FACILITATING BUILDINGS' LIFE CYCLE ASSESSMENT THROUGH FLEXIBLE LCA TOOLS

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ABSTRACT

Several SBA (Sustainability Building Assessment) tools exist for the environmental impact assessment in the building sector. Since the majority support either certification or early design, they cannot facilitate the optimization potential of integrated SBA.

This publication presents the novel tool GENERIS®, which offers improved functions for buildings' Life Cycle Assessment, with focus towards BIM integration of LCA. An XSD-LCA scheme stages the data transfer of BIM models based on IFC4x2 standard to Generis®. Fragmentation of a building model in different LoDs and the automation of LCA through standard constructions is described. LCA follows in every phase of the planning process.

INTRODUCTION (LCA STATE OF ART)

Buildings share 19% of global total final consumption and 40% of resource waste, leading to environmental degradation, yet holding a high potential for contributing to GHG emissions-reduce. Due to their life span, the pollution they generate can have long lasting effects on the climate. Inefficiencies caused by unsuitable decisions can be related to the so far applied materials and technologies as well as the whole construction process itself. This complex living system includes several influencing actors, a large number of stakeholders and decisions that need to be monitored and coordinated.

If the environmental impacts taking place during different processes in the building sector are not monitored from beginning to end, undesirable usage patterns are created, which affect not only the users' quality of life but also act as a basis for wrong repeated decisions in the generations to come (UN-Habitat, 2017).

In order to achieve a holistically sustainable building design, expertise on environmental assessment has to be offered to stakeholders in order to reduce, e.g. the life-cycle-related GHG emissions of buildings. This occurs for instance by optimizing embodied emission investments for new construction or, in existing buildings, by promoting 'carbon-effective' investments for the refurbishment (Röck et al., 2020).

Environmentally aware decision-making is feasible with benchmarking and assessment tools for calculating the environmental profile of buildings and their components. Such instruments should not only be exploited on the conclusion of building design (in the business-as-usual scenario) but should be also included in the early decision-making and then in-depth over the whole planning process (Di Bari et al., 2019). Furthermore, they can also contribute to the creation of a common sustainability language for all the involved parties and reinforce collaboration between stakeholders already in the early design stages (UN-Habitat, 2017) (Battisti et al., 2019). Under these conditions, a number of sustainability assessment and benchmarking systems have been developed the last three decades starting from 1990 when BREEAM (Building Research Establishment Environmental Assessment Method) was introduced in the UK, as a first generation sustainability assessment tool. A number of labelling systems followed after: HQE (High quality of Environment), LEED (Leadership in Energy and Environmental Design), GREEN STAR, CASBEE (Comprehensive Assessment System for Built Environment Efficiency). The second-generation assessment methods such as DGNB (German Certificate for Sustainable Buildings) and LEnSE (Label for Environmental, Social and Economic buildings) were developed much later starting in the year 2008 (Markelj et al., 2013). The large interest of stakeholders on such instruments can be confirmed from the high number of certification submissions and requests (DGNB[1]). An environmental building labelling leads to less efforts of planners, increases market opportunities for owners and investors and certificates a higher living quality for users (DGNB[2]).

37 international and 64 European "qualitative assessment methods" were identified and significant differences were found out in these tools in regards to the assessment scheme they are based on. Each of the schemes puts a different value on the three sustainability pillars: social, environmental and economic; an equal weight is given to each pillar only in the DGNB system. Unlike first generation methods, the newest ones are more precise and demanding since the assessment includes LCA and Life Cycle Costing (LCC) analyses. (OPEN HOUSE, 2013)

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With regard to the environmental quality, LCA analyses based on European standards EN15804 – EN15898, are the only legitimated for buildings and building products (Passer et al., 2015).

The modelling and the Life Cycle Impact Assessment (LCIA) can be carried out by different specialized commercial software (e.g. SimaPro, GaBi) or open-source (openLCA). While such tools are useful and applied for products and services analyses in the building sector, they are not widely used by planners and architects because of the variety of materials and processes to be included into LCA models. For these reasons, alternative tools have tried to solve this gap through specializing on sustainability building analyses.

