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How much is enough? Towards evaluating sufficiency strategies in residential buildings using Life Cycle Assessment

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Abstract. Greenhouse gas (GHG) emissions related to buildings are growing. While efficiency and renewable resources can only partly mitigate the impacts, sufficiency has been highlighted as a strategy with great potential. However, evaluating sufficiency strategies with Life Cycle Assessment (LCA) has several challenges, e.g. defining a suitable functional unit. There are few examples of LCA studies integrating sufficiency, and none related to the building sector. The present study investigates how LCA can be applied to assess sufficiency for residential buildings by using an additional comparison functional unit. Moreover, the influence of functional units is studied. The main finding is that a comparison showing the reduced demand for the evaluated product is required to assess the effect of sufficiency measures, in addition to the impact per functional unit. The solution evaluated is to provide an additional key indicator (comparison functional unit), measuring the saved demand. However, this is dependent on the reference used for comparison, requiring further studies to determine suitable values. Furthermore, including area per user or number of users as a reference flow would better reflect building function and size, highlighting crucial sufficiency strategies. In conclusion, this study confirms challenges in evaluating the sufficiency of buildings with LCA, although the evaluated approach provides a step forward to implementing Sufficiency LCA for buildings, effectively reducing the environmental impacts.

Keywords: sufficiency, LCA, building, design, density, functional unit

1. Introduction

It is widely known that buildings have a huge impact on the environment. Efficiency and renewable resources can only partly mitigate the waste and carbon footprint of the built environment. Improvements in energy efficiency and the use of sustainable resources are consumed by increased expenditure. In buildings, efficiency and renewable energy have historically been successful in reducing the impact per square meter [m²] of floor area. However, increased consumption through larger living areas per person offsets the saved impact [1], [2][3]. This, however, is not evident when using m² as the functional unit for building impact assessments. This motivates the inclusion of sufficiency in the environmental impact assessment of buildings.



The IPCC defines sufficiency measures as "a set of measures and daily practices that avoid the demand for energy, materials, land, and water while delivering human well-being for all within planetary boundaries" [2]. The concept of sufficiency thus focuses on reducing consumption through changed habits, lowering the demand for a product or service [4]. In general, sufficiency is recognized as crucial for stopping global warming and other climate transformations [2]. For example, studies on the Austrian [5], French [6], and Danish building stock [7] show that even with ambitious decarbonization pathways for the industry or increased use of bio-based materials, the projected rates of new construction do not allow for staying within the carbon budget, requiring additional sufficiency measures. However, the concept is not widely adopted and rarely included in official reports [8]. Furthermore, there are few examples of sufficiency in the built environment.

A common way to assess the environmental impact of products or services is life cycle assessment (LCA), widely used in numerous sectors and for various purposes. In Sweden, building sustainability is often assessed using frameworks such as Miljöbyggnad, BREEAM, and LEED [9]. Here, LCA is usually considered essential, making it a prominent tool for holistic building analysis. However, a review of sufficiency in LCA reveals few existing examples, with none related to the building sector. According to André [9], conventional LCA is inadequate for measuring sufficiency. Three possible reasons are discussed. Firstly, LCA compares equal functionality while sufficiency focuses on reducing consumption. Secondly, sufficiency lacks broad incorporation in society. Thirdly, LCA is oriented to the supply side through product focus, while sufficiency is focused on users on the demand side. Additionally, André highlights the difference in output, as comparing a reduction in product size or amount, all other things equal, could increase the environmental impact per functional unit [9].

1.1. Problem statement

In summary, tracing the effect of sufficiency measures is a challenge. The benefits of sufficiency approaches are difficult to quantify using conventional LCA methodologies. Few examples exist, and the effects of sufficiency in building projects are difficult to predict. For density, in particular, using m² as the functional unit for buildings does not display building size or the number of users. Furthermore, as sufficiency is based on reduction, while LCA requires equal functionality and amounts, the element of comparison required to determine the impact saved from reduced consumption is challenging to incorporate in conventional LCA.

1.2. Aim & Research question

The study aims to evaluate how LCA can be adapted to assess the effects of sufficiency strategies in residential building design. Furthermore, improvements for inclusion of sufficiency assessment in early-stage design LCA are suggested. This is done using the research questions:

1. What are the main difficulties with evaluating sufficiency in residential units using conventional building LCA?
2. How does the choice of functional unit influence the interpretation of LCA results with regards to sufficiency?
3. How can suitable reference values be defined to support the application of sufficiency LCA to the building sector?

