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Author

de Gaulmynn, Camille, Dupre, Karine

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RESEARCH ARTICLE

# Teaching sustainable design in architecture education: Critical review of Easy Approach for Sustainable and Environmental Design (EASED)



Camille de Gaulmyn\*, Karine Dupre

*Griffith Architecture, Griffith University, Southport, Qld 4215, Australia*

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## KEYWORDS

Architecture education;  
Energy;  
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Design;  
Teaching;  
Ecological

## Abstract

In the current context of climate change and ecological awareness, designing sustainable environments is definitely understood as a shared responsibility. With the construction sector consuming half of the world's energy, the role of some key stakeholders such as architects becomes even more critical when providing responsible and relevant design for the built environment. Thus, improving the way our environments are being designed challenges some cultural systems that show evident limits, such as the training of future architects and engineers.

In this research, the focus is on architecture students and aims to demonstrate how the use of a new sustainable performance simulation tool, called Easy Approach for Sustainable and Environmental Design (EASED) could contribute to educate them about innovatively sustainable design. This was assessed through the evaluation of student engagement, their use of the tool and its appropriation. Results show that individual work was not convincing, whereas success was met during group work. Limits and improvement possibilities were found in the interface of EASED as well as in the educational set up of the tool.

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\*Corresponding author.

E-mail address: [degaulmyn.camille@gmail.com](mailto:degaulmyn.camille@gmail.com) (C. de Gaulmyn).

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## 1. Introduction

Designing sustainable environments is definitely understood today as a shared responsibility. With the construction sector consuming half of the world's energy (International Energy Agency, 2018), the role of some key stakeholders such as architects, engineers, planners and contractors becomes even more critical when providing responsible and relevant design for the built environment. While the process requires good communication between engineers and architects, professional bodies often identify this as an aspect that still needs improvement. More broadly, it suggests that partition in work, which is inherited from Fordism, may not be the best approach (Dupré et al., 2008). Thus, improving the way our environments are being designed challenges some cultural systems that show evident limits, such as the training of future architects and engineers.

In this research, the focus is on architecture students and aims to demonstrate how the use of a new sustainable performance simulation tool could contribute to educate them about innovatively sustainable design. This was assessed through the evaluation of student engagement, their use of the tool and its appropriation.

The first section of this paper concerns the literature review that underpins the design development framework of the testing tool. The second section details the simulating tool itself and its main features. It also presents the overall methodology to evaluate the student use of the tool. Finally, the third section presents the results and discusses them, prior to the conclusion.

## 2. Research objective & method

### 2.1. Research objective

Our research objective is to evaluate whether the use of a sustainable performance evaluation tool could help architecture students to improve their design in relation to sustainable issues.

Problem solving and design thinking skills are often identified as a key outcome of the architectural studio pedagogy. Such skills are acquired through architectural design courses, whereby students are asked to create a conceptual response to a design problem (Uluengin and Koca, 2014). The typical process that facilitates the response is a non-linear design process where the student moves back and forth between ideas or theories to determine the most suitable response. This process often involves both theoretical and empirical consideration where the student may develop multiple proposals before critically determining the best solution to a problem (Eilouti, 2018). This is further facilitated by site visits and 'hands on' experience, enabling a deeper level of inquiry (Salama, 2012).

At the same time, since the Brundtland report (Brundtland, 1987), all the schools of architecture in the world have embedded sustainable principles of development. As often underlined by many practitioners and scholars, this focus was not new but had the merit to put into words on existing practices (Gauzin-Muller, 2002). However, even if in the industry awards and accolades have flourished to recognise

best practices, less has been done to investigate this aspect at the pedagogical level. For example, there is admittedly scholarship on design assessments (Ghonim and Nehad Eweda, 2018; Utaberta et al., 2013; Murphy et al., 2012; Taneli and Tok, 2010; Wolf et al., 2008), yet few concerned the evaluation of the sustainable components of the student design. Therefore this research addresses this gap.

Our approach to this research question is quite innovative as it relies on a quantitative evaluation of the sustainable performance of student projects throughout their design processes. The aim is to evaluate the sustainable performance of a design, whilst comparing various design projects and various versions of a same project. This means that student progress is tracked in terms of sustainable performance at each design step.

### 2.2. Method

Our research method used both quantitative and qualitative approaches with a focus on problem-solving. It followed four steps: literature review, tool design, tool testing and results analysis.

Using findings of the literature review and the authors' professional knowledge, the second step of this project consisted in creating a new innovative and interactive tool that would help the students to better understand the principles of sustainable design and decision making, whilst evaluating the sustainable performance of multi-storey buildings. The design and development of this tool, called EASED (Easy Approach for Sustainable and Environmental Design), is detailed in the next section.

The third step concerned the EASED trial. It was tested on several case studies through an architectural design exercise for Master students in Architecture (4th year). Students were asked to use EASED in their design process while being monitored. These tests followed the steps of the design exercise and integrated a feedback phase at the end of each step to adapt and improve the tool.

Finally, the last phase of this research involved the critical analysis of the tests along with the conclusion.

## 3. Literature review

### 3.1. Literature review method

According to the United Nations, 66% of the world's population is expected to live in cities by 2050 (United Nations, 2016). Two major trends are known regarding this urban growth, either horizontal or vertical (Urban Hub, online, 2017). In the later case, urban environments are not only facing an increase in population (number of inhabitants) but also a significant growth of the population density (number of inhabitants by surface unit) (Urban Hub, online, 2017; UN, 2016). With a small ground footprint comparing to the total floor surface, higher multi-storey buildings provide more living space without consuming more land. Therefore, high multi-storey buildings may be considered as more 'density efficient' if they have a higher capacity to absorb population growth, without sacrificing livability or comfort (Urban Hub, online, 2017; Yeang and Powell, 2007).



Figure 1 Research method for the literature review.

As part of the worldwide efforts to protect the environment and to tackle climate change, ‘green buildings’ have been developed to reduce or eliminate the negative impacts of the building sector and to create a positive impact on our climate and natural environment (World Green Building Council, 2017). To achieve this goal, green buildings are required to reduce their Ecological Footprint. This means reducing the amount of ecological assets they need; to produce the natural resources they consume; and to absorb their waste, especially carbon emissions (Global Footprint Network, 2017). Among other features, this implies building more energy efficient buildings, that could deliver the same services for less energy input (International Energy Agency, 2017a, 2017b).

Knowing that high multi-storey buildings represent one of the most complex design topics for architectural students, the idea was to address this topic in the research. Combined with the aforementioned elements, this literature review was aimed at better understanding the challenges of multi-storey buildings in terms of density efficiency, ecological footprint and energy efficiency. The literature review consisted of three stages : selecting keywords ; browsing papers with these keywords and selecting some papers for reading ; gathering info in an Excel table (Figure 1).

Searching papers was mostly made through the Science-Direct web database, using the advanced search mode, and restricting findings to English written peer-reviewed journals only in order to reach a level of scientific recognition. Additional studies were also found through manual reference checking. No thematic filters were defined; no publication periods were defined; however the most recent articles were preferred in the selection process to better reflect contemporary research trends.

The first initial search investigated the keyword ‘green multi-storey buildings’ alone to gain a comprehensive overview of the existing studies on this topic, as well as to find other key concepts in relation to it. This search aimed to browse widely the previous studies on sustainable issues applied on multi-storey buildings and high-rises.

Then a combined search was conducted adding the three other key concepts of our research question : ecological footprint, energy efficiency and density efficiency. The two first key concepts stemmed from the first search, whilst density efficiency refers to our specific architectural and urban approach, focusing on multi-storey buildings as an answer to nowadays urban growth issue.

After removing duplicates, papers were selected for the clarity of the research question, the key concept definitions, the research method, and the results and conclusions.

Following the search process and the readings, key information from the papers was gathered in a table. It included author, date, title, research object, research method, results, and gaps or limits. This table provided an overview of the pre-existent works in order to reveal their common points and differences, and as a draft work for this literature review.

### 3.2. Literature review results

Thirty-five papers have been reviewed among which twenty-three come from developed countries (Figure 2). As developed countries are known to be major consumers of natural resources and major emitters of waste, especially greenhouse gas (WWF, 2016), it seems logical that research towards more sustainable buildings hold significant interest with them. In the same way, as China is experiencing one of the fastest urban population growth rates (United Nations, 2014), it makes sense that scholarship about sustainable high-rise buildings is quite present (5 papers out of 35).

Papers were mostly published in the journals ‘Energy and Buildings’ (12 papers), ‘Ecological Indicators’ (4) and ‘Building and Environment’ (3). Other papers are divided between journals on energy, habitat and/or sustainable issues. Overall these results underline the importance of the energy issue in the reviewed literature. Out of the 35 papers, 15 were published between 2015 and 2017, and 12 were published between 2010 and 2015. The other eight papers were published before 2010, with the oldest paper published in 1991 (Figure 2). This shows that this topic is not a new issue, yet it has become an increasing point of interest in the last decade.

Findings from these papers may be classified into two categories (Figure 3).

On one hand, some scholars have focused on passive design strategies and active system strategies applied for ‘greener’ buildings. For instance, they have proved that applying passive design strategies, especially on the building’s envelope, can lower a building’s energy consumption (Cheung et al., 2005; Yu et al., 2013; Cho et al., 2014; Raji et al., 2016). According to the energy simulation results, these passive design strategies on the building’s envelope could lead to savings for both cooling-dominant buildings (Cheung et al., 2005; Yu et al., 2013; Cho et al., 2014) and heating-dominant buildings (Yu et al., 2013; Raji et al., 2016). Others have found that, beyond an energy efficient envelope, passive design principles applied on the whole building and when combined with sustainable strategies for active systems can increase the reduction of building’s energy consumption ( Nui, 2004; Lotfabadi, 2014; Lotfabadi, 2015).

