

# A framework to evaluate the architect-friendliness of environmental impact assessment tools for buildings

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*Legal actions towards a mandatory environmental impact assessment (EIA) of buildings can be expected in the (near) future. Due to the complexity of EIA, software tools will become an indispensable aid in the architectural design process. Especially in early design, feedback on the environmental impact is needed, since early design decisions have a major influence on the final impact of the design. However, most existing EIA tools insufficiently take into account the architect's needs as a user and are especially not suitable for use in early design. Therefore, an evaluation framework with criteria for architect-friendliness of EIA tools, with a specific focus on early design, is developed based on a large-scale survey, interviews and a focus group with practising architects. This framework can be used to evaluate the architect-friendliness of existing EIA tools and as a guidance for the development of new architect-oriented tools.*

**Keywords:** *user-friendliness, architect-oriented, early design stage, design-support, evaluation framework*

## INTRODUCTION

### Context

The last decades, in Europe, building sustainability was mainly associated with energy efficiency during the use phase, as a consequence of the implementation of the Energy Performance of Buildings Directive or EPBD and its recast (EPBD 2002, EPBD 2010). This directive aims to reduce the impact of buildings in climate change and depletion of fossil fuels.

However, the responsible use of raw materials in building construction and the reduction of the environmental impact of buildings throughout their life cycle is gaining importance. Several initiatives on resource efficiency and sustainable management of materials in construction have been initiated.

An evolution towards a life cycle assessment (LCA) based evaluation of the environmental impact of buildings can be expected (European Commission 2011). In the 'Closing the loop - An EU action plan for the Circular Economy' report (European Commission 2015, pp. 17) it is stated that "The Commission will take a series of actions to ensure recovery of valuable resources and adequate waste management in the construction and demolition sector, and to facilitate assessment of the environmental performance of buildings".

In Europe, a wide range of Environmental Impact Assessment (EIA) tools has already been developed, e.g. Elodie [1] in France and MRPI-Freetool MPG [2] in the Netherlands.

Since 2013, the assessment of the environmental impact (without benchmark) of small-scale residential projects and offices is already mandatory upon building permit request in the Netherlands. In 2018, a legal benchmark will be implemented to stimulate the design of buildings with a lower environmental impact (Quelle-Dreuning 2017). In Germany, the application of an EIA tool is not yet mandatory, but it is part of global sustainability certification systems such as BNB (i.e. German assessment system for sustainable construction for federal buildings) (Brockmann et al. 2014). In Belgium, a beta version of an EIA tool, developed by the government, is expected to be released by the end of 2017 [3]. Similar to the requirements for buildings' energy performance, targets for the environmental performance of a building are likely to be set in the (near) future.

### Need for architect-friendly EIA tools

In this perspective, EIA tools should help lowering and/or optimizing the environmental performance of building design. Especially in early design, feedback on the environmental impact of building design will become indispensable in order to facilitate the inherent integration of sustainable material use in the building design process. At this stage, decisions are still flexible and adaptable, whereas, later on in the design process, decisions become more concrete and complex and more difficult to reverse (Weytjens 2013, Basbagill et al. 2013, Hollberg and Ruth 2016).

This was also already established by Wallhagen (2010, pp. 5): "The complexity and difficulty in linking buildings to environmental impact create a need for interactive tools measuring environmental performance, which can be useful as decision support in the early design phase".

In the context of energy efficiency research, the need for design-supportive assessment tools, specifically for architects from early design on, is already widely recognized and aspects to increase the uptake of energy performance simulation tools by architects in early design have been investigated (e.g. Bleil de Souza 2009, Bambardekar and Poerschke 2009, Attia et al. 2012). Weytjens and Verbeeck (2010) composed a framework with criteria that reflect the "architect-friendliness" (i.e. user-friendliness specifically for architects) of these energy performance simulation tools, subdivided in five main themes, being:

1. Data-input
2. Output
3. Usability in the design process
4. Interface
5. General

A number of these criteria, e.g. the ones related to the usability of performance simulation tools during the design process, are almost directly applicable to the context of environmental impact assessment (EIA). However, EIA is much more complex and broader than energy performance (see Figure 1).