2. Background

Sufficiency is an acknowledged but not widespread concept within sustainability literature [10]. Within architecture and the built environment, concepts that can be linked to sufficiency exist, such as tiny house living and co-living. However, the explicit term has not been used historically. In recent years, sufficiency has grown to reach the building sector as well, even if few examples still exist [3]. According to the IPCC [2], the implementation of sufficiency in the building sector should follow the hierarchical SER (sufficiency, efficiency, and renewables) framework to reduce the construction and use cost of buildings without reducing user well-being. Sufficiency in the building sector is focused on avoiding material and energy demand during building and material lifecycles, thereby dealing with the causes of human environmental impact. This is done through long-term actions driven by non-technological solutions, with the most important measurement being floor area per capita. Examples of sufficiency strategies mentioned in the report are density, multifunctionality of space, and adaptive reuse.

LCA in the building sector is to follow the standard EN 15978:2011. The standard divides the building life cycle into stages and modules, enabling a uniform reporting of results. Moreover, the standard stipulates that building LCA is to be attributional. The use of LCA in the building sector is promoted by its inclusion in numerous building sustainability frameworks. Furthermore, LCA in Sweden is actualized by the climate declaration, stating that the reporting of environmental impact for the production stage is mandatory for the category climate change.

André [9] identifies two LCA studies including sufficiency. He uses these and a third, ongoing study to define the criteria for Sufficiency LCA. The focus of the assessment is how the environmental impact and the functional output change with the sufficiency measures. The study divides the functional unit into four aspects - what (the product function), how much (the product amount), how long (for what duration), and how well (in what quality). According to André, the key difference in the comparison is that the what-component remains the same, the others can be non-equal, and the product can still pertain to the same functionality.

André suggests a comparative approach with options that are similar but with different functional outputs. The options all have to be accepted by users, making them functionally equivalent. Only reducing the functional output could cause an increase in impact per functional unit, assuming that other parameters are consistent. Therefore, the suggestion is to use a comparison functional unit, where both the decreased functional output from the sufficiency product and the output from the equivalent product without the sufficiency measure are visible. This facilitates the quantification of the difference in output provided by sufficiency, typically neglected in LCA, enabling a comparison of both functional output and environmental impact.

As the Sufficiency LCA method is general, a slight adaptation is required for buildings. Regarding density, the functional unit is the same, one m² of gross area, although the total amount required per building varies. The area will be considered the functional output, with the extra comparison aspect being the total area or area per person. This is missing in the conventional LCA, as the method and frameworks usually applied do not include overall building size or number of users. Furthermore, the application of Sufficiency LCA requires a conventional product or reference values for the comparison. This choice is crucial for the results – the property of the conventional product provides the benchmark for the saved effect.

3. Method

The method uses a case study approach. The case study is an office building from 1964 located at Heden in Gothenburg, Sweden, intended to be transformed into an apartment building. Nine design alternatives have been generated as part of a master thesis project [10]. Those include six sufficiency design strategies such as density, co-living, and flexibility. This study focuses on density, which in housing commonly refers to the residential area or number of residents per total project area. However, in the case study, this is simplified to dwelling size due to the area confinement of the transformation project and the comparative nature of the study [11]. Density as a sufficiency strategy refers to reduction of dwelling size or area per person.

This study is performed using two design alternatives from the 2024 case study and a conventional design created for comparison in a second master thesis [11]. The design alternatives were created as part of an exploration of the implementation of sufficiency in the Swedish residential sector. The two selected options, here called Small (originally Swedish Standard - small) and Large (Swedish Standard - large), hold vastly different unit types, with the small sufficiency design housing studios and 1-beds and the large option a mix of 1-, 2-, and 3-beds. More details about the case study can be found in [10], while details about the conventional design are provided by [11].

The evaluation follows three steps, each answering one of the research questions. In step 1, a conventional LCA following EN15978 is carried out. The functional unit is square meter of gross floor area, the most common functional unit in building LCA and required by Swedish climate declarations. This serves as the base case. In step 2, an alternative functional unit – per capita – is used. In step 3, an additional functional unit is introduced following the sufficiency LCA approach described by André [9].

