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Sustainable material use in the Zero Pentathlon, a design assignment on holistic sustainable renovation of dwellings

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Abstract: Since six years, in the Zero Pentathlon design assignment, students in architecture have to develop a renovation concept for a detached dwelling, built before the eighties, taking into account 5 criteria: 1) nearly zero energy renovation, 2) sustainable material use, 3) sustainable water management, 4) architectural and functional qualities and 5) constructional logic. Since three years, they also treat the current occupants as their clients. The assignment is strictly scheduled and supported by means of tutoring, lectures, visits and design support tools for energy and material use. The paper first presents the concept of the assignment, the educational vision behind it and the evolution over the years. Then, it focusses on students' material choices along the design process and on decision support for sustainable material use. Prior to this year's assignment, a survey was conducted to investigate students' drivers for material choices. Additionally, students were asked to keep a material diary during the design process to report about their major material decisions. The results of the survey and the material diaries, combined with a synthesis of material use in students' designs, will be used to further enhance the integration of sustainable material use in future editions of the Zero Pentathlon.

Keywords: Education, renovation, environmental impact, design support

Introduction

Despite efforts from EU projects such as IDES-EDU and EDUCATE (IDES-EDU, 2013; EDUCATE, 2012) to develop educational packages for and gather best practices on sustainable building design education, it remains challenging to actually incorporate sustainable building design in architectural education. Often design studios are not eager to allow the integration of well-defined sustainability aspects in the program brief of design assignments. In this context, the Zero Pentathlon design assignment was developed, six years ago, as a design assignment in the first master of architecture, outside the design studio, through a collaboration of two theoretical master courses on building construction and building physics. The Zero Pentathlon was developed both inspired by and as a criticism on the Solar Decathlon Competition. The intuitive reserve to participate to this international competition in Madrid (Solar Decathlon Europe, 2017) or Washington (Solar Decathlon US, 2017) was strengthened after reading *Precedents in zero-energy design* by Michael Zaretsky (2009) in which he criticizes the goals of this competition in view of a broader environmental context. The lack of attention for passive design rules, the paradox between designing for local climatic conditions (Brussels) versus in situ evaluation during the competition week for the climate of Madrid or Washington, the focus on new construction solely and the huge ecological footprint related to the logistics of transporting the actual building and team to

the competition site and back were catalysts for developing a new environmentally improved design assignment instead of participating to the Solar Decathlon.

This paper describes the concept of the Zero Pentathlon design assignment and the evolution over the years. It then focusses on the students' material selection along the design process and on the methods and tools used for the assessment of sustainable material use. The methods and tools used for the assessment of comfort and energy aspects have been presented earlier (Verbeeck and Weytjens, 2013). Finally, lessons learned on the integration of sustainable material use by the students will be presented as well as some conclusions for future adaptations to the assignment.

Concept and evolution of the Zero Pentathlon

Architects and engineers as well as individual home owners have a huge responsibility in tackling global problems such as climate change, depletion of natural resources and waste generation. Because of the very long lifespan of buildings, choices made during design will affect the environment during a long time. Each new building, regardless of its sustainability level, enlarges the impact of mankind on the environment. In addition, the environmental impact of the existing housing stock is still often being neglected. In Flanders (Belgium), more than 60% of the dwellings has been built before 1970 (ADSEI, 2016), more than 50% is (semi-)detached (ADSEI, 2016) and quite large (on average 160-200m²) (Verbeeck and Ceulemans, 2015) and many are occupied by baby boomers whose children have left the house (van de Weijer, 2014). Meanwhile, housing demand is changing due to demographic changes such as an ageing population and changing family structures. Therefore, the Zero Pentathlon design assignment focusses on the improvement potential of the existing housing stock for ecological sustainability, taking into account sociocultural aspects.

General description of the design assignment

For the assignment, students have to redesign in small groups an existing detached single family house, built before the eighties in a suburban neighborhood, into a nearly zero impact house (often a house of relatives of one of the group members). Their design is evaluated for five criteria: (1) zero energy; minimal environmental impact of (2) material use and (3) water use; (4) having good architectural, functional and social qualities and (5) with a good constructional logic. Students are also encouraged to integrate other sustainability aspects (Universal design, food, land use, mobility, ecology,…) in their design. In recent editions of the Zero Pentathlon, students have to treat the occupants as their clients in order to incorporate their needs and wishes, without bargaining on the five criteria of the Zero Pentathlon. The holistic approach of the assignment is illustrated in Figure 1.

