User-friendliness of current building environmental impact assessment tools: an architect's perspective

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Summary

In the building sector, the global environmental impact of buildings is gaining attention. This environmental impact includes all impacts related to the building (materials) throughout the entire life cycle. A number of tools to assess the environmental impact of buildings as a whole has already been developed, usually with an underlying life cycle approach. As architects are a central actor in the design process, they are responsible for the building design and the accompanying environmental impact. Therefore, in the future, they will most likely perform such an environmental impact assessment (EIA) during the design process. So, environmental impact assessment tools should be adapted to the architect's work method and practice. In this context, a comparative evaluation of the user-friendliness of four existing EIA tools is performed from a Flemish architect's perspective. An evaluation framework and a reference building are used to obtain comparable results on the architect-friendliness of these tools. The findings indicate that architect-friendliness is not sufficiently taken into account yet in the existing EIA tools. Therefore, a series of suggestions for improvement of the current tools and guidelines for the development of new EIA tools, oriented to usage by architects, is included.

Keywords: Architect-friendly, Building assessment, Design supportiveness, Framework, Tool evaluation

1. Introduction

The focus of sustainability in the building sector is shifting from energy efficiency of buildings towards global environmental impact of building design [1-4]. To assess the environmental impact of a building during its lifespan, all environmental impacts along the life cycle of the building and its composing materials should be taken into account. Life Cycle Assessment (LCA) is the most objective and quantitative methodology to calculate these environmental impacts. A number of LCA-based tools for environmental impact assessment (EIA) on whole building level has already been developed on different assessment levels: building material level, building component level and even on a whole building level [5, 6]. Tools for impact assessment on a whole building level appear to be the most suited tools for architects to use along the design process [5]. However, studies have already demonstrated that the uptake of assessment tools by architects is limited [7, 8], mostly because architects do not consider such an assessment as part of their work package (too complex, too time-consuming) or because they are simply unaware of the existence of these tools [9]. These aspects provoke that architects are often unfamiliar with these assessment tools and that the usage during the design process is not prevalent. A similar problem is encountered with the energy performance calculations (under the Energy Performance of Buildings Directive [10]). In current Flemish practice, these calculations are often outsourced to an expert at the end of the design stage, which only allows (limited) remediation [11]. To stimulate architects to assess their project from early design on, more attention to the architect's work method and user needs is necessary in the development of these tools [12]. Since it is highly probable that in the future architects will have to consider the environmental impact of their designs, in analogy with the energy performance that they already have to take into account nowadays, the need for more architect-adapted EIA tools will increase in the future [13].

2. Methodology

2.1 Tool selection

To assess the degree of architect-friendliness (i.e. user-friendliness from the architect's perspective) of existing LCA-based EIA tools for buildings, a number of tools have to be selected for testing. As Flanders (or Belgium) does not have a tool for environmental impact assessment on a building level yet, tools from other countries are chosen for evaluation. Elodie® (France) [14], Eco-Bat (Switzerland) [15], Greencalc+ [16] and MRPI® Freetool (Netherlands) [17], all Western-European tools that are suitable for the Flemish building context and available for free or as a demo version, were chosen for evaluation and comparison. A more elaborated tool description can be found in section 3.1.

2.2 Design of a reference building

To test and compare the architect-friendliness and usability during the design process of these EIA tools, a reference building (typical Flemish dwelling) has been developed. The reference building is detailed per design phase (conceptual design, preliminary design, detailed design, tendering and construction) to simulate an actual design process (based on [18]). For the reference building, a simple design project and corresponding design process are assumed; for more complex projects, further research is needed. The design process and available design data are illustrated in Fig. 1. During conceptual design, an idea is formed with some first sketches of the (maximum) building volume and form and floor area. In preliminary design, different design options are evaluated by the architect through sketches, 3D volume studies and (2D) plan drawings. The architect usually draws sketches or plans with solid walls with a thickness, but without details on the exact wall composition. In detailed design, a final solution is obtained and design parameters are developed in more detail. Once the design is finalized, the building permit file is put together and submitted. In the tendering phase, the architect starts detailing the execution plans and developing the tendering specifications and the bill of quantities. The construction phase is technically not a part of the design process as the design is finalized and the building permit is obtained. However, minor changes to the design (internal plan organization, furnishing, …) may still occur. These (intermediate) design data are used as input in the tools, which enables comparison of the usability from the architect's perspective and the design supportive value of the tools in different phases of the design process.