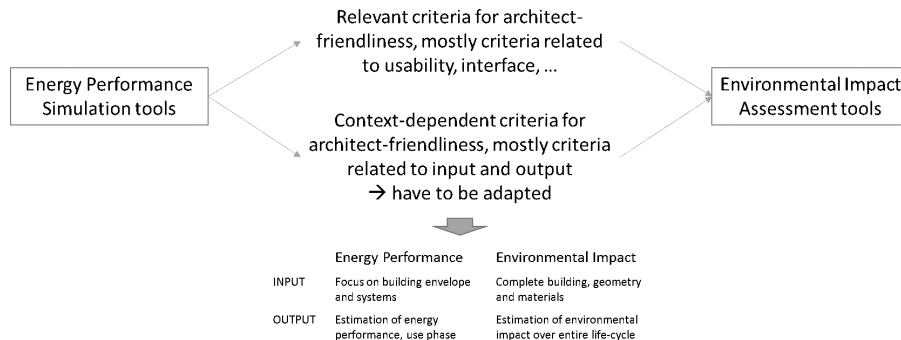


Figure 1 Schematic overview of criteria for architect-friendly Energy Performance Simulation tools (cfr. Weytjens and Verbeeck 2010) versus criteria for architect-friendly Environmental Impact Assessment tools.

Instead of focussing solely on the building envelope and systems, the whole building needs to be incorporated in the assessment and the focus is not only on the expected performance in the use phase of the building, but on the performance over its entire life-cycle.

Additionally, architects' knowledge on sustainable building is currently still mostly linked to energy efficiency and their insights in sustainable material use, life cycle assessment (LCA) and environmental product declarations (EPDs) are quite limited (Meex and Verbeeck 2015, Meex et al. 2017).

Due to both the complexity of EIA and the lack of knowledge and insights of the architects, there is a clear need for EIA tools with an explicit design-supportive value for the early design stage. In this paper, a framework with key-criteria for architect-friendliness of EIA tools is presented.

## **METHODS**

In this research, the framework on architect-friendliness of energy performance tools by Weytjens and Verbeeck (2010) was used as a starting point and further elaborated and adapted to become useful to evaluate the architect-friendliness of EIA tools during the early stages of building design. Literature studies (e.g. Forsberg and von Malmborg 2004, Haapio and Viitaniemi 2008, Bayer et al. 2010, and Han and Srebric 2011) on LCA-based methods and tools for assessing the environmental impact of buildings, building components and building materials were used to move, alter or add framework criteria. Although no specific attention was paid to the architect-friendliness of the tools in these literature studies, user-related criteria that are relevant for the determination of the environmental impact of building (elements/materials) are found and added to the original framework, especially with regard to the framework themes Data-input, Output and General characteristics.

In a next step, the framework criteria were validated and fine-tuned with the Flemish architectural design practice by means of:

1. A large-scale survey
2. Semi-structured interviews
3. A focus group

### ***Large-scale survey***

A large-scale survey (N=364 Flemish architects) was conducted in January-May 2014. Overall goal of the survey was to investigate the architects' current knowledge and practice regarding sustainability in building design, sustainable material use and environmental impact calculations and their future expectations and wishes for EIA tool functionalities. The main findings and more detailed survey results are described in Meex and Verbeeck (2015). The results on expected features and characteristics of an EIA tool for buildings are used to refine the Data-input and Output criteria of the framework on architect-friendliness.

### ***Semi-structured interviews***

In addition to the survey, five semi-structured interviews with Flemish practicing architects were conducted between May and July 2014. Goal of the semi-structured interviews was to gain a better understanding of architects' wishes and needs when using an environmental impact assessment tool. The architects were asked to indicate the aspects they consider to be determinative for each theme of the framework by means of own suggestions and by imposing an order of importance for the framework criteria (by means of a card sorting exercise). The qualitative analysis of the interviews gave deeper insights in the underlying concerns of the architects.

### ***Focus group***

A four hour focus group (held in September 2016) with 12 Flemish architects (10 practicing architects, one recently graduated architect without practice experience and one architecture student) was used to check the validity of the framework criteria, fine-tune them and add new ones if necessary.