Figure 1: Snap shot of the design process showing the holistic approach of the assignment and students' work

Teaching consists of a mixed-method approach, organized in a workshop format. During a ten-week schedule, students work on their project following a predefined process, assisted by design support tools for sustainability, guest lectures on specific topics and weekly moments of discussion/feedback. The overall process of the sustainability concept development (energy, material, water,…) is supported by a self-compiled five-step strategy for increasing ecological sustainability: the PENTA-strategy. This strategy is based on the commonly known Trias-strategy (Trias Energetica (Lysen, 1996), Trias Materia, Trias Aquatica), but is enriched by passive and active design approaches (Figure 2).

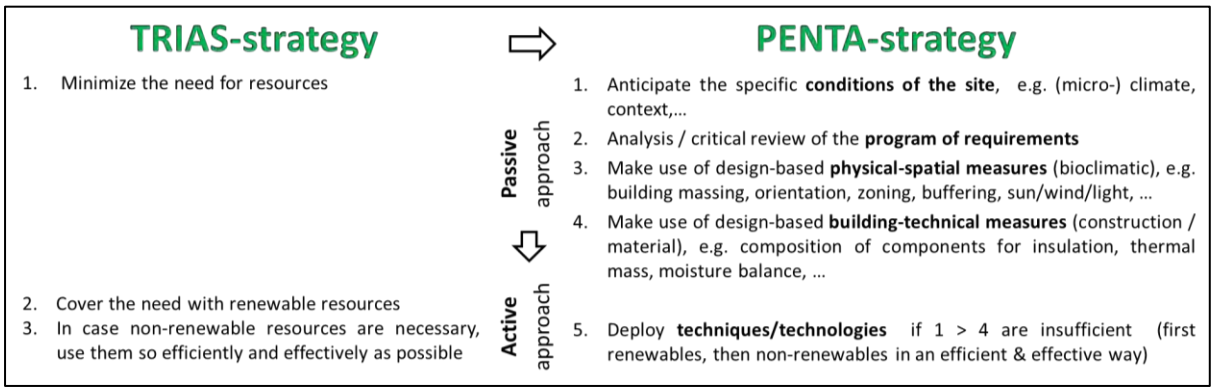

Figure 2: The PENTA-strategy to be used by the students, based on the Trias-strategy, as an overall five-step decision support towards a sustainable concept.

Description of the assignment on sustainable material use

In line with the EU ambitions (European Commission, 2011; European Commission, 2015), the focus on sustainable material use has increased over the years in the Zero Pentathlon assignment. Since the first year, students have to calculate and evaluate material quantities that are removed, reused, recycled and newly added. As a strategy for sustainable material use, the Trias Materia is proposed, which consists of three subsequent steps (Welmer and Ham, 2008; Wouters and Bol, 2009; both with similar, but slightly different definitions): (1) reduce the need for materials by properly designing structures, (2) cover as much as possible the need for materials by choosing materials with a low environmental impact and with unlimited resources, and (3) in case of use of materials with limited stocks and with a high environmental impact, use them as effectively as possible. In the early editions of the Zero Pentathlon, the use of a specific environmental impact assessment (EIA) tool or database with LCA based data was not mandatory and no target values for the environmental impact were set. Also step 2 of the Trias Materia was slightly different defined as ‘cover as much as possible the need for materials with renewable materials’. But since renewable materials not necessarily have a lower environmental impact, the upper definition of step 2 has been adopted. Since two years, students have to use the NIBE classification system, developed by the Dutch Institute for Building Biology and Ecology (NIBE, 2017), to assess the environmental impact of building materials and elements. In Belgium, an EIA tool for buildings is still under development and not available yet (Allacker et al, 2013). The NIBE classification tool, with an underlying life-cycle analysis approach, allows the comparison of several material and element alternatives within a same functional unit. In the assignment, it is instructed that all added materials should belong to the environmental NIBE classes 1 to 3 (best to acceptable choices). In case materials or elements are chosen from another environmental class (4 to >7), an extensive motivation is required.

Students not only have to calculate and evaluate material quantities and their environmental impact, but also write a report with a critical reflection on material use and a motivation for their material choices. At first, students have to analyse the current state of the dwelling by means of a quantitative estimation of the materials present in the house, and a critical evaluation on the current state of materials (deterioration, remaining lifespan,…). In the second step, students have to critically analyse the materials that will be removed during renovation. Again, besides a quantitative estimation of the removed materials, they have to argue about the reasons for material removal and discuss the end-of-life possibilities (reuse, recycle, disposal,…). Thirdly, for the materials added during the renovation process, the use of the NIBE classification for evaluating the environmental impact and comparing alternative materials and elements is required.