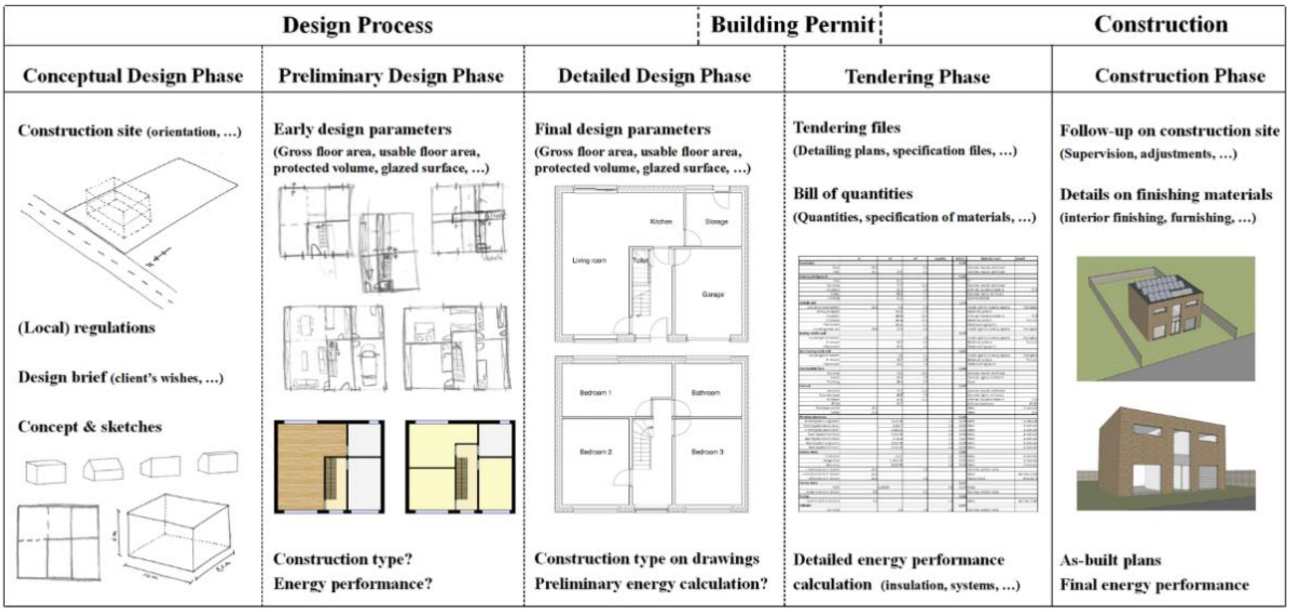

Fig. 1: Reference building and the design parameters per design phase

2.3 Tool assessment with evaluation framework

In 2010, Weytjens and Verbeeck [11] developed an evaluation framework to define the concept “architect-friendliness” of thermal performance simulation tools, based on findings from a large-scale survey (N = 269) and semi-structured interviews with Flemish architects. This framework is used as a starting basis, since it is already adapted to the Flemish context. However, in order to adapt it to the field of environmental impact assessments, it is complemented with criteria from existing studies on the comparison of environmental impact assessment tools [5, 6, 19, 20] and fine-tuned with the results of a large-scale survey among 364 Flemish architects and five semi-structured interviews with Flemish architects [21, 22]. The final framework consists of five main themes: 1) data-input, 2) output, 3) interface, 4) usability in design process and 5) general tool characteristics, each with a number of sub-themes and criteria. These criteria are assessed using a 0 to 4 rating scale. For the tool comparison, the design parameters of the reference building are entered in the four software tools, with the criteria of the evaluation framework kept in mind. In this research, only the modules of the tools regarding the material use are studied in detail, the other modules are only briefly examined. During evaluation, the tools are compared on their design supportive value and usability along the design process. As the focus is on the architect-friendliness and applicability of these tools during the design process, the exact outcome of the assessments (environmental scores etc.) is not relevant for this paper. The final result per tool is shown section 3.2 and discussed in section 4.