Since the survey and interviews revealed that the architects' knowledge on environmental impact assessment is quite limited, the first part of the focus group consisted of two lectures to demonstrate the importance and main principles of EIA on a building level and to give an overview of the current situation in the Netherlands and Belgium.

The second part of the focus group consisted of three participatory steps: an individual brainstorm, a small group brainstorm and a large group discussion. For the first two steps, the participants were randomly subdivided into four groups of three participants, according to the four most specific framework themes: Usability in the design process, Software environment and interface, Data-input and Output. At first, they were asked to come up individually with 10 criteria (related to their theme) which could enhance the usability of such a tool in the early design stage. Then, the individual criteria were discussed in the small theme groups. New, additional criteria could come up at this stage. All criteria were placed on an A0 sheet and participants were asked to indicate the level of importance of each criterion (three levels). As a final step, the small groups presented their findings to all participants during a group discussion. The results were used to fine-tune the framework into its final version.

Since in the focus group the architects were first informed on the subject before delivering input to the framework development and the focus was specifically on the early design stage, the insights and results are considered as more reliable than those from the survey and interviews and therefore also used to a greater extent in the fine-tuning of the framework. In addition, the findings from the focus group are used to determine the main focus points in the development of EIA tools within the themes Data-input, Output and Usability in the design process, based on the number of criteria that the participants spontaneously suggested per framework theme and based on the order of importance which they had to provide during the brainstorm.

## RESULTS

The final result is a framework with 43 criteria for architect-friendliness of EIA tools (see Table 1), structured according to the five main themes of the original framework: Data-input, Output, Usability in the design process, Software interface and General tool characteristics.

### *Data-input*

Based on insights from literature, the criteria for Data-input are subdivided into two subthemes: Input data (which data to enter) and Input method (how to enter data). The empirical research was used to fine-tune the input criteria. The main goal was to specify the preferred input method of the practicing (Flemish) architects.

In the large-scale survey (N=221, multiple options possible), 55% of the respondents indicated that they prefer to input the data from a 3D model (26% prefer a simple 3D model, 19% prefer an advanced 3D model and 10% did not specify the type of 3D model). 43% of the respondents prefer the input to be integrated in the EPB (Flemish implementation of the Energy Performance of Buildings Directive) software. Separate manual input was only selected by 33% (14% with standard adaptable elements, 9% with specific product information per material and 10% did not specify this further).

According to the card-sorting in the semi-structured interviews (N=5), importing a complete (3D) model from drawing software into the EIA tool is desired most as input of building geometry (which corresponds to the survey results), followed by separately modelling the building components in the EIA tool itself, and importing building components already composed in other software packages (e.g. energy performance simulation software). However, as most architects in Flanders do not use advanced 3D CAD (Computer Aided Design) or BIM (Building Information Model) drawing software packages, which allow complete modelling of a building and its building components (geometry and materials) in 3D (Neven and Selke 2016), a link to this type of

Table 1  
Final framework for  
the evaluation of  
the architect-  
friendliness of EIA  
tools in early design

