Testing of PEF method to assess the environmental footprint of buildings – results of PEF4Buildings project

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Abstract. The aim of the PEF4Buildings project, commissioned by the European Commission, was to assess if the Product Environmental Footprint (PEF) method and related guidance documents developed in the framework of the Environmental Footprint pilot test phase are applicable at the building level. The project has been coordinated by VITO with TU Graz and KU Leuven as research partners. As a first step, two PEF studies on new office buildings were performed. The assessment of two office buildings allows to test the PEF method in different geographical contexts. In a second step, a possible approach to benchmark office buildings and to define classes of performance is developed. The approach is developed based on the findings of the PEF study on two new office buildings, the PEF guidance and dedicated desk research. It covers issues like how to define the reference building, how to define system boundaries, how many reference buildings should be defined and how to handle this range of different options. A third step of this study was devoted to the assessment at the building level and on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method.

1. Introduction
Due to the enormous energy and resource consumption linked to the construction sector assessment and reduction of associated environmental impacts has become a top priority on multiple levels [1]. The PEF4Buildings project fits within the European Commission’s Single Market for Green Products Initiative. The European Commission proposes the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) methods as a common way of measuring environmental performance. The approach is tested between 2013-2017 together with more than 280 volunteering companies and organisations. The aim is to understand the real potential of the methods before proposing new policies.

The PEF4Buildings project is commissioned by the European Commission and is carried out by the Flemish Institute for Technological Research (VITO), KU Leuven and TU Graz. The aim of the project is to test the applicability of the PEF method Guide (Commission Recommendation 179/2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations) and the latest versions available of the related guidance documents developed in the framework of the Environmental Footprint pilot test phase [2] to a new office building, and to provide an overview of pros and cons of alternative possible approaches to the definition of the benchmark and classes of performance for the typology of buildings within the scope.
of the study. The assessment and the overview will contribute to the development of a final approach to develop benchmark and classes of performance for different typologies of buildings. As a first step, a PEF study on two new office buildings is performed. The type of buildings (offices) was specifically requested by the EC in the request for proposals. Two buildings from different geographical regions (Belgium vs Austria) are selected in order to allow to test the PEF method to buildings located in different climatic contexts, with a variation in energy performance and built according to different national building codes. The first building is the office building BelOrta of BelOrta CVBA, designed by the architectural firm ar-te and built in Belgium. The second building assessed in this study is the office BE2226 of Baumschlager & Eberle, Lustenau, Austria. The BelOrta building is a business-as-usual new office building, while the BE2226 building is a nearly-zero-energy building.

In a second step, a possible approach to benchmark office buildings and to define classes of performance for newly built office buildings is developed. The approach is developed based on the findings of the PEF study on two new office buildings, the latest version of the PEF Guidance document available at that time [2] and a dedicated desk research which can be downloaded from the EC’s website (http://ec.europa.eu/environment/eussd/smgp/pdf/Matrix_lit_sources.xlsx). It covers issues such as how to define the reference building, how to define system boundaries, how many reference buildings should be defined and how to handle this range of different options.

A third step is devoted to the assessment at the building level, and more specifically how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method. The assessment starts from the results of the PEF study on the two new office buildings, but is extended to other possible European building typologies. Several workshops with stakeholders were organised during this project where the different steps were systematically presented, followed by an interactive discussion with the stakeholders.

2. Research questions
The main research questions of the PEF4Buildings projects were:

- How can the assessment of the environmental performance of construction products used in buildings be linked to the assessment of the building by using the PEF method?
- How can the results and experiences from the PEF assessment of a specific newly built office building be used to develop an approach for benchmarking office buildings and for the definition of performance classes?
- How can the results and experiences from the PEF assessment of a specific newly built office building be used to extend to other possible typologies of buildings?
- What are the lessons learnt and the recommendations based on the experiences and results of the PEF study for a new office building based on the assessment of the environmental performance of construction products?

The Product Environmental Footprint (PEF) is a Life Cycle Assessment (LCA) based method to quantify the relevant environmental impacts of products (goods and services) and organisations. It builds on existing approaches and international standards [3]. One important feature of the PEF method is that it sets the basis for comparability of the results.

