hence net zero is out of reach. Socially questionable. • classification "EC" according to recommendations above.
Carbon uptake through direct air capturing (DAC) of CO2 through ventilation machines	• only effective if it includes long term storage. • how this is building related?

7 Discussion

The European Union, its member states, many cities and other organizations are targeting huge reductions in greenhouse emissions and achievement of the carbon neutrality in short term. This will require extensive efforts including searching for all opportunities for natural and artificial carbon sinks. In addition to legal restrictions and sanctions for inducing emissions, it will be necessary to apply positive incentives to promote the development of low-carbon and carbon neutral innovations.

The purpose of this study was to collect information about potential climate benefits related to buildings and discuss the needs and usefulness of the handprint concept in the assessment and regulation of low-carbon building.

A carbon footprint is the amount of greenhouse gases released into the atmosphere by a particular activity. The need for an opposite approach - the handprint approach - has been argued by claiming that it brings about motivation for efforts to resolve a difficult problem. To motivate building professionals, building owners, and investors to voluntarily search for and implement new and ambitious low carbon solutions, information about the positive opportunities and understanding about the potentials of different alternatives regarding both carbon footprint and carbon handprint may be inspiring.

This study searched for information of several alternative issues that may have potential and significant positive impacts for low-carbon building. The study assessed the benefits and problems of these possible handprints. This section summarises the results and makes recommendations regarding the applicability of different handprint issues. The recommendations focus on the usability of each handprint issue especially from the viewpoint of building regulations. If handprint approach would be considered in the formulation of rules that aim at regulating low-carbon building, it would require the existence of clear rules for assessment.

In the following text, we use the term handprint as a synonym for “potential benefit beyond the system boundary”.

Carbon sequestration and long-term storage in wooden building products

Carbon is sequestrated trough the growth of wood and it is potentially stored in wooden building products in buildings for a long time. An essential issue that affects the justification of this phenomenon as a handprint is connected to two issues: the effect of wood use on further growth and carbon uptake of forests and the length of storage time. Research results indicate that the process may open opportunities for renewal of forests and enable climate benefits, though from a shorter-term viewpoint, harvesting of wood causes a bigger carbon loss in the forest than is the carbon content of wood. Regarding the permanency of storage, the service life of the wooden framework at least equals to that of the building. The significance of this handprint – calculated as negative CO_2 emissions – is big compared to the embodied emissions of a wooden building. This potential benefit is well recognised, a lot of research results is available about the justification, the calculation methods have been standardised, and the use of the indicator on building scale is easy. However, the recommendation is to discuss the adequacy of the criteria given in standards regarding the quality of forestry and permanency of storage and specify the criteria if seen necessary.

Carbonation of concrete

Carbonation of concrete happens slowly during the service life of concrete structures and when recycled or used in landfilling after end of life. During carbonation, a part of the CO2 released in the calcination of Portland cement reacts with the hydration products of cement.

The process depends on concrete's pore structure, cement type, and other properties and the ambient environment, and it normally proceeds slowly. The process is an unwanted phenomenon in reinforced concrete structures because of the simultaneous impair of the protection provided by concrete for steel reinforcement. However, carbonation means true uptake of CO2 from the atmosphere and its significance especially after disassembly could be increased with the help of active methods of carbonation after concrete's end of life.

Carbonation is a well-known phenomenon; methods for modelling and calculation exist. The effect of carbonation can be considered on building-level calculations. Carefully assessed carbonation (negative emissions) during B and C phases could also be added up with A phase (positive) emissions. Thus, there would not be necessary to call carbonation as a handprint. However, much more uncertainness is related to D phase, and it entirely depends on actual treatment methods; the benefit will come true only with the help of active methods. Regarding D phase, separate consideration of the potential benefit is recommended. Recommendation is also to further develop methods for defining valid scenarios.

Carbon capture

Carbon capture and storage technologies involve the capture of carbon dioxide from fuel combustion or industrial processes. There is no broad consensus about the maturity of the technology. Regarding the calculation method of emissions, there are no specific problems. Carbon capture takes place in phase A1 of the building's life cycle. Thus, there is no reason to consider it as a handprint issue on building-level calculations. The benefit would naturally be visible in low carbon footprint of a building constructed with the help of products that are low-carbon in nature because of the application of carbon capture technologies. However, in transition phases towards zero-carbon products, a separate recognition of investment on exceptionally benign products might be good.