3. Results

3.1 Description of the tools

Four tools (Elodie®, Eco-Bat, Greencalc+ and MRPI® Freetool) are chosen for evaluation on their degree of architect-friendliness. After a brief literature review, the most important tool features are presented in Table 1. All tools are intended for evaluation on a building level and handle the environmental impact assessment of the materials used in the building. Most tools also claim to be suited for use in early design stages and by the architect. In the next sections, the tools and their functions are discussed in more detail.

Table 1: Overview of some tool features for the four tools

	Elodie® (France)	Eco-Bat (Switzerland)	Greencalc+ (Netherlands)	MRPI® Freetool (Netherlands)
Tool type	Web-based, save on the internet	Download and save on computer	Download and save on computer	Web-based, save on computer
Availability	30-day free demo	30-day free demo	Free full version	Free full version
Language	French (and English)	French, English, German, Italian	Dutch	Dutch
Version	V2 (limited)	4.0 (limited)	4.2 (full)	Beta 1.1 (full)
Main database	INIES, CSTB	Ecoinvent	NMD (outdated)	NMD (recent)
Impact categories	15	4 (+ expendable at cost)	17	11
Assessment level	Neighbourhood, building block, building	Building	Neighbourhood, building	Building
Modules in tool	Material, energy, water, waste, construction site, transportation, acoustics, indoor air quality, costs	Material, energy use, technical systems	Material, energy, water, transportation (only on level of neighbourhood)	Material (and fixed furnishing)
Claims to be suited for:				
Early design?	Yes	Yes	Yes	Not really
Architect?	Yes	Yes	Yes	Yes

3.1.1 Elodie®

The data-input starts with a building wizard in which basic characteristics such as lifespan, building type, floor area, number of occupants, location (restricted to locations in France), … can be entered. Construction type, current phase of the design process etc. can also be selected (not mandatory), but do not have direct consequences for the impact calculation. However, this would be a useful feature, as it could be used to provide a first indication of the impact in early design.
The input procedure is rather intuitive and simple. In the material input module, the user can choose between three types of studies in order to match the different user requirements [23]: 1) summary study, 2) simple study and 3) detailed study. Depending on the type of study, the material quantities and types are predefined or need to be specified by the user. These study types roughly correspond to the three design phases (conceptual, preliminary and detailed), which enables usage during the design process. Materials can also be imported from a CAD software by using an intermediate step (program Eve-BIM, option not available in demo version).
In contrast to the input, the output is not adapted to different design phases, which limits the design supportive value (especially in early design). There is a wide range of output possibilities available: numeric values per impact category, graphs on a building level or on a component level per impact category, …. However, research [22] has indicated that (Flemish) architects do not really care for output per impact category; they prefer a comparison of different building alternatives to each other or to a benchmark.
The interface is clearly structured, using a tree structure on the side of the screen to navigate. It is flexible to use, but no 2D-drawings or 3D-models of the building are implemented in the tool.
The tool is quite usable along the design process, due to the different calculation types (summary, simple, detailed). Multiple buildings can be created and compared quite easily (copying and altering a project). However, the difference between the impact of two alternatives is not clear until

the output is generated again (no real time feedback). No benchmark, target value or reference building is available and no design optimizations are generated.
In general, the tool is easy to learn and simple to use. For the input, the level of background knowledge is limited, but for the output interpretation, some background knowledge is required. Elodie® is suited for different building types. The tool handles energy calculation (can be imported), but data have to be entered twice (once for energy and once for materials). Due to the different calculation types, the time spent on the tool can be spread over the design process.