One of the challenges in the field of building LCA is its inclusion in an integrated planning process, where several actors have to be coordinated, and digitalization e.g. through Building Information Modelling (BIM) takes place. Both constitute a strategy that optimizes the whole planning process in terms of time, effort and budget, but leads to issues caused by communication between different actors and multitude of interfaces that cannot always easily exchange information (Di Bari et al., 2019).

That is why more standardized formats have been proposed and in this context, the IFC format was introduced from buildingSMART as a neutral and open specification for BIM.

The greatest vendor firms of software products are pushing towards cloud services and consequently web-based interfaces, since through model management on cloud each project team-member can easily access the model for changes and updates irrespective of their location. The cloud platform is considered the future of interoperability and collaboration that is why the use of a unified modelling language for BIM is of fundamental relevance (Amoah et al., 2019).

This paper describes a workflow conceived for data exchange between a BIM model and an SBA tool. The data structure in XSD format (XML Schema Definition) is afterwards applied in the web-based tool Generis® and enables communication between the 3D model and LCA model in order to derive environmental information in a more automated way through an Extensible Markup Language (XML)-document. As advantage, this structure allows environmental feedback on building design already in the early planning phases. Lastly, the derived LCA information can be directly submitted for e.g. a DGNB building certificate (Generis®-solution.eu).

STATE-OF-TECHNIQUE

Building assessment methods are supported by various software tools which exist in the market as web-tools or as offline installable software. In the global context, they entered into the picture shortly after the introduction of the LCA and they continued to develop alongside the progress of LCA methodology. Since they can be used both for the comparison of design alternatives and for the evaluation of environmental performance for certification purposes, they use different data and calculation rules.

Hereafter a review is presented. This is not meant to be exhaustive and is based on the reports provided by tools developers. In Table 1, the main features are grouped in categories (database, data format, building type, certification and extended functions).

Building assessment tools in the German context

In the German context, the first tool LEGEP was developed in 1997-2000 as a DBU funded project. This offline installable software created from Weka Media has seven modules which take into consideration different aspects of the planning process from the construction alternatives to the cost planning and energy certificates. The module *Ökobilanz* offers the possibility to model precise constructions and technical installations based on sirAdos building data. The LCIA calculation gives results on the building level based on Ökobau.dat and ecoinvent databases. LEGEP exports the results in data formats compliable with AVA (Tendering, Contracting and Accounting) interfaces and Excel-spreadsheets. In the module *Certification* the users are able to get submission-ready documentation for their building, in compliance to German systems (DGNB, BNB, NaWoh) and the Austrian ÖGNI certification system (LEGEP report, 2010)

Ökobilanz-Bau.de-tool was developed in 2010-2011 from HOINKA GmbH. The workflow starts with processes from Ökobau.dat, moves on to modeling of products and the grouping of elements follows it. The environmental impact analysis can be carried out for individual elements as well as for whole cost groups according to DIN 276. Results for the elements are exported in PDF, and the summary of processes from the database in Excel. Through an interface between Bim2Sim tool and Ökobilanz-Bau it is possible to carry out environmental analysis for imported BIM models in IFC (ökobilanz-bau Report, 2016).

The second documented tool eLCA was developed in 2012 from Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR/ Research on Building, Urban Affairs and Spatial Development) for the life cycle assessment of office and administration buildings. The tool is web-based and exploits the XML markup language. As advantage, direct link to the BNB certification submission is offered through the XML-

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export. Layers, constructions or complete building assessment are based on Ökobau.dat datasets and visualized through dynamic graphs (eLCA Report, 2014).

Lastly, we mention CAALA, developed in 2016-2018 as an offline software. The applied database is Ökobau.dat but the tool allows also the import of own EPDs. It provides besides data for submission according to German systems (DGNB, BNB, and BNK), a CAALA-plug-in which performs import of sketchup and Rhino models for parametric LCA. Results can be exported in PDF, gbXML, Excel format and in eLCA data format for direct submission to the BNB certification (CAALA website).