3. PEF study on two new office buildings
3.1 Two building case studies
In order to test the applicability of the PEF method to a new office building (as requested by the EC), two case studies were selected, thereby ensuring the findings are not case specific nor geographical context specific. The first building is the office building BelOrta of BelOrta CVBA, designed by the architectural firm ar-te (figure 1). The BelOrta building is an office building built in 2013-2015 in Belgium. It is a compact building with an inner patio around which the workspaces are organised. The architectural firm ar-te provided the necessary data and inputs for the PEF study of this building. We have chosen this building because (a) a BIM (Building Information Modelling) model was available which enhanced the inventory phase of the PEF study and (b) it is a business-as-usual building
regarding typology, energy performance and technologies used. The second new office building assessed in this study is the office BE2226 of Baumschlager & Eberle, Lustenau, Austria (figure 2). BE2226 is a nearly-zero-energy-building without active cooling and heating. Also for this building a BIM model was available. This second case study allowed to test the PEF method on a building with a very high energy performance located in a different geographical context.

![BelOrta building of ar-te in Belgium](image1)

![BE2226 building of Baumschlager & Eberle, Lustenau in Austria](image2)

3.2 Element assessment method
A hierarchical decomposition of the building (element method) was used in order to avoid data gaps as much as possible and in order to allow for inventory data of various sublevels to be used for the assessment of the environmental performance at the building. The model structure is based on a hierarchical subdivision of the building in smaller entities: building elements, sub-elements and materials (figure 3).

![Hierarchical de-composition of the building](image3)

3.3 Functional unit and reference flow
The functional unit is one office building with a reference service period (RSP) of 50 years, assessed from the bill of materials according to the element method for cost control [7] (Table 1).

| Aspect     | Definition                              |
|------------|-----------------------------------------|
| What?      | Office building excluding the surroundings |
| How much?  | One office building                      |
How well? Energy performance and thermal comfort requirements met, relevant technical and functional requirements

How long? 50 years RSP

The reference flow is the amount of products needed to fulfil the defined function and shall be measured in m², m³, kg and pieces as necessary for the various building elements and components. All quantitative input and output data collected in the study are calculated in relation to this reference flow. For the purpose of this study the building as a whole is considered, without the infrastructure for accessing the building. The reference flow is inventoried at the level of building element, sub-element and materials.

3.4 Scope
The system boundaries for the two PEF studies were defined from the perspective of the designer/architect. This means that everything that the designer/architect can influence has been included in the system boundaries, but everything the designer/architect does not control directly is excluded (e.g. paper, furniture, commuter transport). It was moreover chosen to exclude the parts of the office building which are not necessary for the functioning of the office building, such as kitchen/catering. This is seen as important to make fair comparisons of the environmental footprint of office buildings (i.e. benchmarking purposes) which not all comprise a kitchen. Furthermore, the PEF studies are limited to the building as such and exclude the surroundings (e.g. parking lot).

Figure 4 presents the system boundary diagram for the assessment at the building level. The diagram indicates the three levels of situations according to the PEF Guidance document indicating the need for specific data. The diagram moreover distinguishes foreground and background processes and material and energy flows.

Figure 4. System boundary diagram for assessment at building level

Based on a cross-analysis of the life cycle stages defined in the draft PEFCRs for the construction products within the PEF pilot phase and the EN norms related to construction products (EN 15978/EN15804) the life cycle stages (LCS) presented in Table 2 have been defined for the PEF assessment of the two office buildings. So the assessment considers all upstream stages (production of building materials/energy equipment), including transport to the construction site as well as downstream stages (demolishing of the buildings after reference service life and end of life treatment). For the use phase energy and water consumption, as well as replacement, maintenance and refurbishment activities are included. So the assessment is performed from the cradle to the grave.

Table 2. Life cycle stages for the assessment at building level

| LCS name | Description |
|----------|-------------|
| PEF_A1   | Pre-processing and acquisition of raw materials and packaging of raw materials |
PEF_A2  Transport of the raw (engineering) materials to the production site
PEF_A3  Manufacturing of the construction products and the related packaging
PEF_A4  Transport to building site
PEF_A5  Construction - processes necessary for the construction of the building, including all ancillary materials, End-of-Life (EoL) of the packaging material disposed, any losses during construction
PEF_B1  Use stage
PEF_B2  Maintenance
PEF_B3  Repair
PEF_B4  Replacement
PEF_B5  Refurbishment
PEF_B6  Operational energy use
PEF_B7  Operational water use
PEF_C1  Dismantling
PEF_C2  Transport to EoL
PEF_C3/C4  Disposal at EoL (sorting towards the EoL treatment, recycling, incineration and landfill of all materials at the EoL of the life of the building)

For each life cycle stage specific scenarios were developed for the assessment of the environmental impact at building level. In defining such scenarios, the PEF Guidance as well as the draft PEFCRs, EN norms and national norms have been used. These scenarios are mainly focusing on:

- Assumptions related to construction process stage: e.g. transportation of construction products from manufacturers to building construction site, but also the construction process;
- Assumptions related to the use stage: scenarios for the use of the installed construction products in the building, maintenance of the building, repair activities, replacement activities, refurbishment activities, operational energy use and operational water use;
- Assumptions related to End of Life stage: scenarios for the de-construction, reuse, demolition, recycling and disposal; including all transport.