3.1.2 Eco-Bat

As data-input, the component geometry and material specifications have to be entered. No default components are available, the materials have to be specified by means of material or product specific data sheets. In the demo version, a rather limited database (about 30 materials, in contrast to the full version with about 150 materials) is implemented. Therefore, the material choice is quite restricted for certain elements.
The output can be obtained in many different formats: tables with numeric values (per element or for the whole building) or graphs per life-cycle phase, per element, per material, per impact category. The user can choose to include the transportation (generic Swiss data or user-specific data) and the replacement phase, which requires some basic insights in the LCA-methodology. From the wide variety of output formats, some information for decision making can be retrieved, but no design supportive suggestions or optimizations are generated. Since most output is expressed per impact category, this is of little added value for architects as their background knowledge is limited. Multiple design alternatives can be compared on a whole building level (not in depth), but they cannot be generated at the same time and compared. No benchmark, target value or reference building is incorporated in the tool. So, the output is not very suitable for (Flemish) architects as an argument to convince the client.
The user-interface uses standard graphical drawings to represent the building elements, but besides that no visual aids are used. The interface is structured in different tabs on top of the screen (three input tabs and three output tabs) and is easy to navigate.
The tool only provides one calculation mode, in which no default values for early design are included. Therefore, the tool is not really suited for early design. The user could start the assessment based on rough measurements and basic materials of the building components, which can be specified later on, but the tool is not specifically developed for that.
In general, the tool is easy to use and clearly structured. For the input of the components and materials, no specific background knowledge is needed. For the output interpretation, insights in the principles of LCA are necessary (selection of impact categories, life-cycles phases, …). The tool can be used for different building types, both new construction and renovation. The energy module of the tool cannot be imported in the demonstration version, but it is possible in the full version. If no full calculation of the energy use can be performed, a predefined set of energy performance related values can be generated (defaults), in contrast to the material module.

3.1.3 Greencalc$^+$

The data-input starts with a building wizard, in which information on the building neighbourhood and further location specifications (restricted to the Netherlands) are entered. For the building itself, four aspects have to be defined: materials, energy, water and mobility (no influence on building impact calculation). In the project, status (sketch, preliminary, detailed design, etc.) and calculation options (indefinite or definite) are provided, but these do not affect the further calculation or the obtained results. In the building wizard (for early design phases), the building geometry is modelled according to (rough) measurements and the user can already impose some targets/concepts. No visual support is present in the building wizard, but data such as façade surface, gross floor area, etc. are generated automatically. Later on, these predefined data and imposed concepts can be specified by the user, which is also recommended in the wizard (otherwise material quantities are overestimated). Materials (and sometimes components) can be chosen from a database (with about 500 materials and 35 predefined components) and dimensions or quantities can be entered or altered. In addition, the user can define new materials or components.

The output is provided on neighbourhood and building level. Both tables and graphs are provided. The data in the tables are expressed in environmental costs per building aspect (material, energy and water). In addition, a total score is provided. An environmental index, the MIG score, is calculated for each building aspect and the total score (cost of the reference building divided by the cost of the own building design). If the MIG score > 100, the building performs better than the reference building (at a lower environmental cost) and vice versa. The MIG score is also used for graphical visualization.

The building wizard uses a sequence of five steps to model the building (roughly), which are easy to complete. After finalization of the wizard, the basic user interface opens. The interface is simple and uses a tree structure on the left side of the screen. The top level represents the neighbourhood, the lower levels represent the building, subdivided in materials, energy, water and mobility.

The tool can be used from early design on, due to the wizard, the use of target values, concepts, example buildings, etc. Further in the design, the user can go into detail in the material, energy and water modules of the tool by overriding and complementing the conceptual information. The quantity and thickness of the materials from the database can be adapted and new materials or components can be added. The building design can be compared with the reference building and with the targets which have been set on beforehand (e.g. the desired MIG score). Besides that, it is also possible to replace the reference building with another design option, enabling the comparison of two design alternatives.