When a manufacturer of a product is able to bring into the market exceptionally beneficial products because of carbon capture and thus significantly lower the carbon footprint of those who use these products (as for example some steel or cement manufacturers may be able do in the future), results of efforts can be seen as the product manufacturer's handprint – rather than product's handprint. This requires the definition of the base case towards which the benefit is compared and a time frame. However, this is an issue that should be considered on product level, not on building level.

Carbon uptake through photosynthesis by trees and vegetation and accumulation of soil organic carbon

Carbon storage in terrestrial ecosystems can be enhanced by increasing the sequestration of carbon into growing trees and vegetation and the accumulation of soil carbon. Changing land use to ecosystems that sustain higher soil carbon stocks belongs to potential approaches that increase soil carbon stocks. Also soils and green areas in urban areas can uptake significant amounts of carbon. Carbon uptake and accumulation of soil carbon could be an important issue regarding a building projects' carbon benefits / handprint when building on brownfields though the opposite may be true when making use of greenfields. However, the sequestration happens slowly during decades and the construction of new areas causes emissions in the beginning. The carbon uptake can vary considerably depending on environmental and management issues leading to different kind of growth and mortality. The assessment of soil carbon accumulation has typically not been considered in case studies because of lack of knowledge and methods.

This indicator is not yet mature enough to be considered in the assessment on the level of buildings or building blocks together with green areas. The recommendation is to develop more knowledge and better methods for assessment. When the phenomenon is considered in case studies, the recommendation is to assess the handprint separately from carbon footprint because of significant differences in time frames to be considered, uncertainties in the development of needed scenarios, and because of differences in the level of development of assessment methods.

Surplus energy

A building equipped with an on-site energy production system[14] and connected to grid can supply surplus energy to the grid for the use of others. The supply of surplus energy can be made possible with the help of installation of renewable energy technologies. Although the surplus energy can be considered as avoided (”negative”) energy regarding the energy balance of the building, the surplus energy does not have negative or even zero emissions. Its carbon footprint is based on the embodied carbon footprint of PV or other installations. The surplus energy may cause savings in emissions and it can be considered as negative emissions only when it is compared to a chosen baseline such as average carbon footprint of electricity generation. The assessment of supplied energy should happen with the help of advanced energy performance assessment methods; an hourly-based modelling is necessary at least. The climate benefit goes to the building that provides the surplus, but an important question is also how the embodied emissions are allocated to the exported energy. Further rules are needed for the calculation of emissions. Here it is recommended that the saved emissions are calculated on the basis of the emissions of the substituted energy. It is also recommended that the embodied emissions are allocated to energy that goes for own use

14 A building which is exporting energy to the grid is not necessarily an ”energy positive building”. According to the French definition, a building is ”energy positive” if exported energy is equal or higher to energy imported from the grid. This is close to the concept of NetPositive developed in (Norris, 2015).

and exported energy on the basis of the assessed shares. A harmonised method is being developed in the context of EN 15978 renewal. In the future the renewed harmonized methodology needs to be considered.

Versatility

Versatility is an ability to accommodate different functions with minor system changes. Versatility can reduce the required floor area, costs, resources, and emissions when calculating per user or hours of occupation. Versatility can also reduce mobility needs and thus also traffic emissions when different activities can be organised in one premise. The potential benefits of versatility arouse much interest especially among cities, and other big building owners and investors. When estimating the saved emissions because of saved floor areas, calculation is complicated. This is because there is a lot of uncertainty in scenarios and because the potential savings happen during a long term. The recommendation is to take in use new reference units, calculation formulas and possibly also new monitoring methods to assess and show the climate benefits of versatility. These new methods are first recommended to be tested and possibly applied when assessing and monitoring existing buildings. Potential benefits become apparent only when calculations consider the utilization (number of users and/or number or person hours for instance). When assessing the benefits of a new versatile building, there is a need to formulate scenarios about “saved spaces”, which may be difficult. However, quantitative assessment methods need to be further developed before considering it as a building level handprint indicator. LCA may not be the best method but attention should also be given for qualitative assessment methods and results.