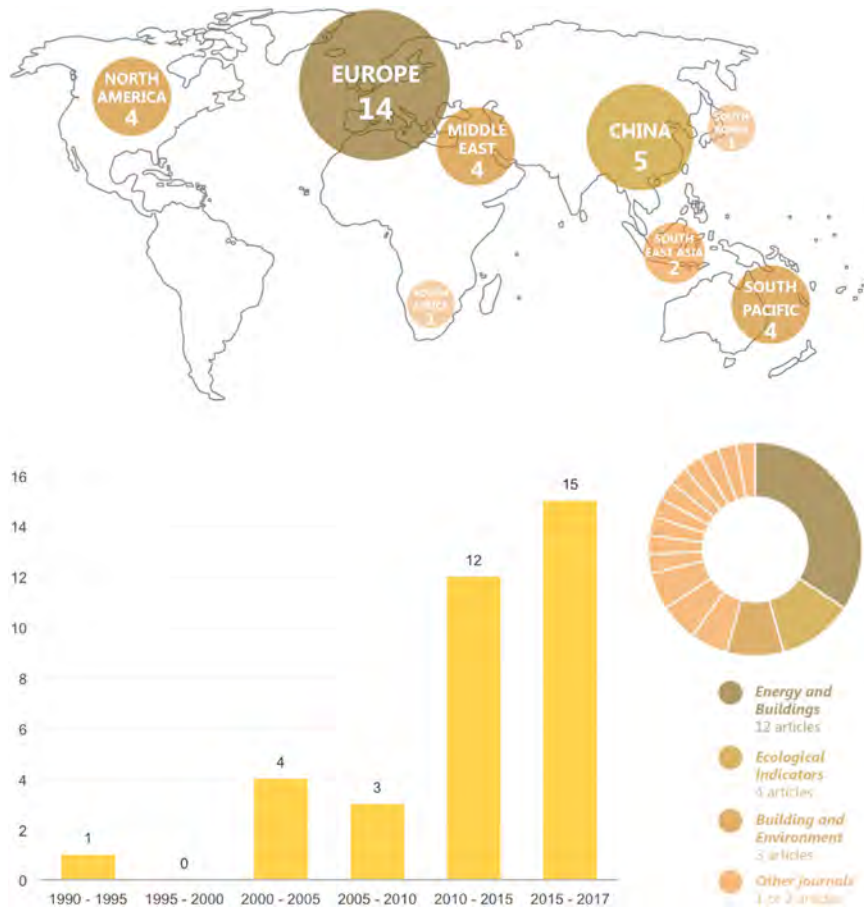


Figure 2 Geographical origin, publication dates and journals of selected papers.

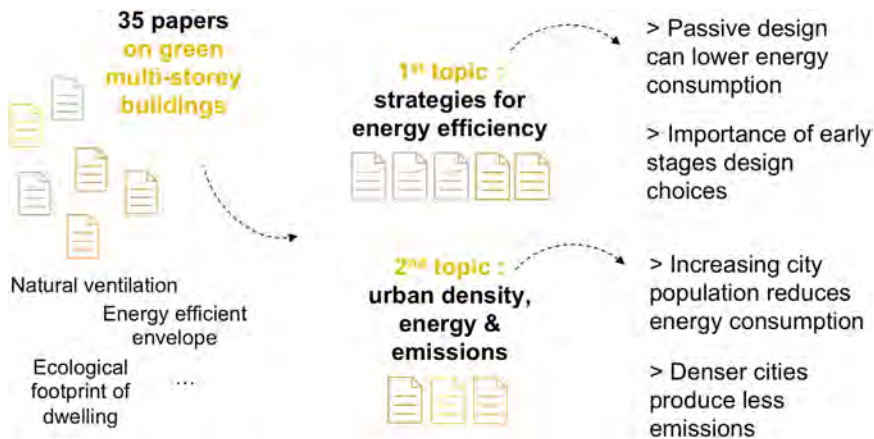


Figure 3 Main results from the literature review.

Yet, scholars have also proved that the energy efficiency potential of these passive design strategies and active system strategies relies on design choices that are mainly made at the early stage of the building design, such as building geometry or urban shapes design. For example, [Tong et al. \(2017\)](#) has argued through an in-house atmospheric boundary layer (ABL) meteorology model that natural ventilation flows vary with building height. [Cheung and Liu \(2011\)](#) conducted several computational fluids

dynamics (CFD) simulations to prove that these flows may vary with building separation, orientation and disposition. In a parametric study of buildings from 3 to 12 floors, [Hachem et al. \(2014\)](#) has showed that solar photovoltaic potential depends on a building’s height, facades orientation and roof design. In a practice based research, [Leung and Weismantle \(2008\)](#) defends that other passive and active strategies may be optimised regarding outdoor environment factor changes with altitude.

In addition, some research has been conducted on the relationships between urban density and energy use and/or greenhouse gas emissions. Scholars have demonstrated that increasing population density in cities could lead to a reduction of energy use, whether focusing only on transport energy demand (Steemers, 2003) or extending the analysis to global urban energy use for space heating, embodied building energy, transportation energy, and road infrastructure energy (Resch et al., 2016). It has also been established that denser cities produce less greenhouse gas emissions, for both on-road and building emissions. Using a City Clustering Algorithm and gridded CO<sub>2</sub> emissions data on inhabited areas in the US, Gudipudi et al. (2016) revealed a sub-linear relationship between population density and total emissions, as doubling the population density would reduce total emissions by 42%. He also pointed out that ongoing urban sprawl will lead to an increase in on-road energy consumption. These conclusions are shared by Borck (2016), whose study on building height limits as a policy to limit urban GHG emissions stressed that building height limits lead to urban sprawl and higher emissions due to commuting.

The literature review also revealed two main gaps that we aimed to discuss in this section.

First of all, the review showed that research on the green building issue lacks common definitions and common calculation methodologies. For instance, several authors have worked on energy consumption of buildings, but their accounting models vary drastically from including only space cooling to including space heating and/or water heating, lighting, appliances and cooking for housing, space heating, fans and pumps, lighting and refrigeration for offices (Cheung et al., 2005; Cho et al., 2014; Hachem et al., 2014); Yu et al., 2013; Lotfabadi, 2014; Lotfabadi, 2015; Raji et al., 2016; Steemers, 2003). The same bias can be found in greenhouse gas emission accounting, as authors may account different greenhouse gas emissions and different sources of emissions (Gudipudi et al., 2016; Borck, 2016).

Authors recognise that for Ecological Footprint analysis, confusion about basic definitions and principles may occur as well, and that more robust and useful resource accounts are needed (Kitzes and Wackernagel, 2009). Several accounting models can be found, based on different impact factors (Solis-Guzman et al., 2013; Gonzalez-Vallejo et al., 2015). Even for the definition of a 'high-rise building', authors do not agree from one paper to another, as a high-rise may vary from around 10 storeys (Yu et al., 2013; Hachem et al., 2014), to 20 storeys (Raji et al., 2016), 30 storeys (Nui, 2004), 40 storeys (Pan, 2016; Cheung et al., 2005) or even more than 50 storeys (Lotfabadi, 2014; Lotfabadi, 2015; Tong et al., 2017).

All these different accounting models, parametric studies and methodologies make the results hard to compare, or can even lead to varying or conflicting results (Gudipudi et al., 2016). From one study to another, the answer to what the density efficiency, the ecological footprint and the energy efficiency of a multi-storey building may vary significantly. As such it is quite clear that there is a great need for more common and more easy-to-understand definitions and accounting models on the key concepts of density, ecological footprint and energy efficiency.

The second gap is even more important, as it reveals the lack of a holistic approach from the reviewed literature.

Firstly, several authors have focused on one of our key concepts, throughout a parametric study that included some parameters but excluded other parameters. Yet, these excluded parameters may be impacted by the included ones, and/or may have an influence on the studied magnitude. For example, Raji et al. (2016), Cheung et al. (2005) and Yu et al. (2013) have all studied the influence of passive design strategies on building energy consumption but with 4, 6 and 8 different passive design strategies respectively. All these parameters were found to have an impact on energy consumption; there may even be other relevant parameters to integrate. Furthermore, Hachem et al. (2014) and Cho et al. (2014) conducted studies regarding the impact that active and passive systems, located around the building facades, have on energy consumption. This was performed without investigating all the impacts of such systems or other features related to the energy consumption of the buildings. For instance, they have ignored the available daylight for indoor lighting that may imply an indirect negative impact on a building's energy performance (in this example, an increase of electricity consumption for lighting).

Secondly, most researchers have not fully investigated the relationships between different parameters related to the different key concepts of density, ecological footprint and energy efficiency. Indeed, several authors argued that many other parameters should be taken into consideration, and that the complex relationships between parameters should be further investigated. For example, Steemers (2003) and Resch et al. (2016) have pointed out this necessity, as well as Hachem et al. (2014), who admitted in his energy performance enhancement approach of solar electricity generation that some density related parameters, such as the land design and the positioning of the buildings, should be optimised to achieve greater energy efficiency of solar systems.

Thirdly, many studies were conducted in a single building case study only (Yu et al., 2013; Cheung et al., 2005; Raji et al., 2016; Cho et al., 2014; Soliz-Guzman, 2012). Yet, other authors have proved that varying the building typology may lead to different results towards the research question and may even lead to the finding of an optimal building typology for one or several parameters. Hachem et al. (2014) demonstrated this point with his study on PV systems of roofs and facades, as the energy potential of the PV systems compared to the building needs varies with the building height. In the same way, Resch et al. (2016) who focused on how density is related to energy use, argued that the optimal number of storeys to lower energy use per capita is found to be in the range of 7-27, depending on population and the building lifetime. (Gonzalez-Vallejo et al 2015), with 92 dwellings construction projects evaluated, has revealed that detached houses generate an ecological footprint by square metre constructed of 1.5 higher than that of 4-floors multi-family buildings, while the indicator remains practically constant for taller buildings.