The tool is freely available on the internet, but further development stopped around 2012. Therefore, the results are no longer up to date. However, the usability and user-friendliness of the tool is rather good in general. Greencalc$^+$ can be used for different building types and different phases of the design process. Therefore, the tool can be used along the design process, so that only a limited amount of time is spent during each design phase. However, improvements could be made on the use of visual aids and data importation.

3.1.4 MRPI® Freetool

In the input-section of the tool, building and construction materials and fixed furnishings are input parameters. Materials have to be selected from a list (per component) and quantities have to be entered in predefined units (m^2, m^3, …). No new materials can be added nor can data be imported from other software packages. No default material quantities are available. Therefore, the tool is mostly suited for the building permit phase (which is also the targeted phase), when materials and quantities are more or less known, but even then the tool is not very user-friendly.

The output consists of two tabs, in which the output can be generated in different formats. The first tab consists of a table with numeric values, expressed per impact category. The second tab consists of several graphical formats: the user can generate a graph on the building level with ratios (percentages of the total impact) for the impacts of the different building components, but information can also be deepened within a certain component, in which the impact ratios of the individual materials used in this component are shown. A one-number score (MPG-value) is

provided in the output of the tool. If this value > 1, the design has a higher environmental impact for the materials than an average building: if the value < 1, the design performs better than an average building, but no suggestions on how to improve the design are included. When a benchmark for the MPG-score will be implemented (future goal of the tool), the tool outcome will give the architect an argument towards the client to strive for a better performance.
The user-interface has a rather simple structure, with drop-down lists per building component, in which the user can select the appropriate material (predefined) and add the quantity.
The tool is not suited for use in early design, as no defaults or predefined components or structures are implemented. Data can easily be altered in the input tab and users can go back a few steps. The tool is not equipped with a reference building, but the MPG-score is calculated in the outcome, which enables comparison with the average performance of buildings. Besides results on the environmental impact of building materials, no other results (e.g. information on energy and water consumption) can be generated (limited scope).
In general, the tool is easily accessible on the internet and suited for a wide range of building types, but the added value for usage along the design process is limited. No link with other software or drawing tools is present. It is a stand-alone tool, suited to calculate the environmental impact of building design once the design is practically finished and all materials and their quantities are known.

3.2 Tool assessment with evaluation framework

The final evaluation (rating scale from 0-4) of the four tools on their architect-friendliness is shown in Table 2 and a global overview is presented in Fig. 2. The theme scores are calculated as an average score of all criteria within the theme and the total score is the average of all five theme scores. When interpreting these scores, it should be taken into account that the evaluation is performed in a specific research context in which the goal is to compare the usability of these tools by architects during the design process, from a Flemish perspective. As this may not have been the intended purpose during the development of these tools, some criteria are not or insufficiently present, which results in a rather bad score. However, these scores do not intent to prejudice any of the tools; they are only used as an example in this research context.