Table 1: Characteristics of SBA tools in the German building sector

N°	TOOL	DEVELO -PER	DATABASE	DATA FORMA T	BUILDING TYPE	CERTIFICATION	EXTENDED FUNCTIONS
1	LEGEP	WEKA MEDIA	Ökobau.dat Ecoinvent	AVA Programs RTF	Not defined (presumably all)	BNB, DGNB, NaWoh, ÖGNI	-Structure based on HOAI Integral Planning -offers cost calculation & planning
2	eLCA	BBSR	Ökobau.dat	XML xlsx CSV	Office Administrati on	BNB	Direct submission for BNB certification
3	Oekobilanz-bau	HOINKA GmbH	Ökobau.dat	PDF xlsx	Not defined (presumably all)	DGNB, LEED, BREEAM	BIM integration - IFC model, interface with Bim2Sim
4	CAALA	CAALA	Ökobau.dat own EPDs	PDF gbXML eLCA-format (XML) Excel	Not defined (presumably all)	DGNB, BNB, BNK	CAD and BIM integration – plug-in for sketchup and Rhino models
5	SBS -> GENERIS®	FRAUNH OFER IBP	Ökobau.dat ESUCO	Excel	All	DGNB, BNB, NaWoh, BNK, BREEAM	Display of results in DGNB template ready for certification

SBA tools – Comparison

According to the review in the previous section, most of SBA tools are suitable within the German building sector, since they use Ökobau.dat database for the environmental performance, with few exceptions whereas EPDs can be considered. The data export format also differs; each one of them offers different possibilities of exporting results. Nevertheless, they all offer export in spreadsheet files allowing flexibility on further data use through the conversion of Excel to other data formats. In most tools, there is no definition of the allowed building types for modeling, with the exception of eLCA, which addresses only office and administration buildings. Even if the building modelling for LCA analysis is anyway possible, due to the missing reference to all user profiles for building certifications, a final evaluation cannot always be carried out, leading to miscalculations of the final points. All tools allow the preparation of results in data templates in compliance to certification systems. Except from eLCA, all of the reviewed tools base the environmental performance on DGNB criteria and depending on the building type. Some of them (LEGEP, CAALA, SBS) offer BNB certification for non-residential buildings as well.

The tools have different extended functionalities that make them unique from each other. Nevertheless, depending on the target audience, where one tool covers the gaps of another, it lacks in a functionality that the other tool offers.

Challenges of SBA tools

Due to the need to address gaps in existing assessment and benchmarking tools, the increase in number of the SBA tools leads to repetitions and overlapping. From the LCA perspective, challenges such as range of chosen indicators and credibility of “green labelling”, weighting of indicators, reliability of data, user friendliness, performance differences, costs, adaptability to regional contexts are greatly affecting the comprehensiveness of SBA tools (UN-Habitat, 2017). These variations are resulting mainly due to differences between countries related to the goals for environmental enhancement in the building sector. On the other hand, from the perspective of planners and the Architecture Engineering Construction (AEC)

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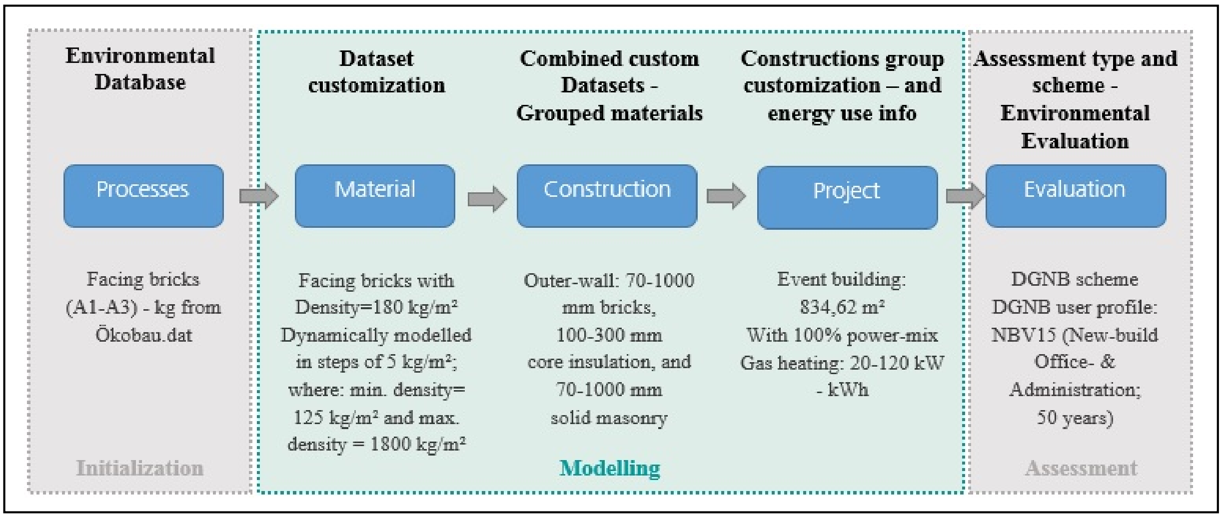
industry, the main concern lies in the existence of ineffective information during data exchange, and/or problems due to insufficient data description of Exchange Requirements (VDI 2552 Blatt 11 BIM-Information exchange). This can lead to three major problems: costly errors in design/ construction, time wasting in making decisions and a missing achievement of the best technical building requirements due to poor judgment (Nguyen et al., 2019).