3.1. LCA methodology

The LCA is performed with generic data from the Boverket climate database [12] and product EPDs. The study is geographically limited to Sweden, with a timeframe of 50 years, and limited to the impact category climate change. The modelling of the building is limited to one typical floor and does not include roof, basement, or entrance floor. The assessment is performed in Grasshopper, using plug-ins for energy demand and LCA calculations. The life cycle modules included in the assessment are A1-A5, B4, B6, C1-C4, and D. Modules B1-B3 and B5 are excluded because they are assumed to be zero for these materials. B7 depends on the number of users and is therefore excluded. The case study is a transformation project, and the design study keeps the existing structure regarding the exterior walls, slabs, ground, and roof, meaning that A1-A5 comes from new internal walls and the closure of existing windows using new opaque materials. This causes the impact from production to be low compared to new buildings, while the high U-value of the existing construction causes high impacts in module B6. More details about the LCA methodology used, materials, values, and results are provided in [11].

3.2. Reference values for sufficiency LCA

As the additional functional unit is based on comparison with a conventional product, reference values need to be defined. There are two ways to measure density, either total area or area per capita. In this case, the functional output is the total area or average area per person, while the comparison functional unit is the area saved. For these two ways to measure, three approaches for comparative reference values are evaluated:

- Using average apartment sizes in Sweden
- Using average area per capita
- Using a “conventional design alternative” without sufficiency measures

The first approach applies to the total area measuring and compares the area per dwelling to the average apartment sizes in Sweden, presented in Table 1. These are summed into a total area for the sufficiency design alternative and a corresponding total area for the Swedish average size of the same apartment types.

Table 1. Average apartment sizes in Sweden [13]

Apartment type	Size [m ²]
Studio	32
1-Bed	52.4
2-Bed	74.3
3-bed	93.7
4-bed	115

The summed areas for the two sufficiency designs are presented in Table 2.

Table 2. Total areas for Small and Large, adapted from [11]

<i>Small</i>			<i>Large</i>		
Unit	Reference [m ²]	Actual size [m ²]	Unit	Reference [m ²]	Actual size [m ²]
4*Studio	32	25.2	1-bed	52.4	42.2
Studio	32	40.3	2*1-bed	52.4	46.0
Studio	32	41.4	1-bed	52.4	52.8
Studio	32	41.5	2-bed	73.4	63.8
Studio	32	43	3-bed	93.7	70.5
2*1-bed	52.4	46.0	3-bed	93.7	72.6
2*1-bed	52.4	46.2	3-bed	93.7	74.2
Total:	465.6	451.4	Total:	564.1	468.1

The second approach applies to the area per capita measuring and uses the average area per person in Sweden, which is 42 m² [14]. The total area and area per capita for options Small and Large are presented in Table 3.

Table 3. Average area per capita, adapted from [11]

Design option	Total area [m ²]	Number of inhabitants	Area per capita [m ²]
Small	451.4	17	26.6
Large	468.1	24	19.5

The third approach applies to both ways of measuring data, comparing the tested product (floor plan) with a conventional design of the same purpose. This currently needs to be developed per project and is possibly the most accurate reference, although also the most time-consuming. The conventional design does not focus on sufficiency, holding for example individual washing machines and desks. The values for the conventional option are presented in Table 4.

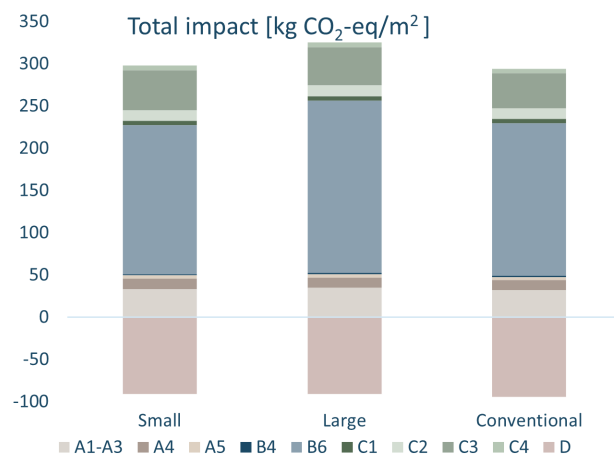
Table 4. Unit types, total area and area per capita for the conventional option, adapted from [11]

Unit	Size [m ²]	Residents
Studio	41.1	1
Studio	41.5	1
1-bed	58.5	2
1-bed	58.0	2
2-bed	58.1	3
2-bed	58.7	3
3-bed	79.7	4
3-bed	79.1	4
Total:	474.7	20
Area per capita	23.74	

4. Results

4.1. Step 1 – conventional LCA

The objective of the first step of the assessment was to investigate whether a conventional LCA can quantify the impact of applying sufficiency measures.