For the purpose of the PEF assessment rules for allocation at building level and at product level have been identified:

- At building level, the allocation of the impacts of re-used building elements could be discussed but was not part of this study as the focus was on new office buildings. Defining allocation rules related to the impacts shared between previous system boundaries and next system boundaries will be necessary when making a PEF study of renovated buildings;
- At product level the allocation follows the approach for the handling of multi-functional processes in the PEF Guidance [2].

3.5 Data model

The complexity of an assessment at building level requires the use of several tools during the various steps of development. Therefore, a process flow connecting the relevant data, processes and tools was elaborated for this project (Figure 5). First of all, sources to define the necessary information on building elements, building materials, scenarios, use phase were identified in the data gathering process. In a second step, a building element catalogue of the building components was developed in a spreadsheet (Excel) and are the main input for the life cycle impact assessment (LCIA) in the LCA software (SimaPro).
3.6 Results and conclusions

The aim of this PEF4Buildings project is to test the applicability of the PEF method to a new office building, as specifically requested by the EC. With this goal in mind the aim is not to focus on the PEF results for the two office building as such but to learn from the assessment in terms of pros and cons (e.g. methodological challenges) when applying the PEF method to office buildings and to develop some recommendations for future developments in this area. That is why we will not discuss the environmental profiles of the two buildings but focus on the methodological challenges during course of the assessment as specifically requested by the EC. So the results in this paper are presented and interpreted with this overall goal in mind.

The challenges and issues that people meet while using LCA at the building level are also valid for PEF assessments. PEF specific issues are mainly the availability of PEF compliant datasets and the quality of generic datasets (not always PEF compliant). As the PEF endorses the use of the Circular Footprint Formula (CFF) it is recommended that all generic datasets allow the application of the CFF formula. This should be a recommendation for further development. The PEF compliant datasets purchased by the EC are seen as an important step in that direction. Other learnings gathered during the life cycle inventory phase are:

- Clear guidelines are needed to model the use phase;
- National scenarios are needed (e.g. for products for materials/building elements for which no draft PEFCR are available);
- During data gathering, the BIM model proved to be an important source with added value.

The LCIA results of both case studies were calculated according to the PEF Guide. It is important to note that two different modelling approaches were applied to the two case studies in order to learn from the differences. The BelOrta Simap pro model follows strictly the hierarchical structure presented in Figure 3, while the BE2226 Simap pro model is made on material level in order to test implications of different modelling approaches. The difference in modelling has mainly consequences during the interpretation of the results. More specifically, the BelOrta model allows to gain insight in the contribution of a material applied in a certain element to the total building impact, while the BE2226 model provides insight in the contribution of a certain material to the total building impact. For example, the BelOrta model gives the impact of concrete in inner walls and in outer walls separately, while the BE2226 model provides the impact of concrete (in all building elements aggregated).

As this project didn’t intend to focus on the absolute values and results obtained, but aimed at understanding the methodological aspects of calculating a PEF of an office building, the numerical
results of the study are not reported here. Although the intention of the two assessments of the two cases is not to compare their LCIA results in detail, some important outcomes can be highlighted:

- Firstly, the overall weighted score of the two buildings differ significantly: the BE2226 building clearly show a lower impact than the BelOrta building. This was expected as the second case (BE2226) is an advanced building (NZEB) while the first case (BelOrta) is a business-as-usual case. However, it should be noted that the building control system (including sensors, control panels…) and piping is not modelled for the second case because of lacking data. Furthermore, the two buildings have the same use and a similar size in terms of floor area but represent different building typologies;

- Secondly, the most relevant impact categories identified differ between the two cases. The most relevant impact categories hence clearly depend on the building (energy performance and materials used), but also on the location (electricity mix). This is important if the aim is to limit the impact categories of PEF4Buildings to the most relevant ones. We can furthermore conclude that several of the most relevant impact categories are ‘additional’ impact categories which are not included in the current version of the EN 15804 and EN 15978;

- Thirdly, for both buildings the operational energy use and the pre-processing of raw materials have been identified being amongst the most relevant life cycle stages. However, for the BelOrta building, the use phase contributes significantly more to the life cycle impact than for the BE2226 building. As the use phase in the BE2226 building causes lower impacts than in the BelOrta building, additional life cycle stages become more relevant;

- Fourthly, the identification of the most relevant processes leads to a different set of most relevant processes for both buildings. This was expected as both buildings consist of different materials and elements, but are also located in a different location and hence a different electricity mix is used during the important use phase of the building.