Figure 1
GENERIS® solution approach for building evaluation



As noticed in Table 1, common denominator of the newest tools is the tendency to reach integrated life cycle assessment into 3-dimensional models and vice-versa. In this regard, the implementation of LCA information in the automation and digitalization (BIM) of building construction offers a fundamental solution. The structure of LCA information in defined LoDs (Level of Development), i.e. material, sub-elements, building elements and building (Röck et al. 2018) and attached to the relevant phases of the Integral Planning (IP), as determined in Germany from the Honorarium Code for architects and engineers (HOAI), gives a plausible solution to the planning process of sustainable buildings (Gantner et al., 2018).

SOLUTION APPROACH

General characteristics of Generis®

Generis® is a sustainability assessment tool developed on the structure of the former SBS web-tool of Fraunhofer IBP, with new functions and improved features. The user has the possibility to model based on the German environmental database Ökobau.dat and the European database ESUCO. The LCA methodology is based on ISO 14040/ 14044 EN15804 EN15898 standards and the predefined designs are based on the DIN EN 18599 design catalog. A three-hierarchical framework is established and three LoDs distinguished (see Figure 1).

- **Process**: i.e. a database entry and the basis for evaluations consisting of building materials, construction, transport, energy and disposal processes
- **Construction**: Group of layers. defined according to DIN 276 cost groups and the respective reference units (e.g.: m² for external walls)
- **Project**: Group of constructions. Further specifications about operational stage, such as electricity and heating consumption, photovoltaics credits are input.

Along modeling the buildings' geometry and dimensions assignment, the user can also enter costs information for the LCC analysis and cost planning. Environmental performance results can be displayed in different assessment schemes in the same quality regardless of the modeling process. Results are downloaded as XLSX or HTML file format. The tool also offers direct export of Excel to DGNB submission.

Modelling in Generis®

There are two workflows for modeling in Generis®.

- **Scenario A**: information on buildings' geometry and constructions, energy standard and building type is provided beforehand. The user aims to carry out a final assessment ready for certification submission.
- **Scenario B**: Environmental impact results of potential solutions need to be assessed in different design stages for decision support. Existing constructions from catalogs can be applied in this case.

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In both cases, modelling starts by choosing the environmental database. Afterwards, in case of Scenario A the user sets up a *Project* through the assignment of processes. The user, groups the selected processes in a construction and edits them to suit the aimed dimensions, functional unit, and end-of-life routes. If the user is looking for environmental feedbacks for decision-making (Scenario B), he can access a list of predefined constructions of building components.

Chosen processes from the database correspond to the material or technical component relevant for the construction. Processes are linked directly to the Ökobau.dat datasets. Constructions can be chosen from the available catalogs (Fraunhofer IBP, Open House, own data) in the Generis® database or can be modeled from the user. Each construction is assigned to the respective cost group (DIN 276). The constructions level includes buildings' elements, which shape its structure (walls, ceilings, etc.), as well as technical components (heat pump, PV collectors, etc.) A new feature that Generis® offers is the dynamic modeling on the layers level: dimensions are given in maximum and minimum value with defined steps progression. This enables to analyze the variations on environmental impact of different thickness configurations. Customized constructions are then grouped as a list in the Project level and attached with information on electricity and heat demand, as well as energy production and supply system.