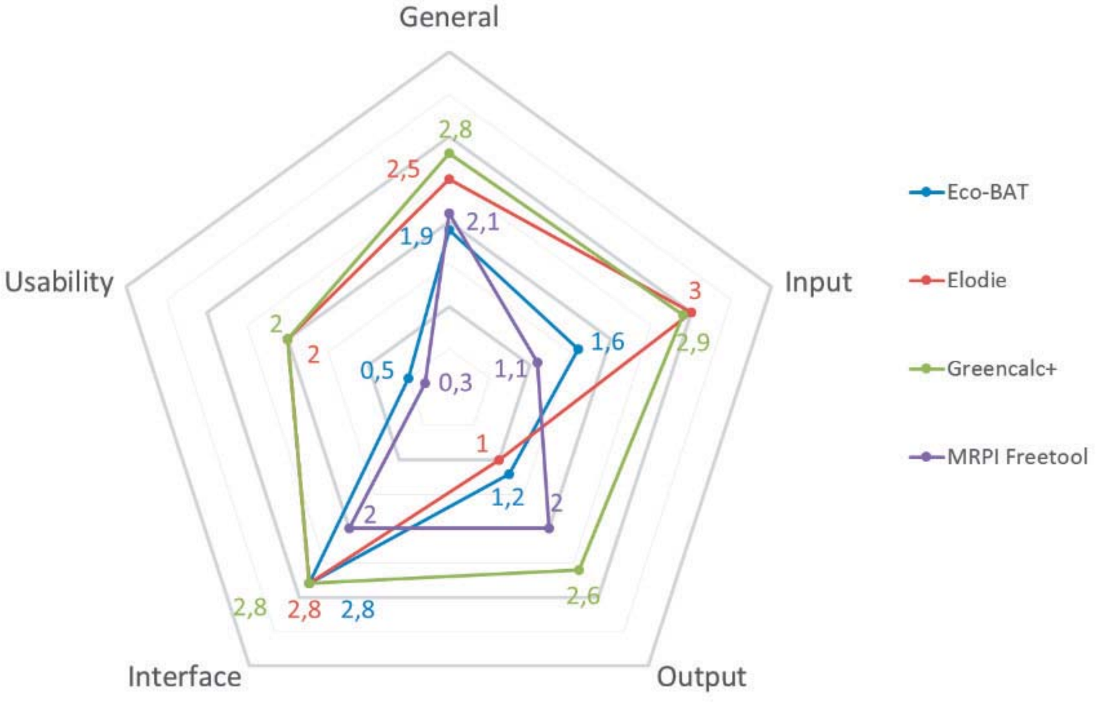

Fig. 2: Final evaluation of the four EIA tools on building level by means of the framework

Table 2: Final evaluation of the degree of architect-friendliness of four EIA tools

	E	EB	G	M
DATA-INPUT	**3.0**	**1.6**	**2.9**	**1.1**
1) Input data				
Limited data-input	3	2	3	1
Quick data-input	3	2	3	2
Default values available (facilitate data-entry)	3	0	3	0
Extensive library/database of standard materials, building components, EPDs, etc.	3	1	3	2
Input consistent with design phase: general (early phases) to detail (final phases)	4	1	3	0
2) Input method				
Simple, intuitive input procedure	3	3	3	3
Input procedure in language of the architect (according to architect’s preference)	2	2	2	0
OUTPUT	**1.0**	**1.2**	**2.6**	**2.0**
1) Output data				
Simple but supportive information for design decisions	1	2	3	2
Adapted output for different design phases	1	0	1	0
Output level (according to architect’s preference)	1	2	3	3
2) Output format				
Convincing, communicative result representation (according to architect’s preference)	2	2	3	3
Benchmark provided	0	0	3	2
INTERFACE	**2.8**	**2.8**	**2.8**	**2.0**
Visual communication of graphical user interface	2	3	2	2
Intuitive and flexible navigation (without constant need for a manual / (online) help function)	2	3	3	2
Clear structuring and construction of the project’s design steps in the software	4	2	3	1
Restrained set of options and functions (picking things out of a list, clicking instead of typing)	3	3	3	3
USABILITY IN DESIGN PROCESS	**2.0**	**0.7**	**2.0**	**0.3**
1) Global to detail				
Adapted for use in early design	4	0	4	0
Adaptable to design phases (simple versus extensive calculation)	3	0	3	0
Adaptable default values (customized choices)	3	0	3	0
2) Adaptability & flexibility				
Easy data review / change (without loss of data)	1	1	1	2
Quickly and easily create and test alternatives (parallel within software)	4	2	3	0
Real-time feedback on design decisions / changes	0	0	0	0
3) Comparison & feedback loops				
Allowing intermediate evaluation (calculation in tune with design process)	2	1	2	0
Comparing a number of different design alternatives in detail (parallel within software)	3	2	3	0
Analysis impact of decisions / parameters (uncertainty / sensitivity)	0	0	0	0
Generating alternatives and/or optimizations for problems (materials, elements, …)	0	0	0	0
4) Others				
Results for non-impact related aspects in assessment (e.g. comfort, health, economic costs …)	2	2	3	1
GENERAL TOOL CHARACTERISTICS	**2.5**	**1.9**	**2.8**	**2.1**
Availability / accessibility of the tool	2	2	4	4
Link to energy software	1	1	1	0
Tool adapted to use by architects (user skills, background knowledge, preferences, …)	2	1	3	1
Adequate for different types and (design) phases of buildings (1 tool for different applications)	4	2	3	1
Decision support value of tool application	1	1	3	2
Easy to learn	3	3	4	4
Simplicity (intuitive, easy to use and clearly structured, …)	3	3	3	3
Minimal interruption of the design process / implementation in workflow architect	3	1	3	1
Quick application, minimal time required to operate tool (learning vs. using later on)	2	2	2	2
Short calculation time	3	3	3	3
Transparency of the tool (underlying assumptions, calculation methodologies, …)	2	2	2	2
Interoperability (import/export, …)	3	1	2	0
Adequate for local usage (units, language, regional and time specificity)	3	3	3	4
TOTAL EVALUATION OF THE DEGREE OF ARCHITECT-FRIENDLINESS	**2.3**	**1.6**	**2.6**	**1.5**