Flexibility/adaptability

The flexibility of buildings aims to adapt to changes in purpose or changes in external conditions, such as climate change, and the resulting needs to make changes in the building or its systems. Flexibility improves the environmental impact of a building because of more efficient use of space. Flexible buildings are likely to use facilities and materials more efficiently during the life cycle than other buildings. Flexibility probably also increase the total service life of the building. In addition, flexibility is linked to improved functionality; the building can be improved and optimised during the service life, for example, by improving energy efficiency. The idea of flexibility or adaptability is:

- to anticipate future changes since the brief phase, including changes of use, from office use to dwelling / residential use for example.
- to respect architectural and technical design principles, to be developed all along the design phases, from general dimensions to details as reversible connections or modular components.
- to use a semi qualitative/quantitative assessment method (some exists, to be adapted to the building type and the national context, or to develop a new one).

Flexibility and adaptability are not only carbon handprints but those also lead to various other benefits of circular economy such as preservation of resources, prevention of waste, reduction of financial risk for investors in the long-term, improved attractivity, functionality and comfort for users, more dynamic urban renewal, and fight against obsolescence.

In spite of many potential benefits related to flexibility, the quantitative assessment of future impacts is very difficult or even impossible. To promote design of flexible buildings, to consider flexibility in building regulations and to take its benefits into consideration when assessing and benchmarking low-carbon / sustainable buildings, better criteria should be developed to enable the regocnition and valuation of flexibility.

Easy disassembly

The main principles for easy disassembly are accessibility, independence, simplicity, standardization, avoiding unnecessary surface treatments, supporting re-use business models and safety in disassembly (20887, 2020). Easy disassembly is expected to save resources in the future, but following the principles of DfD may even increase the carbon footprint in phases A-C due to additional material use for joints etc. Potential benefits of the second use-cycle can be included in module D, but – in accordance with current standards - it is not possible to show additional benefits if the product or component has three or more use-cycles. Allocation of impacts to expected use cycles has been suggested. However, there is uncertainty in the realization of these scenarios and difficulties in the assessment of potential savings. The difficulties are related both to the uncertainty of the real reuse of the components and to the uncertainty of the processes and energy sources that will be replaced. If needs for new building and refurbishment do not disappear and at the same time there will be strong requirements for zero-carbon construction, the willingness to reuse and recycle and thus also the value of easy disassembly will probably increase. Thus, the recommendation is to pay much attention to the potentials of easy disassembly. In practice, it is important to anticipate the potentials for easy disassembly in very early phases of design process. However, the quantitative assessment methods for allocation of impacts are not yet mature for building level assessment. The recommendation is rather to put efforts in the development of more detailed criteria for DfD, new solutions for easy assembly, and getting more practical experience. Although we lack reasonable quantitative assessment methods which complicates the consideration of easy disassembly in the calculation of carbon handprint (or potential benefits beyond the system boundary in other words), easy assembly can be emphasized and promoted by building regulations. For example, according to the Finnish regulation instructions for care and maintenance are mandatory. The recommendation is to extend these instructions to cover a plan for disassembly that supports reuse.

Recycling and reuse of components and elements

EN 15804 (EN, 2019) includes methods for the assessment and calculation of potential benefits beyond the system boundaries. These are already applied in making environmental declarations for building products. The potential benefits based on recycling of products can be taken into account by adding up the product level benefits. The recommendation is to follow the current standardised rules.

Another topic for discussions is whether the potential benefits for other systems should be called as handprints or potential benefits.

On building level, the exceptional utilization of recycled products can also be dealt with as designers' / investor's handprint when the design result is extraordinarily low-carbon building. In that case a baseline and timeframe should be defined. However, regarding building's climate declaration, recycled products enable a low carbon footprint.

Although the recommendation is to follow the current standardised methods, the proposal is also to further discuss what are the expected consequences of considering recyclability benefits. If the footprint and handprint (potential benefit) would be added up, it would lead to double counting, because the potential saving is also considered in the LCA of the coming products based on recycled materials (or it would lead to the exclusion of one part of the emissions that are induced). In addition, the carbon benefit is probably exaggerated (if calculated with using present energy related emissions), because of very probable future changes in energy sources. When the footprint and handprint are not added up, the calculation method strongly favours recycled products. However, regarding metals, it does not lead to the more use of recycled metal globally because the degree of recycling is already nearly 100%. Naturally, it could cause that virgin metal products are replaced by other products such as wood when possible. It may be that carbon footprint and carbon handprint (or potential benefits in other words) are not the best indicators the use of which promote recycling and the development of recyclability. From this point of view the indicator secondary materials or content of recycled materials could be better indicators. These could also be considered on building level and limit values could be defined.