In conclusion, depending on which parameters are taken into account, different answers can be found to which parameters may play a role in achieving either greater density efficiency, minimal ecological footprint or greater energy efficiency in a multi-storey building. In addition, depending on the interrelations of these parameters and how these interrelations are taken into consideration, various answers can be revealed to the question of how a multi-storey building

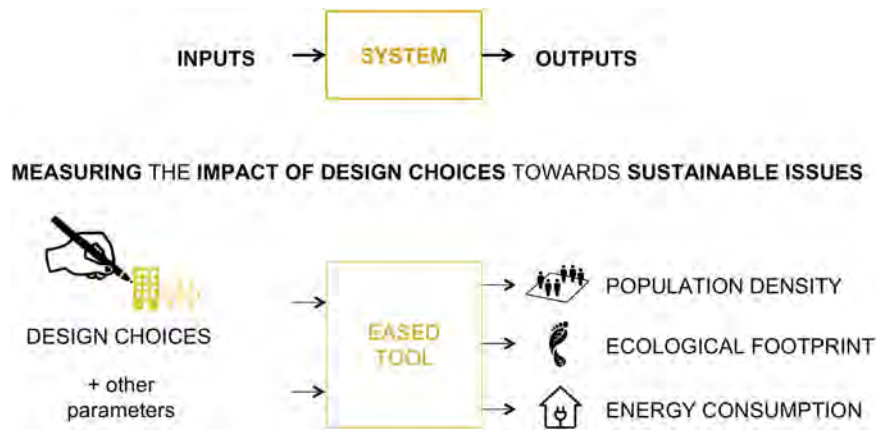


Figure 4 Principles of the EASED tool.

can achieve a greater density efficiency, a minimal ecological footprint and a greater energy efficiency at the same time. If focusing only on the number of floors, the answer may not be the same from one building typology to another.

Knowing this, it appears that simultaneously optimising a greater density efficiency, a minimal ecological footprint and energy efficiency is more complex than having each criterion optimised independently to each other. Thus density, ecological footprint and energy efficiency for multi-storey buildings should be considered within a more holistic approach, that focuses on the interrelations between these three concepts rather than the addition of each. This holistic approach may consider density, ecological footprint and energy efficiency as a global dynamic process which is influenced by a wide range of interdependent parameters, whom successive variations lead to new relationships and results.

Systemic approaches towards sustainable buildings have been the subject of some recent research papers (Franzitta et al., 2011; Okeil, 2010; Kreiner et al., 2015; Vlachokostas et al., 2017). However, because of the manifold parameters that can be taken into account, and of the complexity of their interrelations, holistic approaches are not easy to conduct.

As a result of this literature review, we may argue that there is a need to improve the approach of the concepts of density efficiency, ecological footprint and energy efficiency that could:

- set up common and easy-to-understand definitions and accounting models
- be more holistic in order to enlighten the interdependence of the parameters influencing density, ecological footprint and energy efficiency
- be applied to a wide range of case studies to enhance the results

#### 4. The tool: Easy Approach for Sustainable & Ecological Design (EASED), design and testing

##### 4.1. Design of the tool

The findings of the literature review set up the basis for the development of EASED, along with the professional knowledge of the authors; both being architects with one being an

engineer. The main objective in developing EASED was to study the impact of different design choices on the performance of designed buildings in terms of density efficiency, ecological footprint and energy efficiency. In the end, a possible optimisation of these design choices has been sought.

EASED relies on algorithms and a parametric logic: the inputs are the design choices, and the outputs are the performances of density efficiency, ecological footprint and energy efficiency (Figure 4). The model in itself is a set of definitions and calculation methods that convert the variables into results. This approach is holistic, since the results of density efficiency, ecological footprint and energy efficiency are calculated with the same input parameters. The variation of one of the inputs can impact each of the outcomes for density, ecological footprint or energy efficiency; the optimisation of the input parameters must be sought by considering the three issues at the same time.

The model is to be applied for early-stages design choices. The input parameters integrate the definition of the building typology, in order to measure the influence of the building typology on density efficiency, ecological footprint and energy efficiency, and to reach the best possible optimal typology. This model was developed through the software Microsoft Excel. Microsoft Excel allows the user to define calculation formulas that run automatically when the input values are given; the results are updated at any modification of these inputs. It was chosen for its ease of use both during the creation of the model and its implementation for a case study.

EASED was designed as a 'ready-to-use' tool. Its layout aims to make it easy to use and easy to understand for the designer of the project. The parts that need to be filled in are clearly identified and the rest of the document is locked to avoid the modification of the elements that define the model (titles, formulas, results, and graphics).

EASED has 9 sheets which parameters are linked as follows. The first sheet is the Introduction sheet. It gives the purpose of the tool and explains how to use it. The next 6 sheets correspond to the 6 categories of input parameters: 1. Building, 2. Ground Floor, 3. Density, 4. Open Spaces, 5. Ecological Footprint, 6. Energy Consumption. Categories 1-4 directly refer to design choices (Figure 5). Categories 5 and 6 do not directly refer to design choices, but rather depend on design choices (Figure 6).



Figure 5 Input parameters (sheets 1-4) : design choices.

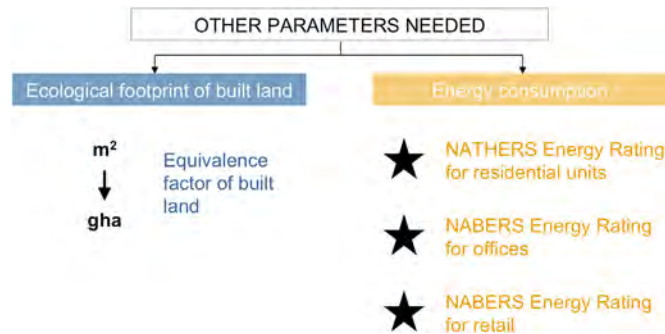


Figure 6 Input parameters (sheets 5 and 6) : other parameters.

The 6 sheets follow the same layout. The first part of each sheet is dedicated to the input parameters. The user has to fill in the cells with their project data; some definitions and comments are provided to specify the inputs needed. The second part of each sheet gives the results that are automatically calculated, according to the predefined formulas. Calculations cross inputs and outputs from different sheets, linking the different design parameters in order to link density efficiency, ecological footprint and energy efficiency according to our research approach. These formulas and some definitions are detailed in comments on each sheet.

### 1. Building

In the 1. Building sheet, the designer has to give the following inputs from its project : the height of each building, and the number of storeys and the floor area of each storey for each storey type for all the buildings of the project.

Two results are calculated with these inputs:

- Maximum height: height of the highest building of the project (unit: m)
- Total floor area: sum of the products of the floor surfaces of the different floor types by the number of floors of each type, for the whole project (all buildings) (unit:  $m^2$ )

Figure 7 gives an overview on the “Building” sheet from EASED: the designer has to fill up the input parameters (in orange) and outputs are automatically calculated (in blue).

### 2. Ground Floor

The 2. Ground Floor sheet gathers inputs on the lot area, the buildings’ ground floor area, the outdoor parking area and the service roads area.

Several outputs are calculated:

- Total buildings ground floor area, total outdoor parking area, total service road area: sum of each type of area for the entire project (unit:  $m^2$ )
- Build land area: sum of total buildings ground floor area, total outdoor parking area, total service road area (unit:  $m^2$ )
- Non build land area: lot area minus build land area (unit:  $m^2$ )
- Footprints: total buildings ground floor area, total outdoor parking area, total service road area, build land area and non build land area are compared to the lot area to express their footprint (unit: % of the lot area)
- Floor area ratio: ratio between the total floor area and the lot area



**BUILDING**

**INPUT PARAMETERS**  
Please fill up the following parameters and add/delete row where needed

**1. BUILDING(S) HEIGHT**  
Enter the height of your building(s)

BUILDING	TOTAL HEIGHT (m)

**2. FLOOR AREA OF STOREYS**  
Enter the floor area of the storeys of your building(s), including underground storeys.

BUILDING	STOREY(S) / DETAILS	FLOOR AREA PER STOREY (m <sup>2</sup> )	AMOUNT OF THIS TYPE OF STOREY

**OUTPUTS**  
Outputs are calculated automatically with the input parameters. Be sure to fill up correctly all the input parameters.

**1. MAXIMUM HEIGHT**  
Height of the highest building of the project, in meters  
0 m

**2. TOTAL FLOOR AREA**  
Total floor area of all the buildings of the project, in square meters  
0 m<sup>2</sup>

Figure 7 The 1. Building sheet of the EASED tool.

### 3. Density

Here the designer has to give info about the population of its project (Figure 8). Firstly, residential units must be described: amount of bedroom per unit, internal area (unit: m<sup>2</sup>), amount of units, amount of resident per units. Secondly, office spaces must be described: internal area of office spaces, amount of permanent office staff. Thirdly, other permanent staff must be added to the population of the project.

These inputs are crossed with inputs and outputs from other sheets to give the following results:

- Total amount of residential units: sum of the units of the project
- Total internal area of residential units: sum of the products of internal area per unit by the amount of units (unit: m<sup>2</sup>)
- Total building residents: sum of the products of residents per unit by the amount of units
- Internal space per resident for residential unit: average of the ratio between the internal area of a unit and the amount of resident in this unit (unit: m<sup>2</sup>/resident)
- Total internal area of office spaces, total permanent office staff, internal space per permanent office staff, total other permanent office staff: same kind of calculations
- Total building permanent users: sum of total building residents, total permanent office staff and total other permanent office staff
- Total population density: ratio between total building permanent users and lot area (users/ha)

### 4. Open spaces

This sheet focuses on the provision of open spaces on the one hand and the part for green open spaces on the other hand.

Inputs are required on private open spaces for residential units, for office spaces and for other uses in the project (type of open space, area, amount, amount of users) and on public open spaces (area). The designer has also to describe if the projects has deep soil zones and green structures (area in m<sup>2</sup>).