- Finally, the inclusion/exclusion of the toxicity impact categories clearly influences the results to a significant extent, especially for the second case study.

4. Proposal for an approach for a benchmark and classes of performance for office buildings

4.1 Research method

In a second step, a possible approach to benchmark office buildings and to define classes of performance was developed. The approach that has been developed is based on the findings of the PEF study on two new office buildings, the latest version of the PEF Guidance documents available at that time [2] and a dedicated desk research on existing approaches. It covers issues like how to define the reference building, how to define system boundaries, how many reference buildings should be defined and how to handle this range of different options. The desk research focused on existing reports on building typologies, sustainability schemes, LCA guidelines (such as the EN 15978 norm and the draft PCR for buildings) and national methods or legal requirements (such as the E+C- method in France, DGNB and BNB in Germany, GWW in the Netherlands, MMG in Belgium). The results of the desk research can be downloaded from the EC’s website (http://ec.europa.eu/environment/eussd/smgp/pdf/Matrix_lit_sources.xlsx). The researched methods are compared on different aspects: the meaning and approach of the benchmark that is defined, how reference buildings are defined, the considered system boundaries, functional unit and reference flow, and the approach used to define performance classes.

4.2 Results

Several important differences were identified in the meaning and related approaches used for defining the environmental benchmarks of buildings. The literature review (http://ec.europa.eu/environment/eussd/smgp/pdf/Matrix_lit_sources.xlsx) revealed that various meanings of benchmarks of buildings are used, ranging from limit values (minimum acceptable performance), over a reference value (present state of the art, e.g. average) and best practice value (values reached in experimental or demonstration projects) to target values (values that can be reached
in medium- or long-term perspective). Depending on the meaning chosen, different approaches and sources are used to calculate the benchmark values, ranging from laws prescriptions, standards (for limit values), over statistical values and reference buildings (for reference values) to political target values or economic and technical optima (for target values). Building certification schemes, such as BREEAM or DGNB, typically use various values, i.e. limit, reference and target values, to define their benchmark and classes of performance. Current national benchmarks mostly represent a level-playing-field with a lower limit as a starting point. Their goal is to allow buildings with a lower value on the one hand, but also to avoid free rider behavior on the other hand. Nevertheless, benchmarks can evolve in time as technology advances and knowledge of the building stock grows.

Another differentiation noticed in approach followed in literature is the use of external versus internal benchmarks. The former is the most common and compares a certain building with a reference building differing in layout and material choice (sometimes also in energy performance). The inner benchmark is more rarely used (e.g. by LEED) and compares the impact of the design building with a reference building with only variation in materials (meaning that the propose-building is identical to the reference building in terms of layout, size and energy performance).

Some systems furthermore have defined a benchmark for each environmental impact category separately (e.g. DGNB), while others have defined a benchmark for the aggregated single score (e.g. The Netherlands). In the systems with benchmarks for each impact category separately, the final score is obtained by weighting the different scores on the different impact categories. The weighting of the different impact categories is then part of the methodology.

From the desk research we can conclude that reference buildings to determine the benchmark can either be real buildings representing the reference building, or can be virtual buildings (i.e. based on statistical analysis of a representative part of the national building stock). Such statistical analysis differentiates various building types, sizes, materials and energy performances.

“50 years” has been found as the most common reference study period for office buildings. A commonly used reference flow is “per floor area, per year”. Some studies suggest to take the function of the building into account, e.g. the number of work stations in the office building or the amount of people in full time employee equivalent. No relevant assumptions on cut-off rules or scenarios were found in the desk research.