**Figure 1.** Total impact per m² using conventional LCA, adapted from [11]

The results presented in Figure 1 confirm the difficulty in tracing differences in density or size using m² as the functional unit. The differences between the options are relatively small, and there is no indication of the number of users or the overall size of the building.

4.2 Step 2 – capita as functional unit

The objective of the second step was to investigate whether a change of functional unit can better quantify the impact of sufficiency measures.

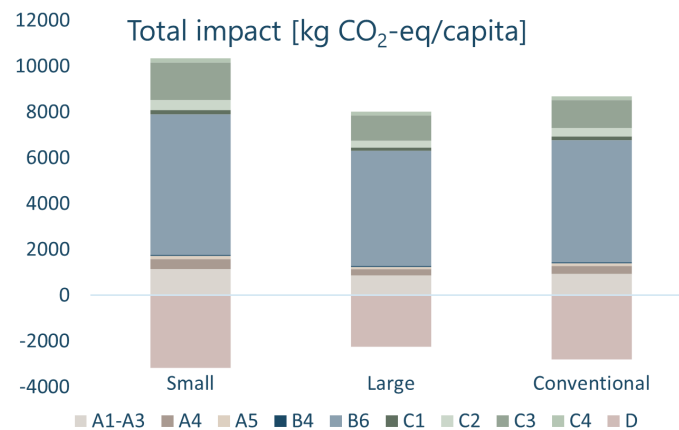


Figure 2. Total impact per capita, adapted from [11]

Figure 2 shows that the differences between the options are more visible. It can be concluded that the apartment sizes make a difference in density. The small option holds many studios and 1-bedroom apartments, requiring more kitchen and bathroom space. The large option instead focuses on larger units, such as 2- and 3-bedroom apartments, where lower area per person is achievable through less required bathroom and kitchen area per person. The comparison option is a mix, hence the results are in between the other options. Nonetheless, differences in size are more visible using capita than m² as a functional unit.

4.3 Step 3 –Sufficiency LCA

The objective of the third step was to investigate how the inclusion of an additional sufficiency functional unit can improve the understanding of the impact of sufficiency measures.

Measurement 1 – total area.

First, the total area of the sufficiency design options and the conventional design were benchmarked against a reference value calculated using average Swedish apartment sizes.

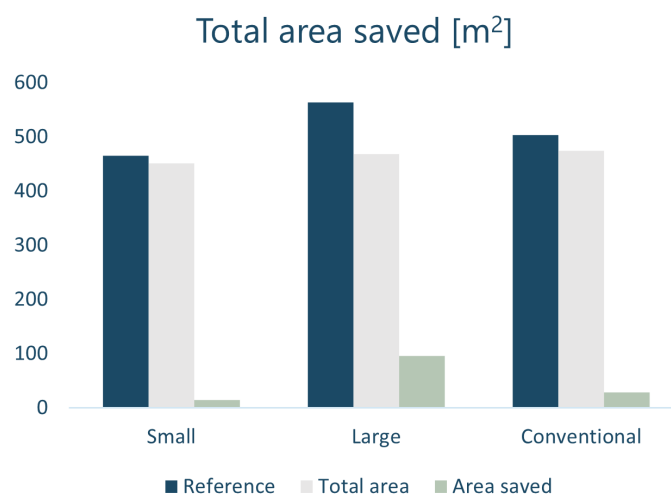


Figure 3. Total area saved compared to the summed reference values per dwelling, adapted from [11]

Using the average Swedish apartment sizes shows a small difference, and the same tendency in apartment types can be seen, with better density in the options with larger units.

Measurement 2 – area per capita

Second, the area per capita design options were benchmarked against the average residential area per capita in Sweden.