Outputs area calculated following the Density sheet logic:

- Total private open space area for residential units, private open space per resident for residential units, total private open space area for office space, private open space per permanent staff for office space, total other private open space area, total private open space area, total public open space area, public open space per permanent user;
- Total deep soil area, total green structures area, total green open space area, total green open space per permanent user

### 5. Ecological footprint

In this sheet, no input is required from the designer; instead, an input is given, similar for all project: the equivalence factor of built land. This factor allows to convert built-up areas required for building construction (expressed in hectares) into the bioproductive "land areas" (expressed in global hectares) used in the determination of the Ecological footprint. This equivalence factor is expressed in global hectares per hectares, its value is 2,51 gha/ha. It was defined by the Ecological Footprint Network (cf 3. Literature review).



"RESIDENTIAL-LIKE" SPACES	"OFFICE-LIKE" SPACES	"RETAIL-LIKE" SPACES
Residential units	Offices	Shops and services
Hotel and accommodation	Health center (day use), doctors	Cultural facilities (museums, cinemas...)
Age care	School	Sport facilities

Figure 9 Definition of the three categories of spaces for energy consumption.

The energy consumption values used in the model therefore do not correspond to the true energy consumption of the project, as it could have been calculated with adapted simulation software. At this stage of the model, the approach is limited, both because it would have been complex to link the model to another energy simulation tool, and to remain in simple and consistent methods with the sketch phase to which one attaches.

The choice of the energy performance of the building is therefore based on the designer, who decides how many stars s/he thinks or aims for the project. This choice must be guided and justified by the different energy efficiency strategies implemented in the building (passive design and/or active systems). The designer must demonstrate judgement and critical regard for the project: this point is essential in the use of the EASED tool.

Various outputs are calculated:

- Total energy consumption for residential units and for offices spaces
- Total energy consumption for residential units per resident and for offices spaces per offices staff: calculated with the previous result divided by the amount of resident and the amount of permanent office staff
- Total area of residential-like spaces, of offices-like spaces, of retail-like space
- Total energy consumption for residential-like spaces, for offices-like spaces, for retail-like space: product of the total area of each kind of space and the energy consumption per square metre for each kind of space
- Total energy consumption: sum of the previously cited energy consumptions

#### 4.1.1. Results

The penultimate sheet is the Results sheet. It automatically gathers all the results from the sheets 1-6, presented by categories. Every result is illustrated with a black and white symbol, in order to generate an easy-to-understand and visually attractive summary of the outcomes. This summary can be integrated into the presentation of a project; it is also a good medium to compare the results of different projects (Figure 10).

#### 4.1.2. Evaluation

The last sheet is the Evaluation sheet.

The aim of this sheet is to calculate and present the performance of the project on three aspects related to sustainable design: liveable density, sustainable land use and energy efficiency.

Each aspect is evaluated using six criteria, crossing quantitative and qualitative data. These criteria are selected among the outputs calculated in the previous sheets. For each criterion, the output value calculated for the project has to be compared to a reference value,



Figure 10 Extract of the Results sheet of the EASED tool.

through a scale of scores from 0 to 100, in order to determine the good or bad performance of the project on this criterion. The reference value can be extreme (value 100/100) or medium (value 50/100). Reference values come from Australian building standards or regulations, or from ideal choices in terms of sustainable performance.

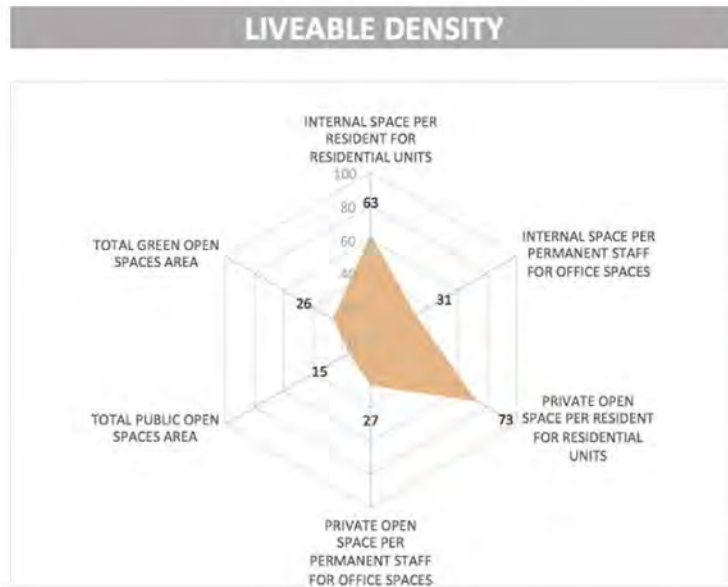
Final evaluation is presented through three radar charts, one for each sustainable aspect.

Liveable density performance (Figure 11) aims to evaluate the balance between the density efficiency of the project (high density of population hosted) and its liveability that assure a good quality of life despite this high density (enough internal space, open space and green space). Six criteria are analysed:

- Internal space per resident for residential units
- Internal space per permanent staff for offices spaces
- Private open space per resident for residential units
- Private open space per permanent staff for office spaces
- Total public open spaces area
- Total green open spaces area

Sustainable land use performance (Figure 12) focus on the balance between building and built land footprint, deep soil area, population density, and ecological footprints, in order to determine how the project can provide a high population density without sacrificing too much land space. The six criteria selected among the outputs and compared to reference values are:

- Building footprint
- Building land footprint



**INTERNAL SPACE PER RESIDENT FOR RESIDENTIAL UNITS**

	m <sup>2</sup> / resident	Rating (%)
Reference	26,5	50
Project	33	63

**INTERNAL SPACE PER PERMANENT STAFF FOR OFFICE SPACES**

	m <sup>2</sup> / staff	Rating (%)
Reference	12,0	50
Project	7	31

**PRIVATE OPEN SPACE PER RESIDENT FOR RESIDENTIAL UNITS**

	m <sup>2</sup> / resident	Rating (%)
Reference	4,8	50
Project	7	73

**PRIVATE OPEN SPACE PER PERMANENT STAFF FOR OFFICE SPACES**

	m <sup>2</sup> / staff	Rating (%)
Reference	2,2	50
Project	1	27

**TOTAL PUBLIC OPEN SPACES AREA**

	m <sup>2</sup>	Rating (%)
Reference	14425,0	100
Project	2170	15

**TOTAL GREEN OPEN SPACES AREA**

	m <sup>2</sup>	Rating (%)
Reference	14425,0	100
Project	3755	26

Figure 11 Extract of the Evaluation sheet of the EASED tool, Liveable density performance.



**BUILDING FOOTPRINT**

Project	51 % of the lot area
---------	----------------------

**BUILT LAND FOOTPRINT**

Project	59 % of the lot area
---------	----------------------

**TOTAL DEEP SOIL AREA**

	m <sup>2</sup>	Rating (%)
Reference	14425	100
Project	3135	22

**ECOLOGICAL FOOTPRINT OF BUILT LAND PER TOTAL FLOOR AREA**

	EF of built land per total floor area (gha/m <sup>2</sup> )	Rating (%)
Reference	2,91E-05	50
Project	1,36E-05	23

**POPULATION DENSITY**

	Population density (users/ha)	Rating (%)
Reference	1600	100
Project	1308	82

**ECOLOGICAL FOOTPRINT OF BUILT LAND PER USER**

	EF of built land per user (user/m <sup>2</sup> )	Rating (%)
Reference	9,31E-04	10
Project	1,14E-03	12

Figure 12 Extract of the Evaluation sheet of the EASED tool, Liveable density performance.

- Total deep soil area
- Ecological footprint of built land per total floor area
- Population density
- Ecological footprint of built land per user

Energy efficiency performance (Figure 13) gathers the energy consumption of each type of space, as a gross result,

and the weight, in terms of energy consumption, of each type of space in the total energy consumption of the project, as expressed by these six criteria:

- Energy consumption of residential-like spaces
- Energy consumption of offices-like spaces
- Energy consumption of retail-like spaces

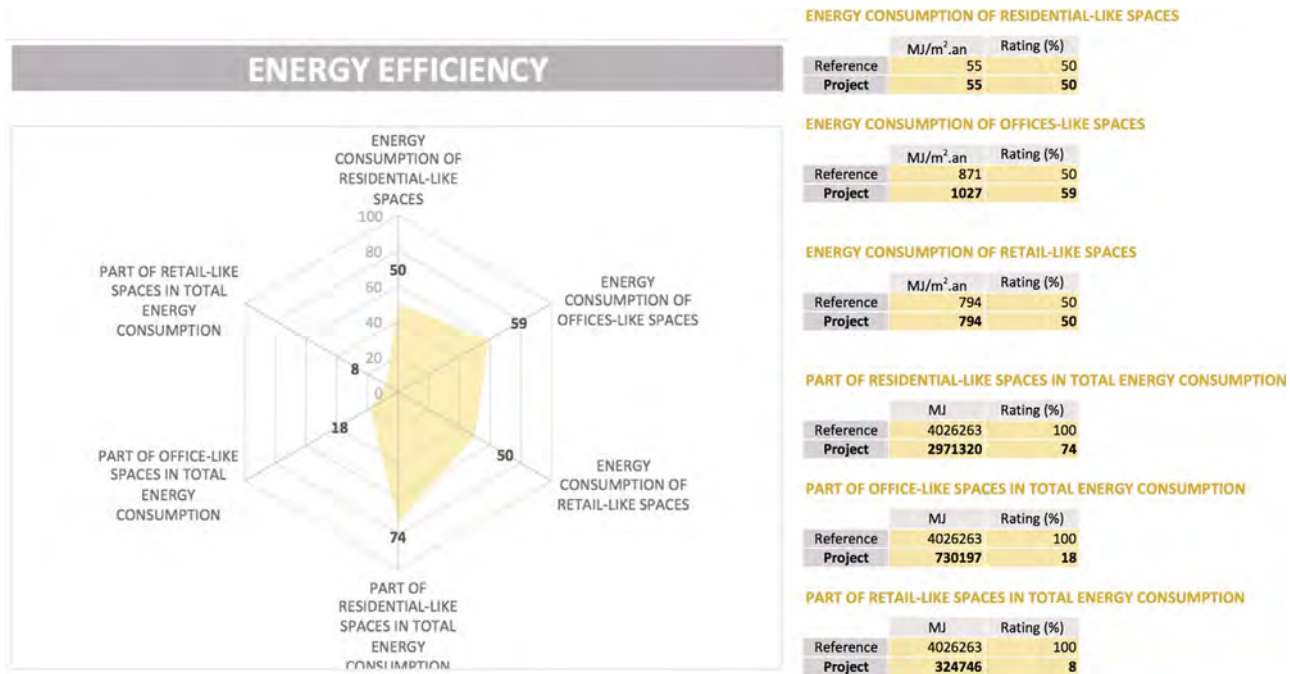


Figure 13 Extract of the Evaluation sheet of the EASED tool, Liveable density performance.