Methods for analysing students' material selection process

The actual material use in students' designs and their critical reflection in the written report are analysed and will be discussed in the next section. To gain more insights in their material selection process, a survey is conducted and students are asked to keep a material diary along the design process. Students were informed for both the survey and the material diaries that the answers are handled anonymously and would not influence the evaluation for the Zero Pentathlon assignment. An important objective of this analysis is to investigate to which extent and in which manner students take sustainability aspects into account when choosing materials for their designs. This can be used for further improving tutoring on sustainable material use.

Survey

Prior to this years' Zero Pentathlon design assignment (October 2016), students were asked to fill in a survey on drivers and motives for material choices, on their interpretation of sustainable material use and on the aspects they take into account when choosing sustainable materials (N=31, response rate 89%). They were explicitly asked to answer the questions with respect to the choices they make in their everyday lives and in their design projects in general and not in the Zero Pentathlon assignment in particular.

Material diaries

Additionally, during this years' assignment, each group of students (seven in total) was asked to keep a material diary. The main purpose of the material diaries was to analyse the material selection process and to evaluate students' use of tools and implementation of design strategies for sustainable material use during the design process. At six moments during the exercise (before and after the workshops), students had to report about the major material decisions by filling in a questionnaire.

At first, they had to illustrate the current status of their design project by means of a 2D or 3D sketch, indicating the most important concepts and material choices. The main part of the diary consisted of an elaborated description of their material choices up to now for each of the following building layers: (1) building structure (load bearing function), (2) building skin (visible, exterior, f.e. façade, roof), (3) building shell (mostly insulation), (4) building systems, (5) interior finishing materials, (6) non-load-bearing interior walls. Materials that are removed, preserved and added for each building layer needed to be specified and a motivation had to be included. Additionally, it was asked to which extent the environmental impact was determinative for the design decisions and material selection.

Results and discussion

Motives for material choices and interpretations of sustainable material use in general

The survey results show that all students recognize the importance of sustainability and environmental issues in the future. However, only 42% indicates that environmental aspects already play an important role in the choices they make in their everyday lives today. When asked for the drivers' for material choices in their design projects (Figure 3), similar results are found. Aesthetics, technical performance and own intuition are the most common drivers for material selection. The environmental footprint of materials is only important for 42% of the students and is therefore the least decisive factor in the material choice process. Nevertheless, some sustainability related aspects, such as durability and impact on human health, are highly ranked as a motive. As the students are not architects in practice yet and do not have to deal with clients' budgets, cost and own experience are of less importance.

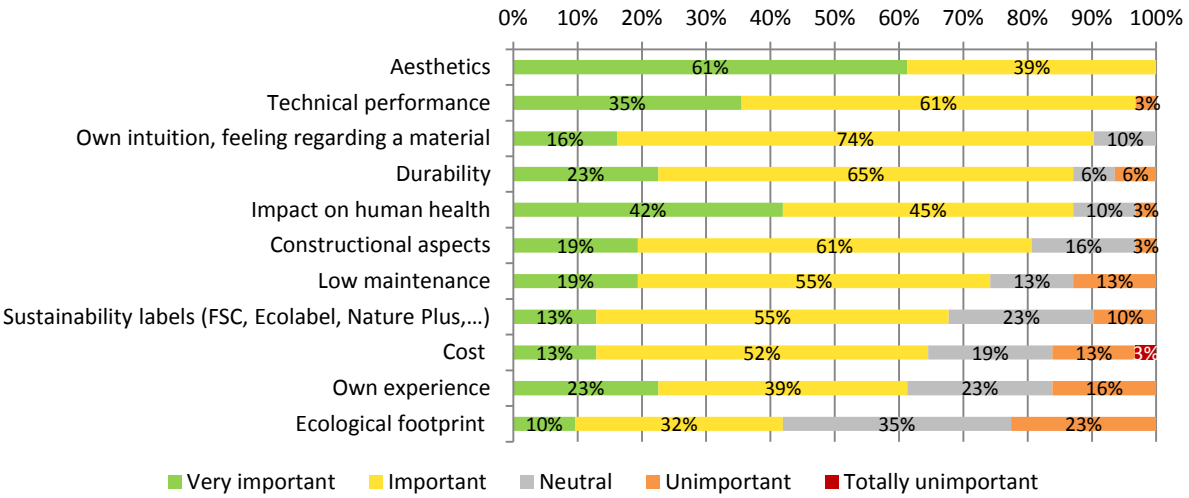

Figure 3. Students' motives for material choices (N=31).

In an open question, students were asked to give 5 keywords to describe their interpretation of sustainable materials. As a first keyword, 35% of them mentions renewable materials in general or specific renewable materials such as wood and straw, and 32% focusses on the durability of materials. Local materials (10%) and recyclable or reusable materials (10%) are also mentioned. As a second keyword, recyclability/reusability (26%) and renewability (23%) are again the main aspects associated with sustainable materials.