<b>DATA-INPUT</b>	
<b>Input data</b>	Limited data-input Input consistent with design phase: general (early phases) to detail (final phases) Default values / default settings available (facilitate data-entry) Extensive library / database of standard materials, building components, EPDs, etc. Clearly structured library / database, with search function
<b>Input method</b>	Quick data-input Simple, intuitive input procedure Preferred input method: linked to simple 3D drawing model (e.g. SketchUp), no manual input
<b>OUTPUT</b>	
<b>Output data</b>	Simple but supportive information for design decisions Adapted output for different design phases Preferred output level: aggregated environmental score with easy access to more detailed data (per element, per life cycle stage,...) Link to energy calculation Results for non-impact related aspects (e.g. comfort, health, economic costs, ...)
<b>Output format</b>	Easy to interpret, clear and limited e.g. visual elements such as graphs, a grading scale, ... but no extensive report Benchmark or reference provided Convincing, communicative result representation Compliance with building codes and regulations
<b>USABILITY IN THE DESIGN PROCESS</b>	
<b>Time use</b>	Quick application, minimal time required to operate tool (learning vs. using later on) Short calculation time: no (additional) heavy load Minimal interruption of the design process / implementation in workflow architect Interoperability: integration in / add-on to existing (drawing) software
<b>Adaptability &amp; flexibility</b>	Adaptable to design stages (simple versus extended calculation) Adaptable default values (customized choices) Easy data review / change (without loss of data) Quickly and easily create and test alternatives (parallel within software)
<b>Comparison &amp; feedback loops</b>	Allowing intermediate evaluation (calculation in tune with design process) Comparing a number of different design alternatives in detail (parallel within software) Real-time feedback on impact of design decisions / changes (sensitivity, ...) Clearly indicate problem areas and generate suggestions/alternatives
<b>SOFTWARE INTERFACE</b>	
	Visual communication of graphical user interface Clear structuring and construction of the project's design steps in the software Intuitive and flexible navigation (without constant need for a manual / (online) help function) Clear help function or discussion platform Restrained set of options and functions (picking things out of a list, clicking instead of typing)
<b>GENERAL TOOL CHARACTERISTICS</b>	
<b>General selection criteria</b>	Availability / accessibility of the tool: public, free Simplicity (intuitive, easy to use and clearly structured, ...) Easy to learn (without education) Decision support value of tool application Tool adapted to use by architects (user skills, background knowledge, preferences, ...) Adequate for different types and (design) phases of buildings (one tool for range of different applications)
<b>Calculation preferences</b>	Database with verified and independent data Data adequate for local use (units, language, regional and time specificity) Transparency of the tool (underlying assumptions, calculation methodology, ...)

drawing software is not preferred, especially not in early design. This was also confirmed during the focus group (N=12): input of the geometry in early design should be linked to a simple 3D drawing software package (e.g. SketchUp, used by 68% of the respondents in the large-scale survey (N=354)), not to a BIM-tool since most architects do not work with BIM (yet) and BIM is not considered as a design tool, but more as a tool for the later design stages. Similarly, a link with the energy performance should be present in the assessment to allow simultaneous calculations for energy performance and environmental impact assessment. As no material-related information can be imported from SketchUp (low level of detail), a database with standard materials and building components and default values / settings was also found to be important in early design.

**Order of importance.** First of all, a link with a simple 3D drawing software tool is preferred; separate input or modelling of the geometry should be avoided as much as possible, since this would be too time-consuming in early design. In addition, material-related information should be based on a well-structured and clear database with standard material and component solutions. The use of default settings and default values is inevitable in early design, as, at this stage, architects just need a quick check of a design option, which is still subject to change. Therefore, the tool should also be simple, quick and limited (and thus cause as little as possible additional time or work investment).

### **Output**

Similar to the Data-input theme, the theme Output was subdivided into two subthemes: Output data (which results are obtained) and Output format (how the results are displayed). Since different levels of complexity and detail in the outcome of an environmental impact assessment are possible, the main focus of the empirical research was on determining the architects' preferences regarding the output data and the output representation format.

In the survey, multiple options could be selected for the output data level (N=220, multiple options possible). An aggregated score for the total environmental impact of the building was most preferred (61%), followed by more detailed scores such as an environmental score per building element (33%) or per material or product (29%), more detailed information on environmental impact in the use phase (24%) and an environmental score per life cycle phase of the building (19%).

In the interviews and the focus group, an aggregated environmental score on building level was also most preferred for a quick overview, but always with easy access to more detailed information (e.g. building component, etc.) in order to derive the origin of this score. Most architects are not really interested in the environmental score per impact category (e.g. global warming potential, expressed as kg CO<sub>2</sub> equivalents), as this is too difficult, abstract and meaningless to them, due to their limited background on environmental impact.

Nevertheless, some of them want to consult more detailed environmental impact scores, depending on their own interests and knowledge level. However, it should be noted that this comes with a risk: taking decisions based on one single environmental impact category can lead to burden shifts to other impact categories that are not taken into account. Therefore, this detailed information should not be the primary information source for decision-making, especially not in case of limited knowledge and insights.