XSD for LCA information request

In order to integrate LCA information in the digitalized automated process of buildings' planning, Generis® has developed an interface for BIM integration. In collaboration with buildingSMART within the BIM2LCA4IP project, an XML/ XSD schema has been conceived for the interconnection between LCA methodology and BIM, based on IFC standard (Ebertshäuser et al, 2019). According to buildingSMART-user handbook for BIM-IFC data exchange published in 2008, free flow process is realized by three factors (buildingSMART-IFC user handbook, 2006):

- a standardized understanding of what the exchanged information actually is, i.e. Industry Foundation Classes (IFC);
- the format for the IFC information exchange (e.g. xml);
- a specification of which information has to be exchanged and when over the planning process, i.e. Information Delivery Modelling (IDM).

An important step in the transfer process of the BIM model information to the LCA-XSD is the Bill of Quantities (BOQ) which contains a list of all geometric constructions, elements and materials as well as their respective dimensions and quantities. The BOQ is extracted from BIM-software in the form of a spreadsheet and transferred to the SBA tool, which carries out the life cycle assessment (Wastiels et al., 2019).

The LCA-XSD is developed together with a DGNB-XSD in order to enable the linking of life cycle data with the DGNB certification system for direct submission. In the LCA-DGNB-XSD, the information contains three LoDs, which correspond consistently to the modeling levels in Generis®. Application of the information transfer is described in the case study.

CASE STUDY

The selected building model for the application of the method is the "office building" designed from the Institute for Automation and Applied Informatics of Karlsruhe Institute of Technology (KIT) in the ARCHICAD software. This model is available on the internet free of charge as an IFC file (Figures 2-3). The model has four floors including basement. Main areas and volume are listed in Table 2.

Table 2:
Building areas and volume (www.ifcwiki.org)

definition	Quantity	Unit
NFA	1790,74	m²
GFA	2066,2	m²
GV	769,98	m³

The information on the building model is not changed or edited, since the focus of this paper is to demonstrate how the LCA information is bundled into the information on building's geometry coming from IFC file, through the XML-structure. This means that information on the structure composition, U-Values of the construction parts as well as the relevant information for the EnEV standard is taken as default and not optimized.

Figure 2:
Selected BIM model - 3D view and ground floor (www.ifcwiki.org)

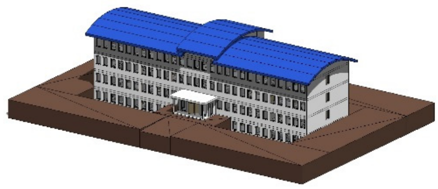
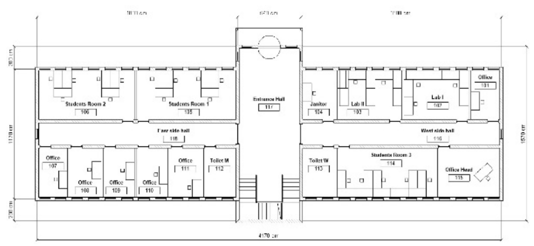


Figure 3:
Selected BIM model - ground floor (www.ifcwiki.org)



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Application of XSD scheme

The LCA-XSD scheme begins with the xsd-element “project” corresponding to Project level in Generis®, which requests information from the BIM model. The information on title, id, description and lifespan is entered from the user as a free text. The settings of LCA are defined in Generis®, and the information on construction and lifecycle are assigned in the separate extended elements (xsd-complex types). Information of the case study is entered in the following element:

```
<lca:project>
    <title>BAUSIM_CaseStudy</title>
    <title>BS_001</title>
    <description>office_building</description>
    <lca:settings/>
    <lifespan>50</lifespan>
    <construction/>
    <lifecycle/>
</lca:project>
```