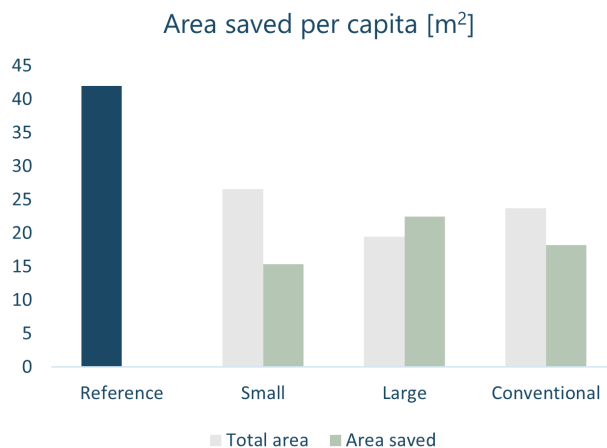


Figure 4. Area saved per capita, adapted from [10]

In Figure 4, a more significant difference between the layouts is visible. A concatenated value such as the Swedish average area is not representative of this building. These results show a difference in unit sizes and occupancy rates. When only looking at size, the units are similar to the Swedish average. However, when putting the area per person and sizes together, a large discrepancy between the intended area per person and the actual area per person can be seen.

5. Discussion

The first step of the study confirms the inadequacy of conventional LCA in the evaluation of sufficiency, with small traceable differences. No indications of the number of users, area per person, or total area are visible, meaning that total functional output is not reported.

The second step explores the use of a different functional unit [15]. Using capita as the functional unit enables the traceability of impact per user. Furthermore, it facilitates comparability between two buildings with equal functions and shows the intended occupancy of the building. Moreover, tracing your impact is easier as a resident. However, switching from square metres would provide less reliability, being a widespread measurement in society. Furthermore, comparing units or buildings of non-equivalent functionality is more difficult, as those spaces are concatenated into an average per user. Moreover, new frameworks and reference values would be required in the building sector to comply with this change.

The third step, using the area saved as the comparison functional unit, shows that the Sufficiency LCA approach can be considered successful in evaluating density as a sufficiency strategy, as the difference in impact between the design alternatives is traceable. However, the different approaches used for measuring area savings highlight the importance of reference values for the quantification of the saving effect. Using the average value of Sweden is too generic to provide an accurate value for similar residential buildings or units. Simultaneously, a discrepancy between dwelling sizes and the areas per person can be seen, showing that the occupancy in homes is generally lower than the intended density, indicating lower savings than expected. Comparing the sufficiency option to a conventional product would be the most realistic, although this also requires guidelines for comparison. In this case, the conventional option has different attributes than the two others, making the difference is smaller than expected.

Furthermore, this design should be developed on a case basis for optimal accuracy, requiring additional time and resources for the LCA modeler.

With this in mind, the most reasonable alteration to the conventional LCA would be to add a reference flow, showcasing the number of inhabitants or users per functional unit. This enables keeping the benefits of using m^2 as a functional unit. At the same time, sufficiency could be measured through the number of users to empower the visualization of area per person. This would enable comparability between buildings of the same function, where both environmental impact per sqm and the number of users could be compared for a realistic assessment of the building's use and function. Reference values or benchmarks for area per user could be developed for various functions, such as offices, hospitals, housing, and even specific rooms in a home. However, this would need to be carefully researched and curated, so as not to limit the core functionality of the space or impact quality in design.

6. Conclusion

Sufficiency is a growing concept, considered necessary for the mitigation of climate change. However, there are few examples in the building sector, and sufficiency is also rarely included in LCA, with suggestions that LCA is inadequate for assessing sufficiency strategies in terms of environmental impact. Furthermore, using m^2 of gross area as the functional unit provides no indications of size or number of users. This three-step study evaluates the suitability of using conventional LCA for sufficiency, examines the impact of using capita as the functional unit, and finally explores the implementation of Sufficiency LCA in the building sector.

The study confirms the challenges of evaluating sufficiency in residential buildings using a conventional LCA approach. The traceable difference between the design options is negligible, and there is relation between the impact and building size or number of users. The second step shows that using capita as the functional unit can effectively trace differences in density, although, this would be less relatable to the public. The evaluated method of measuring the saved demand using a comparison functional unit successfully displays differences between the design layouts, showing the area and the impact saved through increased density. However, this method is strongly dependent on the quality of the reference values used for comparison, therefore requiring further research or guidance. Nonetheless, Sufficiency LCA has proved successful in clarifying the effect of including sufficiency strategies in a design process.

Therefore, adding the number of users as a reference flow or extra unit would improve the measurability of sufficiency in LCA and provide a step forward for the implementation of sufficiency in the building sector. This would enable the measurement of density while keeping the advantages of using m^2 of building area as a unit. Finally, the inclusion of sufficiency in LCA provides a step forward for sustainability in the built environment, enabling a more holistic approach to assessing the impact of buildings.

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