In the focus group it was also clearly established that a link to the energy performance should be integrated and results for non-impact related aspects (e.g. comfort, health, economic costs, ...) should be added, as these allow participants to have a more global overview of the impact of their design decisions and relate the impact to aspects they are more familiar with. This overview can help them in finding the right balance for the impact of their decisions.

For the output format, the interviewed architects mostly preferred to have a report (most suited for communication with the client), closely followed by

output in graphs and tables (which can also be part of the report). The focus group participants asked to limit the size of the report to one A4 page in early design. A visual representation of the output that is easy to be interpreted by architects is needed, as, in early design, the focus is more on testing a number of different design solutions that are not always communicated with the client. In case the client wishes to be informed on the environmental impact, the output should facilitate this communication.

Furthermore, the output should be comparable to benchmarks or references to ease interpretation and enable comparison. In early design, ranges for the environmental impact can be presented instead of an exact calculation due to the high degree of uncertainty. In addition, in light of the growing attention for the environmental impact of a building, the assessment should be compliant with (future) regulations and building codes.

**Order of importance.** The criteria regarding the output data and format were less numerous and concrete than those for the data-input. A possible explanation for this is that EIA is not part of the architects' daily design practice yet, so they do not really know what to expect. However, there were some clear requests, e.g. easiness to interpret, quick access to an aggregated score (and underlying detailed results) and a link with other aspects of the building (e.g. energy performance, but also economic costs, health, ...). The results should also be clear and limited and visually represented on a grading scale or in graphs. All results should be design-supportive throughout the design development and communicative towards clients (if necessary).

### ***Usability in the design process***

Based on the interviews and the focus group, a classification of the criteria into three subthemes was made: Time use, Adaptability & flexibility and Comparison & feedback loops.

Regarding the subtheme Time use, in the focus group, the architects emphasized that the evaluation should not take over half an hour per design solution

in early design. To obtain this, interoperability and integration in or add-on to existing (drawing) software was frequently mentioned by the participants of the focus group (to avoid double work and having to learn a complete new tool and to have a visual input of data).

In the subtheme Adaptability & flexibility, it was specified that data and defaults should be easily adaptable, without loss of data. In addition, an EIA tool should allow architects to quickly and easily create and test alternatives (parallel within software e.g. by means of the copy-paste method which is often used by architects (Weytjens 2013)), especially in early design when many different design options are considered.

In subtheme Comparison & feedback loops, criteria mainly reflect the need for comparison and feedback on the output part of the tool. The architects in the focus group also prefer real-time feedback, as this directly reflects the impact of decisions and enables comparison of different situations. Furthermore, the participants in the focus group really require recommendations on how to improve the performance of their design. This could help them to broaden their horizon, deviate from their own standard choices and introduce a learning process on the environmental performance of buildings.

**Order of importance.** All criteria related to the time investment and the adaptability and flexibility of the tool were very important to the participants in the workshop. The core feature is that the tool should operate fast, integrated in the design process, so that it can be used as a quick check along the way. Comparing multiple design options to each other (and to a reference), indicating problem areas and generating suggestions for improvement or alternatives and real-time feedback on their design decisions were a little less important, but still very valuable.

### ***Software interface***

These criteria are more general and reflect the practical usability of all facets of the tool. Most of all, the interface should be visual (e.g. large font size, clear lay-

out, ...), with a clear follow-up structure. In addition, a clear help function or discussion platform should be present, so that the architects can look for helpful information and/or contact people with similar problems if necessary. During the interviews and the focus group, some criteria were also specified in more detail to increase the usability, e.g. restrained set of options was specified as picking things out of a list and clicking instead of typing; flexible navigation had to imply without constant need of a manual or (online) help function.

### **General characteristics**

Based on the literature review (e.g. Haapio and Vitaniemi 2008, Forsberg and von Malmberg 2004, Bayer et al. 2010, Han and Srebric 2011), a number of criteria were added to the general tool characteristics, which were all found to be relevant throughout the empirical research: the tool should be adapted to use by architects (user skills, background knowledge, preferences), have a decision-support value and be adequate for different types and (design) phases of buildings (one tool for a range of different applications), so that the application can be integrated in the design process and the work flow of the architect. Furthermore, the tool should be available and accessible to architects. In light of the expected requirement to use a tool to calculate the environmental impact of a building design, this is further specified as a tool which is publically and freely available (which was very important to the focus group participants). These criteria can be considered as selection criteria, prior to actual tool application and therefore they are classified in the subtheme General selection criteria.