Information on constructions is further specified in the xsd-element “construction”, and corresponds to the construction level in Generis®. The required data for constructions is structured based on the modeling workflow in Generis®. The information input for the outer-wall construction of the case study is shown below:

```
<constructions>
    <lca:construction>
        <name>Außenwand_Kalksandstein</name
        ><description>Erdgeschoss_Kalksandstein
        _Verputz_weiß</description>
        <tags>DIN276: 300, 330</tags>
        <quantity>31,05</quantity>
        <unit>m2</unit>
        <lifespan>50</lifespan>
        <dynamic>false</dynamic>
        <lifecycle/>
        <parts/>
    </lca:construction>
</constructions>
```

With respect to materials/ layers level in Generis®, the xsd-element “part” requires the information on each layer of the given construction from the BIM-model next:

```
<lca:part>
    <shortname>Kalksandstein</shortname>
    <quantity>31,05</quantity>
    <unit>m2</unit>
    <dynamic>false</dynamic>
    <factorToDisposal>1,8</factorToDisposal>
    <lifespan>50</lifespan>
    <lifecycle/>
</lca:part>
<lca:part>
    <shortname>Gipsputz</shortname>
    <quantity>31,05</quantity>
    <unit>m2</unit>
    <dynamic>false</dynamic>
    <factorToDisposal>1,0</factorToDisposal>
    <lifespan>30</lifespan>
    <lifecycle/>
</lca:part>
```

In the xsd-element “lifecycle”, the relevant information for the generation of environmental profiles of the BNK defined layer are extracted from environmental databases (Ökobau.dat/ ESUCO) through processes in Generis®.

```
<lifecycle>
<lca:lcdata>
    <lcphase>A1-A3; B4; C3-C4; D</lcphase>
    <lcphaseName>Construction, Replacement,
    Demolition, Credits</lcphaseName>
        <lca:lcphasedata>
            <Quantity>31,05</Quantity>
            <Unit>m2</Unit>
            <indicators>
                <lca:indicatordata>
                <indicatorName>Glo
            bales Erderwärmungspotenzial
            </indicatorName>
            <shortDescription>GWP</short
            Description>
            <exchangeDirection>out</excha
            ngeDirection>
            <dynamic>false</dynamic>
            <amount>3253.481</amount>
            <unit>kg CO2 eq.</unit>
                </lca:indicatordata>
            </indicators>
            <lifecycle/>
        </lca:lcphasedata>
</lca:lcdata>
</lifecycle>
```

Lastly, the input of detailed environmental impact data follows further through information-request of structured xsd-complex types, which for simplification purposes are not included in this paper.

OUTLOOK

The necessity of including environmental impact data in the design process has become essential related to the digitalization of the planning process. Most of SBA tools in the market are developing or have already developed in recent years with the focus of integrating LCA results within the IFC format, for enabling the interconnectedness of BIM-model information and life cycle assessment methodology. Nevertheless, this process is ongoing and faces continuously new challenges, forcing the developers to focus only on the BIM-integration problem. On the other hand, most of SBA tools address their service to limited groups of interest through offering specific functions.

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This paper introduces Generis®, as a new SBA tool, which includes existing basic functions and presents especially a novel BIM improved interface. Through the implementation of the LCA-XSD scheme, which has been developed in BIM2LCA4IP, an ongoing research project, the compilation of a XML format has been carried out. This allows the import of BIM information to its modeling interface and a backup of different benchmarking schemes. The development of a joint DGNB-XSD interface enables the direct submission for DGNB certification.

The ongoing development of Generis® contemplates the improvement of workflows and increasing of assessment and exchange possibilities. As an SBA tool, it considers all aspects regarding the environmental quality of building. Environmental database update and enrichment with more innovative materials and components, is one of the main challenges. Furthermore, the creation and upload of new databases may enable automatic LCC or social assessment (S-LCA, LCWE) by achieving evaluation on a holistic perspective.

Within further ongoing projects, Generis® aims to achieve life cycle assessment on higher level, that of whole districts, by considering building groups and energy generation and supply systems. Lastly, with regard on LCA methodology, probabilistic ones will accompany dynamic assessments in order to provide more robustness to LCA results and aware support on decision making, during all the stages of planning and construction process.

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