- Part of residential-like spaces in total energy consumption
- Part of offices-like spaces in total energy consumption
- Part of retail-like spaces in total energy consumption

In the end, the Evaluation sheet aims to give three results regarding the research question:

- A synthesis of the sustainable performance of the project, given through a unique score scale from 0 to 100, in comparison to references values, in a quantitative approach
- A way to compare several projects or several versions of a same project, in terms of sustainable performance, using this synthesis evaluation
- A direct visualisation of the manifold and complex relationships between the parameters taken into account in EASED, as one change in the project design - for example the area of residential unit, or the building footprint - may change several outputs and impacts the performance on the three aspects - liveable density, sustainable land use and energy efficiency - at the time. Indeed, the Evaluation sheet is designed as an interface for the designer to understand the links between design choices and their impact for the sustainable performance of the project, in the holistic approach wanted for this research.

#### 4.2. Tool testing

To test this new tool, it was decided to integrate EASED into an architectural design exercise conducted with the Master students of the Advanced Architecture Studio 2 of Griffith Architecture (4th year, Master - 7602 ENV - Semester 2 - 2017). In this studio, architecture students had to design a mixed-use development located on a real context site. Their proposals could be mid-rises, high-rises or

skyscrapers; the whole building development is required to meet high environmental sustainable performance.

This design exercise lasted 13 weeks, divided in two main phases. The first phase, individual work, concerned a site analysis and a master plan design proposal (3 weeks), followed by five weeks to develop the mixed-use development design, at the architectural and technical scales (from 1/200 to 1/20). During the 5 weeks of the second phase, students worked in teams on the enrichment of some proposals selected from the previous phase. They especially focused on the detail development of engineering issues (structure, acoustic, light, and HVAC, for instance).

In this design exercise, EASED was given to the students as a tool for sustainable design assistance. In particular, the tool aimed at helping them process four main objectives:

- the evaluation of the sustainable performance of their project
- the identification of the design choices that have a positive or negative impact on the sustainable performance of their project
- the optimisation of the design choices to achieve the highest level of sustainable performance in their project
- the support for decision-making in the design process

EASED was presented to the students on week 4, at the end of their analysis process and at the start of the design process. A one hour lecture was given on the tool and its research project background followed by a one hour training on the tool. During this training, the students were taught how to fill in the sheets, using the example of an existing building development located near their site. This example was chosen for its similarities with their project: same program, same climatic and urban context. All the data needed in the tool was provided to the students on a separate PowerPoint presentation. Definitions and explanations were given on every

comments for the students. This criterion ends with a free expression section for general feedback, suggestions for improvements or any other comments from the students.

### EXCEL TOOL FOR SUSTAINABLE DESIGN APPROACH – STUDENT FEEDBACK

*Please fill in this survey to give your feedback on the Excel tool. This survey is anonymous.*

#### 1. COMMITMENT

- > Did you open the Excel tool once?  YES  NO
- > Did you start to fill it in?  YES  NO
- > Did you finish to fill it in once?  YES  NO
- If yes, did you modify your first version and / or fill in different versions of the Excel?
- YES  NO

#### 2. EASE OF USE & OF UNDERSTANDING

- > In your use of the Excel tool, did you have any difficulties for:
- Opening the Excel file?  YES  NO
  - Switching from one sheet to another?  YES  NO
  - Writing in the orange cells?  YES  NO
  - Adding or deleting rows?  YES  NO
  - Saving the file?  YES  NO
  - Understanding the input parameters needed?  YES  NO
  - Extracting the data needed from your project?  YES  NO
  - Understanding the outputs?  YES  NO
  - Understanding the "RESULTS" sheet?  YES  NO
  - Understanding the "EVALUATION" sheet?  YES  NO
- > If you answered yes to any of the questions above, or if you had another difficulty while using the Excel tool, please explain the difficulty encountered:

#### 3. ROLE & HELP FOR THE DESIGN PROCESS

- > Did you modify your project in relation with the Excel tool?  YES  NO
- If yes, explain what you modified, why and how:
- > Did the Excel tool help you to take any decision in your project?  YES  NO
- If yes, explain the situation:

**Figure 14** Survey for student feedback over the EASED tool, page 1.

sheet; an analysis of the results and the evaluation of the example were presented. At the end of the tutorial, students were given a filled-in version of EASED with the example and an empty version of EASED to be used for their project.

Over the next two weeks of the mixed-use development design phase, students were interviewed by the studio's tutors on their use of EASED as part of the individual weekly review of the students' projects. Concerning the tool, the review aimed to determine if:

- the student has opened the file and started to fill it in
- s/he had any difficulty so far in using the tool, or any questions, remarks or comments on the tool

- s/he has used the tool in the development of his or her project; and if yes, what, why and how

At the end of this phase, students had to present their project through a graphic and written submission. In particular, they had to demonstrate the sustainable character of their proposal, and the relevance of the chosen typology in terms of energy efficiency, density and land footprint. A report on these issues was required, along with a completed version of the EASED tool. Submissions were followed by a review of all the projects: every student had to present their project orally in front of a jury composed of the studio tutors and of guest professional architects.

#### 4. APPROPRIATION & PERSONAL USE

> In your final presentation (whether on your presentation documents or orally), did you present:

- Any result or data from the Excel tool?  YES  NO
- The layout of the results of the "RESULTS" sheet?  YES  NO
- The diagrams of the "EVALUATION" sheet?  YES  NO
- Your analysis of the results?  YES  NO

> Will you use the Excel tool in other projects, if it's not compulsory?

- YES  NO

#### 5. CRITICAL FEEDBACK

> Overall, would you say that the Excel tool:

- Was easy to understand?  
 DISAGREE  RATHER DISAGREE  RATHER AGREE  AGREE
- Was easy to use?  
 DISAGREE  RATHER DISAGREE  RATHER AGREE  AGREE
- Helped you to evaluate the sustainable performance of your project?  
 DISAGREE  RATHER DISAGREE  RATHER AGREE  AGREE
- Helped you to identify the influential parameters over the sustainable performance of your project?  
 DISAGREE  RATHER DISAGREE  RATHER AGREE  AGREE
- Was relevant to evaluate the sustainable performance of your project?  
 DISAGREE  RATHER DISAGREE  RATHER AGREE  AGREE
- Was useful in your design process?  
 DISAGREE  RATHER DISAGREE  RATHER AGREE  AGREE

> General feedback, suggestions for improvements, other comments?

Figure 15 Survey for student feedback over the EASED tool, page 2.

After the review day, the students were surveyed on their use of EASED and its usefulness for their design project (Figures 14 and 15). This survey relied on five evaluation criteria. For each criterion, closed-ended questions and open-ended questions were asked. The first evaluation criterion determines the level of student engagement with the tool. Four levels of commitment are defined through the four questions. The first level is achieved if the student has opened the tool. The second level is achieved if the student has started to fill in the tool. The third level is achieved if the student has finished filling-in the tool once. The fourth level is achieved if the student has modified his or her first version of the tool and/or has filled in different versions of the tool. All the questions are closed-ended: students have to pick 'yes' or 'no' depending on what they have done.

The second evaluation criterion is about the ease of use and of understanding. This part aims to reveal if the students had any difficulties in filling-in the tool. Two kinds of difficulties are defined. The first part of the questions focuses on difficulties in the handling or ease of use of the tool. This includes: opening of the file; switching from one sheet to another; writing in the orange cells; adding or deleting rows; saving the file. The second part of the questions focuses on difficulties in the understanding of the tool. This includes: understanding the input parameters needed; extracting the data needed from the project; understanding the outputs; understanding the 'RESULTS' sheet; understanding the 'EVALUATION' sheet. Questions are closed-ended: the student is to choose between 'yes' if they had any difficulty and 'no' if they didn't. If the student

answers yes to any of the questions, or if s/he had another difficulty while using the tool, s/he is then required to explain the difficulty encountered.

The third evaluation criterion concentrates on the role and the benefit of EASED on the design process. The first question aims to reveal if the tool has led the student to modify the project. The question is closed-ended ('yes' or 'no'); if the answer is yes, the student needs to explain these modifications (what, why, how). The second question aims to reveal if the tool has helped the student in some decisions made through the development of the project. The question is closed-ended ('yes' or 'no'); if the answer is yes, the student needs to explain the situation. The fourth evaluation criterion is about the appropriation and the personal use of the tool by the students. Firstly, it attempts to reveal if the students have extracted elements from the tool to include them in the final presentation of their project (whether on their presentation documents or orally). The questions focus on four kinds of elements extracted from the tool: results or data; the layout of the 'RESULTS' sheet; the diagrams of the 'EVALUATION' criteria; the analysis of the results. The questions are closed-ended: the student is to choose between 'yes' and 'no'. Secondly, students were asked about their possible future personal use of the tool: whether they would use the tool in other projects if it is not compulsory. Students must answer using 'yes' or 'no'.