During the interviews and the focus group, also some other criteria related to the preferences for the calculation methodology were mentioned. For instance, all data in the database should be verified, independent and adequate for local use, so that they form a reliable starting point for the assessment. Since the architects' knowledge level on LCA and EIA is quite limited, the architects mainly require transparency, with insights into the underlying assump-

tions and the calculation methodology used by the tool developers (cfr. with the energy performance calculation). These criteria are classified in the sub-theme Calculation preferences.

### **DISCUSSION AND CRITICAL REFLECTION**

The framework, including the order of importance of the framework criteria, can serve as an evaluation tool for existing EIA tools and as a guidance for the development of (new) EIA tools, which are adapted to the needs of architects in early design.

Currently, architects mainly trust in their gut feeling and intuition to implement sustainable material use in building design. Therefore, such a tool, which covers all criteria for architect-friendliness, can help in creating a support-base for and an awareness on environmental impact assessment. However, it should not just be a calculation tool, but a supportive tool which also introduces a gradual learning process among architects to increase their awareness and knowledge level regarding the environmental performance of buildings and the integration of sustainable material use. This increase in knowledge level on sustainable building through tool use was also mentioned by 64% of the respondents in the large-scale survey as an expected advantage, closely followed by a higher quality of the design (61%, N=224, multiple options possible). However, it should also be noted that the implementation of all criteria for architect-friendliness would not automatically imply the uptake of the tool by architects. For instance, although the majority of the focus group participants claims that they would use such a tool, for most of them this would still require a change of habits which is not easily made. In addition, they fear extra work and budget implications of this additional assessment. Nevertheless, an EIA tool which meets all requirements for architect-friendliness would be a good step in obtaining more sustainable buildings.

In an exemplary study (Meex et al. 2016) an intermediate version of the framework was already applied to four existing EIA tools and all framework criteria were evaluated on a scale of 0 to 5. It was found



that none of the existing assessment tools met all criteria for architect-friendliness. Although the focus of that study was not specifically on early design, most of the evaluated tools lack a gradual data input, the presentation of an aggregated one-number score for the whole building to the user and real-time feedback on design-decisions, which are essential aspects of architect-friendliness and inducing a learning process among architects.

### **Limitations of the research**

The framework development is performed from a Flemish perspective. In Flanders, the design context is characterized by a large number of small-scale architectural offices (1-2 people) who are mainly involved in dwelling design for private clients (T'Jonck 2013). However, according to "the Architectural Profession in Europe 2014" report (Mirza & Nacey Research 2015), the situation in the rest of Europe is quite similar: 74% of the practices are one person practices and 53% of the European architects' work is private housing. Therefore, these findings are also valid for countries with a similar context. Nevertheless, this specific geographical, cultural and professional background of architects should be taken into account when interpreting the results of this research, as a different context might lead to (slightly) diverging needs and desires.

### **CONCLUSIONS**

Early design decisions have a significant influence on the final environmental performance of the building. In light of the upcoming importance of reducing the environmental impact of buildings, architects should be able to evaluate the environmental impact of building design, already from early design on. However, currently, architects lack knowledge and appropriate tools to do this.

As a result of this research, a framework with criteria for architect-friendly EIA tools is developed, with a specific focus on usability in early design. In addition, an order of importance of the framework criteria is provided. It is found that especially the data input

format and the type of data input, the time spent on tool application and its adaptability and flexibility to the architects' way of working are very important criteria when evaluating the architect-friendliness of a tool.

This framework is an important step in obtaining more architect-friendly EIA tools. By means of an evaluation with the framework, strengths and weaknesses of existing EIA tools can be established and recommendations for future tool development can be formulated. In future steps of the research, the feasibility of implementing all these criteria in an EIA tool will be investigated.

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