New low-carbon solutions and doing good for others

All new effective low-carbon solutions including innovative solutions for renewable energy technologies are extremely welcome. These are very much needed to solve the challenges that are faced in the development of design solutions for carbon-neutral buildings. The benefits of low-carbon solutions can be shown both on product and building level with the help of life cycle assessment and in terms of global warming potential indicator. Thus, the calculation of carbon handprint or calling these as handprints is not relevant.

However, from the viewpoint of developer organizations, outstanding innovations that help to solve challenges of carbon neutrality, can be taken as handprints. Putting efforts on development and achieving results that help the societies to achieve extremely important goals, is doing good for others who can utilise the innovations. To assess the significance of these kinds of innovations, a baseline is needed for comparison. In the cause of time, the value of innovation decreases as the solutions become common, and thus also a timeframe is needed. Unfortunately, here is also a true risk for considering the carbon benefit twice. However, when looking at low-carbon innovations, the handprint – doing good for others - belongs to an organisation or actor, while the low GHG impact because of the utilization of the innovation goes for the product (building) in which the innovation is used. Organizations' handprints and buildings' footprints are probably not calculated together.

In addition, investment on exceptionally good low-carbon appliances or other solutions that help occupants to save emissions because of use (when those are not considered on building level GHG calculations) could be dealt with as an investor's handprint.

The recommendation is to support the use of the handprint approach in the sense of "doing good for others". It may give significant motivation for doing low-carbon product development if there is an accepted procedure to report the significance of the innovation and use this information in developer organization's communication.

Surplus energy, offering space for renewable energy supply, versatility, design for easy assembly are also issues that can considered as handprints. These are building scale performance issues that may help to reduce the carbon footprint of other buildings or units.

Compensating actions

The benefit of a compensating action is the possibility to compensate own GHG emissions by supporting other projects that can implement emission reductions or sinks. A common recommendation is that the project should create added value and cause adequate, solid, and assessable reductions, which should be verified and registered to avoid overlapping use of the benefit. Attention must also be paid on the longevity of carbon sinks. Certification or labelling programs dealing with the validity and robustness of compensating actions are interesting tools, but still too few; they should be developed more widely.

If the consideration of compensations is allowed in the calculation of the carbon footprint of a building, it naturally lowers the carbon footprint of a building under scrutiny. Even if the compensating action is considered separately as a carbon handprint or potential benefit, there is a risk for double counting, when both buyer of the building and seller of the building (or its part)/the buyer of the carbon offset units consider the compensating actions.

Because of possibilities for motivation are very important, the recommendation is to approve compensations as handprints in the assessment of climate impacts of buildings. However, clear rules for building scale calculation are needed. In addition to rules, also practical calculation examples are needed to clarify and concretize. As there are many possibilities to utilize the benefits by compensating actions, not on building level, but also on organizational levels, allocation principles are needed.

8 Maturity assessment

The use of carbon handprint approach in parallel with carbon footprint requires the development of quantitative calculation methods. The following table assesses the maturity of current methods. The assessment is given in three classes where the most mature means that quantitative assessments are already possible with current methods, but the methods need some improvement, while two other classes refer to moderate or high needs of development. The middle class is also given for those handprints which already have a standardised method, but the solving of some existing problems is difficult.

Table 18. Assessment of maturity of calculation methods.

	Carbon handprint alternative	Problematic aspects from the viewpoint of assessment	Maturity of assessment technologies. * = much development needed. ** = development needed/current methods are not satisfactory. *** = some improvement of methods needed.	Relevant standards
1.	Carbon sequestration and long-term storage in wooden products.	Temporary nature of storage. Time scale of carbon uptake of forests. System boundaries regarding forests.	** regarding the consideration of time scales boundaries. *** regarding the calculation of storage.	EN 15804/A2 (2019). EN 16485 (2014), PCR for wood and wood-based products for use in construction. EN 16449 (2014), Wood and wood-based products. Calculation of the biogenic carbon content of wood and conversion to carbon dioxide.
2.	Carbonation of concrete.	Technologies for accelerating / amplifying concrete carbonation are not mature. Validity of scenarios. Time scale of carbonation after use.	*** regarding the carbonation phenomenom as such. ** regarding technologies to accelerate and dealing with scenarios.	EN 15804/A2 (2019). EN 16757 (2017), PCR for concrete and concrete elements.
3.	Carbon capture in the manufacture of building products.	Technologies as such are not mature. Rules for the definition of a base-case and timeframe.	*** (existing LCA methods enable the consideration of carbon removals in A1). ** regarding benefits for others.	EN 15804/A2 (2019) for the product level. CEN specific PCR standards for certain families of products.