Legend: E = Elodie®; EB = Eco-Bat; G = Greencalc⁺; M = MRPI® Freetool. Theme score = average of individual criteria scores within theme; global score = average of five theme scores.

4. Discussion

The global evaluation shows that the overall approach in Greencalc⁺ best meets the (Flemish) architect's wishes and needs, especially for the themes output and usability along the design process (Fig. 2). For the data-input, Elodie® (3.0/4) and Greencalc⁺ (2.9/4) achieved the highest score, which is mostly due to their gradual implementation along the design process (e.g. start from an average building which can be refined). For the output, the desired approach for architects (e.g. a one-number score with options to get more information, a custom-made report per project, …) is not found in the tools evaluated in this paper, even though some aspects were present (e.g. the one-number score in MRPI® Freetool (2.0/4) and Greencalc⁺ (2.6/4)). All user-interfaces are quite easy to navigate, but visual representation of the building and indication of possible problem zones, etc. is missing. Another barrier is that input and output are often presented in different tabs. Therefore, the impact of a design change is not directly clear to the user (no real-time feedback). For the usability along the design process, there still are some possibilities for improvement. Elodie® (2.0/4) and Greencalc⁺ (2.0/4) have the highest score within this theme, even though analysis of the impact of a certain design change and generation of alternatives and optimizations could provide some additional useful information. In general, the tools are easy to learn and freely available on the internet (full or demonstration version).

5. Conclusion

Despite the availability of a large number of LCA-based EIA tools for buildings, the uptake among (Flemish) architects remains limited. In this paper, the degree of architect-friendliness of four existing EIA tools (Elodie®, Eco-Bat, Greencalc⁺ and MRPI® Freetool) is evaluated by means of a framework, based on literature and a large-scale survey among 364 Flemish architects and five semi-structured interviews with Flemish architects. For all tools, there is still room for improvement. The data input requirements should be linked more to the ongoing design phase: from global and limited input with adaptable default values for missing data in early design phases to detailed input data in final design phases. The output should be more adapted to the architect's preferences: a global score for the environmental impact for the whole building rather than scores per impact category. Especially, in the early design phases, a one-number score can already give a good indication of the building performance, whereas in the more detailed design phases, the architect should have the opportunity to deepen the results (per building component, per life cycle phase of the building, etc.). In addition, a one-number score enables architects to compare different solutions within their own design to a reference building or a benchmark. As most architects are mainly visually oriented, the interface should use more visual building representations (2D, 3D drawings). In addition, more interoperability and data import and exchange possibilities (especially with already obliged energy performance calculation tools) could facilitate the usage even further and could help to avoid double input of data. Finally, a clear link between modifications of the input (building design) and changes in the output (impact) should be pursued (real-time feedback) to induce a learning process on sustainable material use. These suggestions could improve the design supportive value and architect-friendliness of EIA tools for building design and increase the EIA tool usage by architects during the design process.

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