The fifth criterion of evaluation is the critical feedback of the students on the tool. In this part, the survey aims to collect more concise feedback on the tool from the students. The first questions focus on the ease of use and the ease of understanding it. The second range of questions deals with the relevance and the usefulness of EASED regarding the sustainable approach in the design process. All these questions are closed-ended; in order to get more critical and nuanced feedback, answers are to be chosen from 'disagree', 'rather disagree', 'rather agree' and 'agree'. This criterion ends with a free expression section for general feedback, suggestions for improvements or any other comments from the students.

In the last phase of the design exercise (group work for the final development design), the students were asked to use EASED again. For the first four weeks of this final phase, the process was quite similar to the previous phase. The students were interviewed on their use of the tool as part of the weekly review of each group's project. At the end of the development, they had to present their project with a graphic and written submission; a report on sustainable issues and an updated version of the tool were required. A similar review of all the projects was conducted after the submission.

After the review, students were given one more week to improve their proposal on the basis of the critics and submit again all the documents. After this final submission, the students were again asked to answer the survey on their use of EASED and its usefulness for their design project, and how it was applied in this phase.

The relevance of EASED for architectural students was assessed through three different forms of feedback. The first concerns the teacher's review on student use of the tool. This feedback comes from the weekly review of the projects conducted by the teachers in studio, and from the analysis of student final submissions and presentations. Secondly, there is the EASED report's feedback that comes from the analysis of

the EASED reports, filled in by the students. This analysis was made by the creators of EASED. Thirdly, there is the student feedback on their own use of the tool, through the survey they had to answer twice.

It must be noted that for these three forms of feedback, the individual phase and the group phase were analysed separately and successively. The analysis of these forms of feedback followed the four analysis criteria established for the survey:

- commitment
- ease of use and understanding
- role and help in the design process
- appropriation

The following two sections discussed the results that emerged from the individual and then group phase.

## 5. Results: individual phase

### 5.1. Quantitative results EASED review

What mostly emerges from the analysis of the three forms of feedback during the individual phase is quite a negative result revealing several challenges.

#### 5.1.1. Commitment

In terms of commitment, the weekly review shows that students did not really engage with EASED before the last week of the individual phase (week 6).

This was confirmed by the EASED reports analysis, which showed lack of completion, lack of careful input (filling in the wrong area), lack of congruency with the project (data filled in does not correspond to the project specificities) and lack of thorough checking, therefore skewing the results. Some students even worked with the wrong version of the tool, the one that was given as a pre-filled example during the tutorial. Altogether, only 30% of the students completed their EASED reports without mistake.

The same conclusions emerged from the survey: all the students affirmed they opened EASED once, and started to fill it in, yet 5% of them admitted that they did not finish to fill it once, and only 29% of them modified their first version of the report. For 39% of the students, the main reason invoked was the lack of time, whilst 10% expressed difficulty in understanding the data input or meaning of the tool.

These results are of course frustrating because with the only one student who opened EASED earlier (and was able to fill in a first version and show it to the teacher), there was the proof of the relevance of the tool as there was an opportunity to answer some questions about it, and to discuss over the sustainable performance of the student's project and how it could be improved.

Overall these first findings show that engagement is primordial if one wants to achieve results in regards to the purpose of EASED. The challenge of time is known to all educators, but in the architectural context specifically it raises the question of the prioritisation for the students: how to make them understand that in the long run EASED could benefit both their conceptualisation and design processes. Another challenge that emerged was the fact that EASED was not so user-friendly in a first approach since



students had trouble with it, despite the two hour introduction, with a very hands-on approach.

### 5.1.2. Ease of use and understanding

This lack of commitment had an effect on assessing criterion 2 (the ease of use and understanding) since it was quite hard to know if the students had any difficulties in use/ing and/or understanding EASED. However the two hour initial EASED workshop already revealed some difficulties that the students had using it. They mostly concerned how to use the tool (e.g. how to delete or add a row), understanding the data needed (for example, which area to fill in for the floor area: with or without the walls), understanding EASED's given hypothesis and references (for example, why is the lobby of buildings considered as residential, Is the Star Rating System international) and, importantly questioning the limits of the tool (for example, how can shared facilities and flexible space be taken into account in the sustainable performance).

These early questions summarise quite well the different levels of potential improvement for the tool, as well as allow an assessment of the basic skills needed to use the tool. Despite being all in the 4th year of their architecture education, all the students did not have the same proficiency with Excel and even less with some environmental vocabulary. This means that before teaching EASED, it would be beneficial to level up the competencies of all the users to the minimum required.

Finally, only one student included the results of the EASED report on his panels and discussed them during his project presentation. Two students made a short summary on the EASED report to explain the results with some critical perspectives on the sustainable performance of their project. This may reveal that the EASED results were hard to understand for the other students, who might not have known how to explain them in relation with their project.

The previous overall findings were consistent with the analysis of the EASED reports that confirmed that the students had some difficulties in using and understanding the tool. Indeed, some results appeared to be completely incoherent, like very low or very high values, often coming from wrong data entries. A wrong data entry can be linked with a false understanding of the input parameters needed. For example, many mistakes were made concerning the private open spaces of the residential units, and especially concerning the number of users for these spaces: in many cases, the students gave the total number of users that could use private open spaces in the project when the actual data needed was the number of users per private open space. This mistake led then to incoherent results for the area of private open space per user in the project, an important result for the evaluation of the liveable density of the project. It must also be noticed that the energy consumption part of the tool was not completed by the majority of the students (12 out of 21), who just left the pre entered data. Again, this may mean that this part was not understood by the students.

The survey really confirms these aforementioned results. Concerning the ease of use during the individual phase, the survey reveals that the strongest difficulties for the students were about deleting or adding a row: 29% of the students encountered this difficulty. Concerning the ease of

understanding, the survey reveals that almost 1 out of every 4 students (24%) had some difficulties in understanding the input parameters needed, and that almost 1 out of every 3 students (29%) had some difficulties in understanding the evaluation sheet. Some difficulties were also encountered in understanding the outputs (19% of the students). Yet, all the students agreed (67%) or rather agreed (29%) that the tool was easy to understand (one student did not answer this question). All the students agreed (76%) or rather agreed (19%) that the tool was easy to use.

Altogether, these results reveal that even if the students expressed a general feeling of easiness using the EASED tool, in reality they had some difficulties using it. In fact, most students thought they were using it correctly, when the analysis of their files showed it was not the case. Furthermore, they did not really understand what they were doing while using the EASED tool. This kind of gap between the students' perception of how they are answering an exercise and what the teacher is really expecting from them is quite usual in education. This finding raises the fact of the necessity of providing a better education on the EASED tool, to support the students in the use and understanding of it. More explanations have to be given regarding the meaning of the tool and its results in relation to the design process. In particular, more details on *what the teachers expect the students to do, and what they will be evaluated on*, have to be expressed in order to help the excel.

It may also be useful to give students precise feedback on their file after the evaluation, to bring out their mistakes; and to perform this feedback in close relation with their project, in order to show them how EASED can help them in the design process.

### 5.1.3. Role and help in the design process

This leads to the third criterion of the role and help EASED provided to the design process.

Since almost all the students opened and filled EASED at the end of the phase, it can be said that the tool did not have any real role in their design process. According to the observations of the weekly review, they did not use the tool as a design tool, a helping or guiding tool for designing their building, for making some decisions, or for finding a better answer to the initial question of the most sustainable architectural project for a given context. In this individual phase, EASED only intervened, in the best case scenario, as a post-design evaluation tool for the students. Yet, the fact that the vast majority of the students did not mention the sustainable performance of their project during their final presentation shows that this post-evaluation was not really completed as they did not take any perspective on the results and their meaning for their project.

It is not so easy to identify the role and benefit of the tool in the design process when analysing the reports, as it does not keep memory of the different versions of the file corresponding to the modifications made in the project. However, it can be assumed that if EASED had a real role in the design process, the file should be properly filled, with strong attention given to the data needed as it directly influences the results that are then used in the design process. In this case study, reports from the individual phase

aggregate several mistakes of negligence or misunderstanding that highlight the fact that the tool was not used as a design tool in full awareness, or as a support for the development of the project.

The survey reveals mixed results over students' perception of the role and benefit of EASED for the design process. During the individual phase, only 14% of the students modified their project using this tool; yet 29% affirmed that the tool helped them to make some decisions in their project. The answers given in the 'Critical feedback' part gave some precisions on these issues. Indeed, 57% of the students agreed and 24% rather agreed that the tool helped them to evaluate the sustainable performance of their project; but 5% of them rather disagreed and 5% of them disagreed on this affirmation. The same division is found in the answers to the question "do you think that the tool was relevant to evaluate the sustainable performance of your project". Almost the same division appears for the question "do you think that the tool helped you to identify the influential parameters over the sustainable performance of your project" (62% agreed, 14% rather agreed, 10% rather disagreed, 5% disagreed). Overall, 33% students agreed and 33% rather agreed that the tool was useful in their design process, when 14% rather disagreed and 10% disagreed on this affirmation.

All these results confirm that the students did not really understand the purpose of EASED - which was to help them improve the sustainable performance of their project through their design process. They only saw the post-evaluation aspect of the tool, in an 'assignment' perspective. This, again, means that the purpose of the tool and its benefit for the project, and even more its benefit for the process have to be explained if not *proved* to the students. One way to do it may be to offer a tutorial on a 'bad' building, with a low sustainable performance, to show students: how to improve its performance, what the influential parameters are, and how it can help them in design choices.