In an issue paper of the PEF Technical Helpdesk guidance is giving on how to calculate performance levels for products (based on most relevant parameters and by determining market realistic minimum and maximum values). The desk research aimed at exploring if other methods are used to define performance classes for buildings in existing approaches. We can conclude that the aim of performance classes can be different and determines the approach to define performance classes. For the definition of performance classes, a lot of information is needed on the relevant buildings to be “represented” in different classes, to be able to set the desired thresholds. For that, just as for benchmarking, one needs to have an overview of the environmental impacts of the various buildings to be covered by the performance classes, which can be either real buildings or virtual buildings. In the case of performance classes, as the amount of data needed is large, generally virtual buildings are used. To set the thresholds between different performance classes, some systems rely purely on the relative improvement compared to the benchmark (e.g. 5%, 10% or 15% better than the benchmark). Other systems are based upon the statistical spread of the analysed building stock.

4.3 Recommendations
Based on the learnings from the desk research, we recommend to define a common EU method to calculate the environmental impact of buildings and a common EU methodology on how to define environmental benchmarks. This is needed in order to reach a harmonized approach in Europe. This could be reflected in a PEFCR for buildings which is in line with the PEF method, but provides more
specific guidelines for buildings. As sustainable building is more than environmental impact solely, such method could moreover be integrated in a broader assessment framework such as the LEVEL(s) framework [5]. If this is aimed for, the Level 2 “Comparative performance assessment” could be considered as a starting basis to further develop a common EU methodology for environmental benchmarks for office buildings in order to make meaningful comparisons between functionally equivalent office buildings. The Level 2 framework lays down rules to support the comparability of results at national level (without flexibility to reflect in methods between Member States) or building portfolio level. The PEF method can be used in this framework to fix certain key parameters and input data and assumptions used for calculations. The experiences gained and the tools developed during the PEF assessment of the two office buildings can give input to the so-called “overarching assessment tool: Cradle to grave LCA” within the LEVEL(s) framework.

It is furthermore recommended to calculate the benchmark values at national level in order to take into account external factors such as climate, construction practice and culture influencing the environmental impact of a building. It is also recommended to use a stepwise conservative approach, meaning that initially benchmarks are defined representing lower limit values and which gradually become more severe in time. This allows all stakeholders to get used to the method first and to ensure that the full market is included in a transition to sustainable building.

In order to define an environmental benchmark for office buildings, insight is needed in the average environmental impact of office buildings in Europe and on the variation of it throughout the building stock. This insight can either be gained from real cases or virtual cases. The first conservative benchmark should be set to allow all office buildings that fulfill minimum legal requirements on energy, water, fire safety, etc. To define the environmental impact fulfilling the improvement or target value, this can be based on best-practice buildings (experimental or demonstration projects) or based on virtual buildings with for example 30% less impact than the reference value (i.e. representing business-as-usual). In the second approach, the percentage reduction could either be based on a statistical analysis of building practice in the specific Member State or based on political targets set.

For the definition of reference buildings, building typologies must be defined that represent the building practice in a specific Member State. To calculate the environmental impact of each of the building types, the influence of the market variations on the impact of the building needs to be identified per building type in a dedicated statistical study. Market variation in terms of size, materials used and technical solutions are to be considered.

The desk research revealed that benchmarks can be defined to cover both material and energy impact of the building, or a separate benchmark can be defined for each. The project team recommends to have one benchmark including both material and energy impact. However, taking practical implementations into account, it might be easier to separate both (in a first phase) because energy benchmarks are currently already established in the EU Member States. Although material and energy impact can be separated in a first implementation stage, it is recommended that the same environmental indicators are assessed in order to allow for a smooth aggregation in the second implementation stage.

The desk research provided an overview of insights gathered, but it is clear that additional data is needed at the national level in order to define explicit recommendations on certain aspects that are relevant to defining reference buildings. Most countries lack a large database on non-residential buildings, and therefore the gathering of more data and the creation of databases are recommended.

Providing a clear reference flow for the assessment of buildings will greatly improve comparability of future studies. From a scientific point of view, the project team would recommend to define an appropriate functional unit for benchmarking that takes the function of office buildings into account, e.g. full time equivalents per year. However, energy performance requirements of buildings already established in all member states use m² floor area for all benchmarks defined in current certification
schemes of buildings. Therefore, taking practical implications into account and in order to allow consistent analyses of buildings, the project team recommends m² floor area per year as the most appropriate reference flow. When opting for m² floor area, it is recommended to define clear and strict rules on how to define the floor area: e.g. gross, net or heated floor area.

Further, it is recommended to assess the complete building and its elements: foundations, building envelope, inner walls and intermediate floors, including all finishes as well as technical equipment. Furniture, desks, IT equipment, kitchen and parking space should be excluded. Most importantly, clear rules should be defined in a PEF method for buildings. PEF recommendations can be followed related to cut-off rules and scenarios.