Table 18. (Continued).

	Carbon handprint alternative	Problematic aspects from the viewpoint of assessment	Maturity of assessment technologies. * = much development needed. ** = development needed/current methods are not satisfactory. *** = some improvement of methods needed.	Relevant standards
4.	Carbon uptake through photosynthesis by trees and vegetation and accumulation of soil organic carbon (on-site).	Assessment method for soil carbon accumulation. Time scale of accumulation.	*	
5.	Surplus energy / energy positivity.	Rules for allocation of the embodied emissions of on-site energy system.	***	EN 15978, Assessment of environmental performance of buildings – Calculation method (2012, under revision). The ongoing revision of EN 15978 will provide a harmonised method on that question but, due to a lack of consensus among experts, there will probably be a default method and the possibility to apply an alternative one. The latter shares the embodied impacts between self-consumed energy (by the building) and exported energy in proportion of energy flows.
6.	Offering space for systems that supply renewable energy for others + surplus heat.	Rules of allocation.	**	
7.	Versatility.	Validity of scenarios if versatility is an option. Introduction of new units (instead of GWP per building area).	** regarding the validity assessment of scenarios. *** regarding new units.	ISO 20887 (2020), Design for disassembly and adaptability. No methods for impact assessment.
8.	Flexibility.	Validity of scenarios. Criteria for flexibility.	*	ISO 20887 (2020), No methods for impact assessment.

Table 18. (Continued).

	Carbon handprint alternative	Problematic aspects from the viewpoint of assessment	Maturity of assessment technologies. * = much development needed. ** = development needed/current methods are not satisfactory. *** = some improvement of methods needed.	Relevant standards
9.	Easy disassembly enabling easy recycling or reuse of components and elements.	Validity of scenarios. Criteria for easy disassembly and reuse. Time scale / consideration of probable decarbonisation of manufacturing technologies.	*	ISO 20887 (2020), No methods for impact assessment.
10.	Recycling and reuse of components and elements.	Criteria for reuse. Time scale/ consideration of probable decarbonisation of manufacturing technologies.	** regarding the consideration of problematic aspects *** if we accept the current methods which do not consider the aspects mentioned here.	EN 15804/A2 (2019), provides rules for consideration of carbon benefits beyond the system boundaries. CEN specific PCR standards for certain families of products.
11.	New technologies - Photobioreactors (artificial or enhanced photosynthesis) and DAC systems.	Immature technologies	***	EN 15804/A2 (2019). Enables consideration of carbon removals.
12.	Different kinds of improvements that lower others' carbon footprint.	Base case definition. Time scale for the consi-deration of the benefit.	**	
13.	Compensating actions.	Rules for allocation and consideration of overlaps. Durability of compensating actions on the long term.	**	BSI PAS 2060 Carbon Neutrality (2016). ISO/WD 14068 Carbon neutrality (ISO TC207/ SC7/ WG15, under development). Compensation is not in the scope of product and building LCA standards.

9 Conclusions and policy recommendations

Carbon handprint and carbon footprint

Carbon footprint of a product is the sum of greenhouse gas emissions and removals in a product system, expressed as CO2 equivalent and based on a life cycle assessment. As the emissions normally are far bigger than removals, we commonly consider carbon footprint as an indicator that expresses adverse impacts. In opposite to this, the carbon handprint refers to the good we do. The carbon handprint emphasises positive impacts for climate change, in contrast to the negative impacts denoted by the footprint concept.

Recent research has recommended carbon handprint approach because it opens the possibility to report potential benefits in contrast to negative impacts, and this may motivate entities to voluntarily search for and implement new outstanding solutions for low-carbon societies. As buildings belong to the main contributors of greenhouse gas emissions, all opportunities to encourage the building sector for significant climate efforts are important.

However, one problem related to the carbon handprint approach is related to the definition of carbon footprint as it already covers both emissions and removals. Therefore, Grönman and others (2019) have recommended to restrict the notion of (carbon) handprint to mean (carbon) benefits for others. This idea also brings the concept of carbon handprint very close to the idea of 'benefits beyond the system' as the positive impacts of module D are called in standards belonging to the family of "Sustainability of construction works". This approach is also recommended in this report when carbon handprint concept is connected to building regulations.