#### 5.1.4. Appropriation and personal use

Finally, regarding the last criterion of appropriation and personal use; the fact that the students completed the report at the very end of the individual phase restricted their appropriation and personal use of the tool. They did not have the time to become familiar with the tool, and especially with its results in relation to their project. As a result, as said before, during the individual phase, only one student used results and diagrams from the tool in his presentation boards, and talked a bit about it during his oral presentation. Only two students wrote a report to explain, with their own words, how they used the tool in relation to their project and how they understood the results.

The analysis of reports, whether from the individual phase or from the group phase, does not reveal a lot about the appropriation and personal use of the tool by the students. This can be explained by the fact that the modifications in the file are restricted, with no possibility for the students to add rows or lines, to change the colors or the titles, to add comments in the existing sheets. However, some elements about the appropriation of the tool can still be inferred. For example, some students did not write their

name nor the name of their project on the first sheet; this may reveal that they did not really make it theirs. On the contrary, some students took the time to describe a bit more about their project in the cells, by giving some details on the use, location or name of the space they were defining. This made it easier to read and to understand in relation to the project; and these made them more "personalised", and more linked with the project.

The survey showed that only 2 students (10%) decided to use, in the final presentation, results or data from the tool, the layout of the 'RESULTS' sheet, the diagrams of the 'evaluation' sheet and their analysis of the results. Yet 71% of them think that they will use the tool in other projects, even if it's not compulsory (2 students said no, and 2 said maybe).

#### 5.1.5. Conclusion

From these results, it may be inferred that the students did not really understand that there was an important expectation concerning the sustainable aspect of their project. Indeed, they were expected to justify their design choices in regard to the sustainable performance of their project, and to defend their proposition as the better choice in terms of sustainability. But in the end, most of them did not talk a lot about sustainability in their presentation, and they did not illustrate it on their panels. Furthermore, they did not consider EASED as a means to achieve this part from their brief - even if the RESULTS and EVALUATION sheets were designed for this purpose. As said before, it is quite often in education that the purpose of an exercise is not understood by students, and that a tool given to help them to achieve this purpose is not correctly used. Here again, more explanations on teachers' expectations for the exercise may have to be given - even if a balance has to be found with the development of students autonomy and critical mind.

## 5.2. Qualitative approach

Even if the research focuses on quantitative data through the use and review of EASED, a qualitative analysis is important to assert the quality of the work being produced.

During the individual phase, it appeared that sustainability was not a strong point of attention for a majority of students. Most students were already focused on addressing urban and architectural issues, program and uses, floor-plans, shapes and facade design. They did not really address to environmental issues, nor did they use sustainable approach as an entry point for their design. Their designs were not sustainable-oriented; thus the sustainable performance of their projects was non-existent, or marginal, or even a resulting consequence rather than a true intention.

Yet, six projects in 21 showed a real concern and stood out for a sustainable sensitivity (Figure 16). Their designers clearly made design choices for environmental reasons, in order to improve the sustainable performance of their project and to lower its impact on the planet. Among other elements, their projects included some of the following environmentally oriented features:

- Rainwater collection and reuse systems
- Green spaces at various floor levels

- Architectural compactness, to minimize both ecological footprint and energy consumption
- Double facade design, to provide efficient shading and/or natural ventilation and/or open spaces
- Solar panels, for example on the facade, providing shading at the same time
- Central atrium, that could provide a good stack effect for natural ventilation
- Bio-based materials: wood, rammed earth
- Urban farming, in a wider ecosystem approach including rainwater collection and reuse, compost of organic waste, local food provision...
- Shared facilities: laundry, bike shed...

These projects revealed that the integration of sustainable issues oriented the students in their design choices, and helped them to improve their projects towards more detailed, more coherent and more suitable architectures in regard to the project exercise question.

## 6. Results: teamwork phase, great success

### 6.1. Quantitative result: EASED review

After the individual phase, students had to work in groups. Analysis of reviews, submissions and surveys from the group phase revealed better results than the individual phase. This leads to an overall positive feedback of EASED, yet some questions remain.

#### 6.1.1. Commitment

In terms of commitment there was a radical change during the teamwork phase: every team fully engaged with EASED without exception. Interestingly, each group named one person to be in charge of the EASED report, a kind of expert who inherited the previous report from the individual phase and updated it, along the design improvements. EASED reports from this phase presented less mistakes than those from the individual phase. All the files were completely filled, and they were almost completely congruent with the projects.

The survey conducted at the end of the individual phase echoes these conclusions. Indeed, the survey revealed that all the teams filled in several versions, along with the modifications of their project. These results show that working in a team had a positive effect on students commitment with EASED. As one person was expressively in charge of the tool for the group, s/he had a *responsibility* towards the group to use the tool (and eventually to earn the maximum mark for its marked section). This responsibility led to a greater commitment. In this situation, the rest of the group had a kind of 'checking power' and maybe 'checking responsibility' on the tool. All the group was working in the same direction, as everyone was willing to improve the project. In this configuration, students were able to question each other, and to discuss and argue over the tool. In doing so, they were able to improve their file step by step. This underlines the benefit of teamwork regarding EASED but also for education in general: it helps students to learn from each other, to progress together, and to develop their critical minds.

#### 6.1.2. Ease of use and understanding

In terms of 'Ease of use and of understanding', both the weekly review and the EASED reports analysis revealed that it was easier for the students to use and to understand the tool than during the individual phase. As it was the second time they used EASED, and because they restarted from the completed version made during the individual phase, they had less questions concerning the use or the understanding of the tool itself and made less mistakes. They were even able to notice the mistakes made by other students - and by themselves - during the individual phase. For example, one group quickly realised that the previous EASED report had a wrong area for the project site, and wrong areas for indoor and outdoor spaces.

It can also be said that the students had a better understanding of EASED during the teamwork phase as they identified some of its limitations. For example, one group noticed that the water collection system developed in their project was not taken into consideration in the tool, even if this is an efficient way to reduce the consumption of water in the project, making it a sustainable asset of the project. Another group underlined that the environmental impact of construction materials was not taken into account in the tool, leading to an equivalent sustainable performance of their improved project compared to the initial one, despite their decisions to use environmental-friendly materials. These remarks revealed a better understanding of the tool, which was confirmed via the survey. The students did not encounter difficulties in deleting or adding rows, but one group had some trouble in writing in the orange cells. The same group also had difficulties understanding the outputs and understanding the evaluation sheet. Overall, from the original four groups, two groups agreed and the two other rather agreed that the tool was easy to understand and easy to use.

Overall it demonstrates a strong improvement regarding the use and the understanding of the tool between the individual phase and the group phase. This confirms the benefit of filling in the tool several times, as it was suggested to the students from the start. This also shows the interest of using EASED in a multi phase exercise. Repeating the exercise helps to correct mistakes, to better understand the data needed, to analyse the results and how they can be improved, and also to discover the limits of the tool. This is a classic rule in education: repeating is learning.

#### 6.1.3. Role and help in the design process

Regarding the Role and Help in the design process criterion, during the teamwork phase, the tool took a more important role in the design process. Indeed, the teacher's review shows that the tool was used by the students to discuss some dimensions of their project, and helped them to make some design decisions and to make some modifications. In this case, the evaluation of the sustainable performance of the project was not the end of the process but rather more data for the students to integrate in the development of their project, and to improve step by step. Besides, because the challenge of this phase was to improve an initial proposal, they were able to measure the impact of every decision on the sustainable performance of their project by



**Figure 16** Examples of projects which integrated sustainable elements from the start of their design. Top project: Fluidity of Water by Lachlan North; bottom project: Transparency by Taylah Jardine.

comparing it with the sustainable performance of the initial proposal, and this guided them in the improvement process.

Another element has to be pointed out. Two groups decided to submit two files: the first one filled with the data of the project as it was at the end of the individual phase (with the mistakes in the file corrected by the group), and the second one filled with the data of the project as it was at the end of the group phase (with all the design improvements and modifications made by the group). This reveals that these groups used EASED as a tool to evaluate the initial project, to find some ways of improvement, and to compare their new propositions with the initial project. In this approach, EASED took a real role in the design process, and helped the students to improve the sustainable performance of their project.

The survey however showed some slight differences towards this result. One group did not modify its project using the tool or considered that the tool helped it to take any decision in the project, when the three other groups did. Yet, all the groups agreed or rather agreed that the tool helped them to evaluate the sustainable performance of the project, helped them to identify the influential parameters over the sustainable performance of their project, and was relevant to evaluate the sustainable performance of their project. Yet still, overall, two groups agreed that the tool was useful in their design process, one group rather agreed and the last group rather disagreed on this affirmation. It

must be noted that it was the same group that did not modify its project using the tool or considered that the tool helped it to take any decision in the project; they did not find the tool useful for the design process.

#### 6.1.4. Appropriation and personal use

Finally, regarding the last criterion of appropriation and personal use, the students became more and more familiar with EASED. The weekly review revealed that they were able to “play” with the tool, to trick it, and challenge its limits in order to improve the results for their projects. At the end of this phase, no group decided to integrate some results or diagrams from the tool into their presentation boards, but all groups presented the results and diagrams in a report. Two groups explained in this report their use of the tool, showing their appropriation of the tool. The survey showed that 1 group out of 4 decided to extract the results, the layout of the results sheet and the diagrams of the evaluation sheet into their final presentation. But all the groups think they will use the tool in other projects, even if it is not compulsory.

#### 6.1.5. Conclusion

These findings reveal that EASED did indeed take a role as a ‘sustainable design helping tool’ in the group phase. The tool echoed the design process: starting from a given

**Table 1** Results synthesis.

	Teacher review		EASED report analysis		Student survey	
	I	T	I	T	I	T
Commitment	-	+	-	+	-	+
Ease of use and understanding	-	+	-	+	+	+
Role and help	-	+	-	+	+	+
Appropriation	-	+	-	+	-	+

I = individual phase, T = teamwork phase.