Although a benchmark should not differentiate between design (for obtaining a building permit) and post-construction phase (e.g. when 2 years in use), we recommend to define clear and different calculation rules on how to calculate the impacts in the design and post-construction phase when comparing these to the benchmark.

To avoid burden shifting or trade-offs between impacts, the project team recommends to have a benchmark for each impact category separately, as well as at the aggregated level. Once the most relevant impact categories for buildings have been identified, the benchmarks could be limited to the relevant impact categories only.

As data quality requirements are seen as crucial for benchmarking purposes in LCA, it is recommended to follow the same approach as in the PEFCRs. This ensures the necessary data quality and therefore the representativeness of defined benchmarks.

Starting from the benchmarks defined at national level, performance classes can be defined. If environmental assessment data is available on a large amount of buildings representing the office building stock, data on existing buildings should be used. If such data is not available, few representative buildings should be chosen and virtual variations of these buildings analysed. Market variations in terms of size, materials used and technical solutions are to be considered.

When the legal requirements define the lower limit of the first performance classes, and a statistical analysis defines the upper limit of the best performance classes, this range can be divided in five performance classes, as defined in the PEF Guidance.

5. Guidance for the assessment at the building level

A third step of the PEF4Buildings project was devoted to the assessment at the building level. It gives guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method. The assessment started from the results of the PEF study on two new office buildings, but has been extended to other possible European building typologies.

Existing methods to assess the environmental performance at the building level were screened during desk research. The results and references to the respective methods are published at the website of the EC (http://ec.europa.eu/environment/eussd/smgi/pdf/Matrix_lit_sources.xlsx)

It can be concluded that national systems are very valuable since they usually take national guidelines into account and therefore have the highest potential of complying with the local realistic situation. In case national Product Category Rules (PCR) for construction products provide guidance on the definition of the functional unit, this results in an easy link between the Environmental Product Declarations (EPDs) of construction products and the LCA at the building level.
It is recommended to develop a PEFCR(s) at building level in the future, which forms the basis for all (new) PEFCRs for construction products and should be aligned to existing PEFCRs at the construction product level, for example by consistent definition of life cycle stages. Currently, the number of life cycle stages considered is different in the various construction PEFCRs. The project team recommends to consider the life cycle stages as presented in Table 2. A clear reference flow should be defined, as described in the previous section, and clear rules should be defined at the building level for what is included or excluded and on cut-offs. Different PEFCRs should be developed for different building typologies and include national scenarios, for example on the use phase and for the dismantling/demolishing of the building. A differentiation in rules/guidelines is needed for PEF studies for design support/building permissions and ex-post construction. Clear guidelines to model the use phase and the reference study period and related references service lives are crucial. At building level, the PEFCR(s) for building(s) shall be clear on the procedures related to the allocation of impacts of re-used building elements (mainly important during renovation projects) by setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary (such as the reuse of pile foundation of previous building). At product level, the allocation should follow the approach for the handling of multi-functional processes in the latest version of the PEF Guidance document.

A more extended list of generic datasets is needed to model an entire building. It is therefore recommended to provide a common EF database for the most frequent processes, e.g. using PEF compliant datasets purchased by EC, with integration of the CFF formula in the datasets.

Another aspect that has the potential to increase the feasibility of an LCA at the building level, is creating a link with design tools (CAD systems and BIM systems), assessment tools and PEF compliant databases. This can make data gathering a lot easier and greatly reduce the time and effort spent by the LCA practitioner. As modelling a building is very complex, a more flexible parameter structure for the amounts of elements and materials has to be found to further support a parametric approach. We recommend a hierarchical decomposition of the building as shown in Figure 3.

Today only a few assessment tools can calculate all PEF-required environmental impacts. However, all PEF categories could be integrated into these tools in the future to avoid burden shifting. Most of the current assessment tools are focused on the construction phase because there is a lack of information from environmental profiles on building processes (maintenance, repair, refurbishment, etc.). All life cycle stages should be taken into account. It is recommended to use PEF/LCA software that allows to directly extract the LCIA results at the level of the building, at the level of the life cycle stages, at the level of the element in each life cycle stage, and at the level of the material/process. It would be helpful if in future the PEF/LCA software would allow to do the hotspot analysis (identification of the most relevant impact categories, life cycle stages and processes) directly in the software.

A critical review of all PEF studies of buildings is recommended to ensure that the assessment is fairly, completely and accurately reported and in line with the latest version of the PEF guidance document.

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