Carbon handprint in relation to benchmarks for buildings

On the other hand, it is important to allow and inspire forerunners to bring up exceptional solutions for low-carbon building. That is why we also recommend developing and exploiting benchmarks and climate declarations for buildings (as supported by (ISO 21678, 2020)). Exceptionally low emissions can be declared as positive achievements with the help of benchmarks. In addition, the framework of LCA based climate declarations could allow the explanation of the exploited climate innovation and its significance. An example could be a building built of zero-carbon concrete; the benefit could be separately noted in the building's climate declaration by informing the quantitative savings compared to ordinary solutions.

Manufacturers' carbon handprint

The idea of carbon handprint as a possibility for doing good for others can also be important for manufacturers of building products. When a manufacturer makes an exceptional innovation, the saving potential for others can be calculated and presented as a handprint - improvement that lowers others' footprint - of the developer organization. In principle, methods for calculation exist and are applicable though the determination of a baseline and timeframe is also required.

The recommendation is to enable the inclusion of benefits for others based on outstanding leaps in the reduction of greenhouse gases also in environmental declarations of products.

Aspects of building performance as handprints

Energy positivity, offering space for systems that supply renewable energy for others, easy disassembly, flexibility, and versatility are all building level performance aspects that potentially help to reduce emissions related to other buildings. We define these also as actual handprints. When quantitatively assessed, the result should not be added up with the assessed emissions of the building under study. Regarding easy disassembly and versatility, the calculation methods are not fully developed. Calculation requires decisions about details of scenarios, which easily leads to too simplistic picture. The recommendation is to further develop assessment methods and consider also qualitative methods. The recommendation is also to promote design for disassembly and versatility with other regulations than those making use of LCA. Mandatory life-cycle instructions giving information about disassembly and reuse would be one option.

Recyclability can also be included to the previous group of handprints linked to the aspects of building performance. Building-level high recyclability can be achieved with the help of using recyclable materials and products. Calculation method for the assessment of potential benefits beyond the system boundary have been standardised regarding products though some uncertainties are related to the results. Although the product-level results could basically be added up on building level, this is not recommended. The recommendation is to rather ask reports about the content of recyclable materials and consider the introduction of material passports in the context of service life plans and maintenance manuals.

Carbon storage in wooden products as handprint

Long-term carbon storage in wooden products in buildings has also been suggested and used as a carbon handprint. The essential question is, how harvesting of wood and its use as long-term storage in buildings affects the carbon balance of forest and future growth of wood. Although research results are already available, the recommendation is to further discuss and clarify the conclusions to strengthen the credibility of the benefit.

Compensating actions as handprints

In addition to positive performance aspects, potential benefits can also be achieved with the help of compensating actions. Regarding these, the main recommendation is to determine clear rules also considering allocation and risks for overlaps.

Carbon accumulation in soil and vegetation as handprint

The possibility to promote carbon accumulation in soil and carbon uptake by trees and vegetation in the context of parks and green areas related to buildings and built environment is an important issue. Only few studies have focused on the assessment of potentials. The recommendation is to support further research and development of assessment methods. However, the issue is more relevant in urban level assessment than in the scale of a building and plot.

Summary of recommendations

On the basis of these conclusions and recommendations the meaning of the term carbon handprint is the same as potential climate benefits beyond the system boundary. Our recommendation is, however, to also keep both the terms carbon footprint and carbon handprint. Depending on the context, the expression "potential climate benefit beyond the system boundary" may be better because of its precise nature, but in some other contexts, it will be good to speak about footprints and handprints because of their expressive nature.

As a summary, we recommend the following actions for policy makers:

- develop the content of buildings' climate declarations to enable the builders and designers to bring up significant climate innovations
- develop benchmarking to support positive and motivating presentation also regarding achievements in decreasing carbon footprint
- in the context of product manufacturers, restrict carbon handprint to climate benefits for others
- boost the further development of standards to offer a chance for manufacturers to report about outstanding innovations that help to reduce the carbon footprint of others
- promote the development of new methods – also qualitative – that enable the reporting of climate benefits based on aspects of building performance – such as easy disassembly, versatility, and recyclability
- encourage design for disassembly, recyclability, flexibility, and versatility with other regulations than those making use of LCA; consider introduction of mandatory life-cycle instructions giving information about disassembly and reuse
- promote the development of further information and clearer rules for the consideration of carbon storage, carbon accumulation, and compensating actions as handprints.

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