**Figure 17** Images of the Fluidity project after the group work phase.

project in a given state, with a given performance, identifying its strengths and weaknesses, improving the project and improving its performance. To go further, it may be said that EASED may be more suitable to use when the design process is already in a 'second phase'. Indeed, the tool may not be adapted for the initial first design choices, as it requires some precise information (like areas or functions) to give results - even if this information can change later in the design process, leading to new results. Furthermore, as the tool relies on a holistic approach, of linking all the parameters, all the choices asked by EASED need to be determined all at once to produce some results - the tool cannot be partly filled up if the user is willing to have a good overview on the sustainable performance of the building. This may be why the EASED tool did not play the same role in the design process during the individual phase. Students only had the time to make out a first version of their design, so they were able to fill up the EASED tool only once; they were not able to try several versions of their project, to change their design choices.

Time is a big issue in architectural education. It is not always easy for teachers to know if what they asked is realistic compared to the time students have. It is not always easy for students to manage their time, and to define the priorities in order to spend the right time on the right things. Regarding our EASED example, it may reveal that the individual phase may be too short for student to use the tool several times as a helping tool for design. Or, if this is really what teachers are expecting for this phase, then maybe the priority has to be given more clearly to this point at the beginning of the exercise - like in the group phase (Table 1).

## 6.2. Qualitative approach

Echoing the EASED review of the group phase, group projects revealed a much more sustainable-oriented design overall : three projects out of five revealed a real sustainable quality. The other projects did also address it but without much innovation.

Two projects - "Fluidity" and "Scarborough"- already integrated a sustainable design approach during the individual phase so the group phase further improved it. For example, in the "Fluidity" project (Figure 17), green deep soil areas were expanded, rainwater collection system was detailed. Students worked on the technical details of the double-skin facade, including high thermal and solar performance glass and natural ventilation. They also improved the design of the balconies: the intention of the initial designer was to use them as a solar protection, but the initial design was wrong regarding this goal, so the group reshaped them to make it effective.

In the "Scarborough" project (Figure 18), students went even further: using insolation studies, they optimised the design of the shading devices of the facade.

The project called "OKAN" did not really integrated a sustainable approach at the end of the individual phase, so students had to re-question the design through an environmental glance during the group phase. They worked on the shape of the building in order to optimize its orientation regarding to sunlight, and they decided to reduce the South facade in order to lower its cooling needs. Photovoltaic cells were integrated in the facade, both as a productive and a shading device. A double skin facade was added, in order to provide

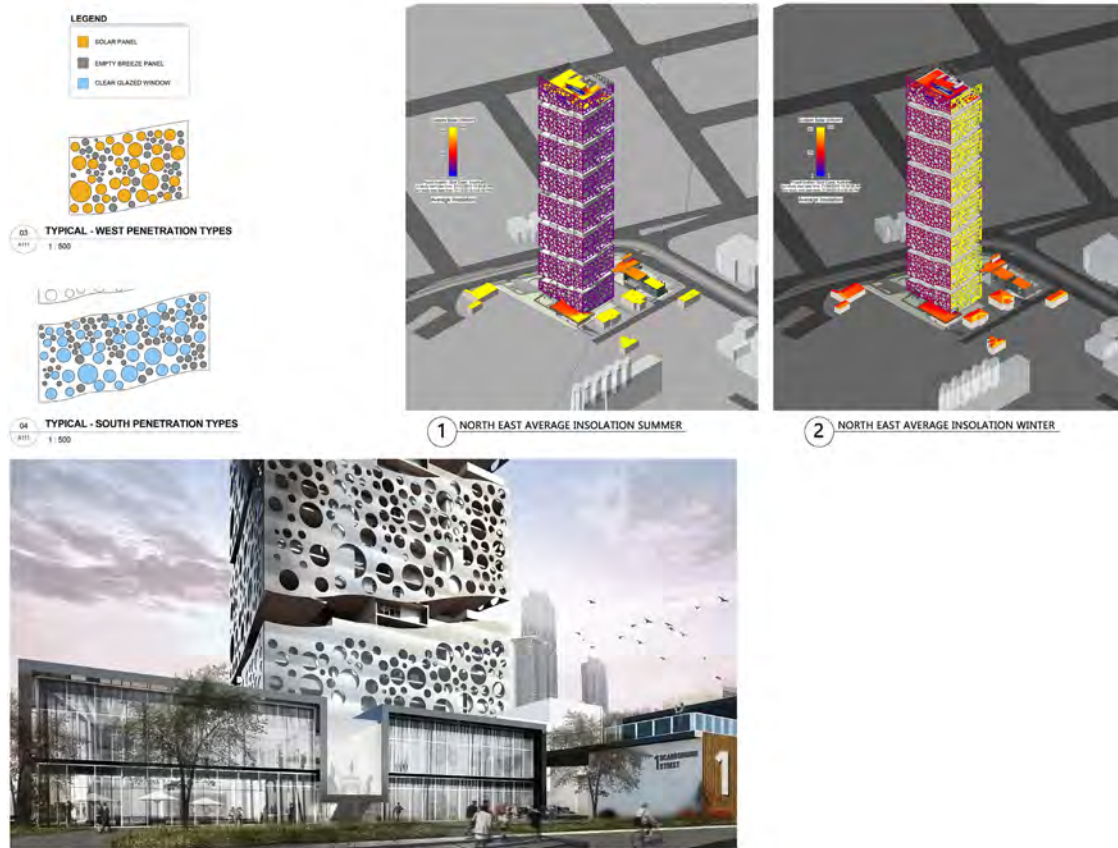


Figure 18 Images of the Scabourough project after the group phase.

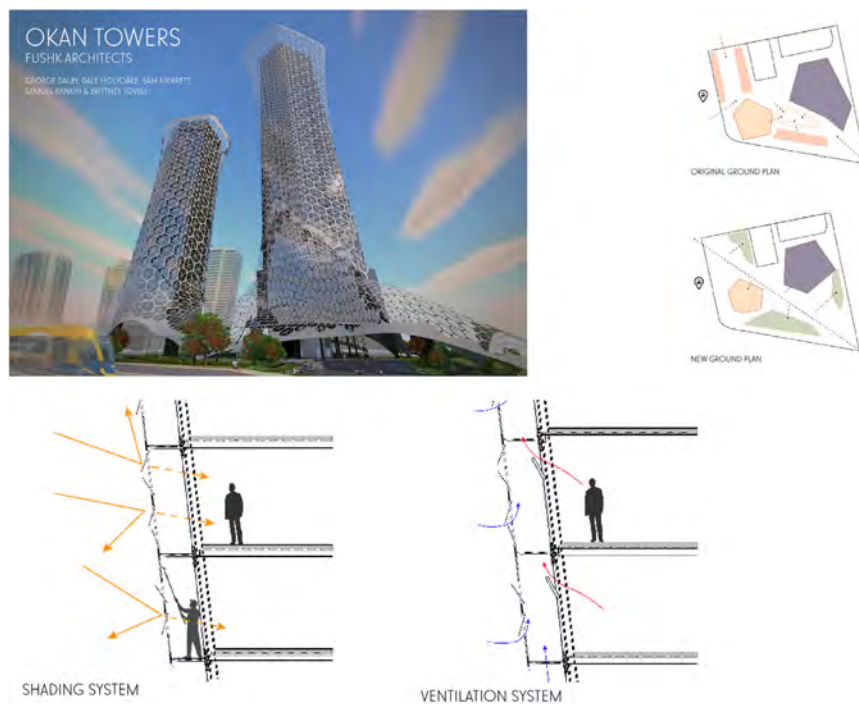


Figure 19 Images from the OKAN project after the group work phase.

natural ventilation using a stack effect between the two skins (Figure 19).

Overall, it shows that quantification helped the students to understand the value of the sustainable design intents and contributed to educate them towards better sustainable approaches.

## 7. Conclusion

The aim of this research was to investigate whether EASED is an efficient tool to innovatively educate architecture students about sustainable design. Results show that individual work was not convincing, whereas success was met during group work.

The first main conclusion from this study is that a two phase process was necessary for the students to understand the effective benefit of EASED. The second main conclusion is that teamwork has a positive effect on the use and understanding of the tool. The third main conclusion is that the appropriation of the tool by the students remained limited, although most students affirmed that they will use the tool again, even if it is not compulsory - and this may lead to a greater appropriation. In this sense, it could be concluded that EASED software really helped students to really become aware of the need to well manage input data, starting from the early stage of the design project, for really fighting climate change with their work as architects.

From an educators perspective, these results also show that EASED can still be improved upon for better use and understanding. For example, EASED could be further developed on a website, with an easy-to-use user interface. Another perspective could be to develop the EASED tool with Grasshopper, the plug-in of Rhino, in order to push forward the parametric logic of the tool and even to pair it with 3D modeling. In this development of the tool, new input parameters may have to be considered and added to the evaluation of sustainable performance. Ecological footprint and energy consumption approaches are limited in this first version of the EASED tool, and can be deepened. Other data like material or water consumption could also be relevant to integrate.

Reviews and surveys also underlined the necessity to give more explanations on both the input parameters needed and the EASED results. These explanations could be integrated directly into the tool, with more comments, more complete definitions and real examples. The “helping dimension” of the tool has to be improved as well, and coupled in closer relation to the design process: for example, weaknesses of the project could be identified using EASED after a first evaluation, and design solutions could be given to the user to help him/her to improve the building design.

In addition, some improvements could also be tested in the educational set up of the tool as a stronger attention has to be given to the explanation of the meaning of the tool, of its interest and its role in the design process. At the same time, teachers may have to further explain what they are expecting students to do with EASED in relation to their design brief.

In conclusion, many scholars and practitioners have already demonstrated that sustainable approach has to be fully and cleverly integrated into the design process in order to become a positive component of the project rather than

a constraint (Gauzin-Muller, 2002; Piano, 2009, etc). This study showed that it was not yet fully the case in architecture education. However this is a great challenge to embrace as young architects may be able to place themselves as game-changers in the current context of climate change and shared ecological awareness.

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