When students were asked to select as many sustainability associated aspects as they preferred from a list and to arrange them in order of importance, durability, recyclability, reusability and the local origin of materials are again the most important aspects which they take into account when dealing with sustainable material choices (Figure 4). In their previous design projects, students were not explicitly encouraged to consult LCA based data, which might explain the low rank of LCA based data.

Based on the survey results, it can be concluded that the students recognize the importance of sustainability and environmental issues, but this is not reflected yet in their everyday life behavior and in the choices they make while designing. When selecting building materials, multiple criteria have to be taken into account and, up to now, the ecological footprint of materials appears to be the least decisive factor.

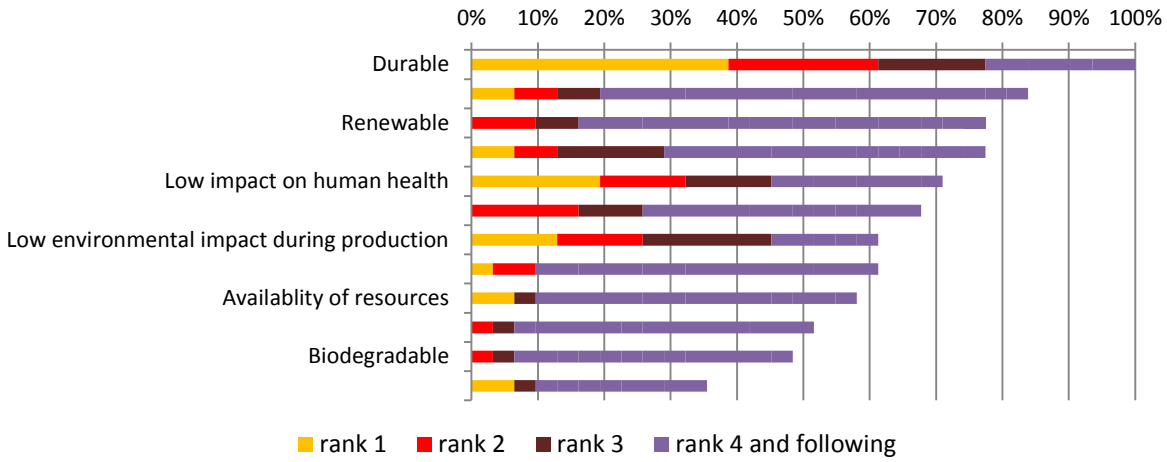

Figure 4. "If you choose a sustainable material for a design project, which aspects do you take into account? (pick relevant aspects from a list and rearrange them in order of importance)".

Material choices in the Zero Pentathlon assignment

In the Zero Pentathlon assignment, the material selection process and the final material choices are analysed, based on the material diaries, the written report and the final design project. Besides a quantitative estimation of the removed materials (between 5 and 70% of the total amount of materials), students had to argue about the reasons for material removal. Although some materials in the existing dwellings are deteriorated and needed to be replaced, most materials are removed in order to improve the compactness and the energy efficiency of the dwelling (removal of the outer skin, roofs and floors for better insulation, replacement of windows,…), to adapt the building to new living patterns or for aesthetical reasons (indoor spatial rearrangements, removal of annexes or wings,…). Students identified many of the removed materials as appropriate for recycling. Not all students actually reflected on the recycling options for materials, and if they did, they mostly came up with down-cycling options. For certain material categories, mainly bricks and (roof) tiles, reuse possibilities are identified, but students did not always consider to reuse them for their own project and designated them for reuse in 'other projects'. The most frequently reused elements in the students' projects are wooden inner doors, staircases, floor tiles and elements in natural stone.

The diaries clearly showed that during the design process, students mainly focused on the energy performance of the dwelling and not so much on the environmental impact of the chosen materials. Material choices along the design process were rarely motivated from an environmental point of view, but mostly from an energetic, aesthetic or technical perspective or because they belong to standard practice. Most students consulted the NIBE classification system only at the end of the design process, when most design decisions were already taken. At this stage of the design process, the selection of lower impact alternatives was not always possible, because of thickness restrictions or because it would require a reconsideration of an already elaborated design concept. However, by analysing the material diaries, it was found that some students used ecological drivers when choosing insulation material, window profile material and interior finishes, but some of these choices changed during the further elaboration of the project and were not present in the final design. Based on the analyses of material choices in the final design and on the material diaries, it seems necessary to further stimulate students to already consider and integrate sustainable material use from early design on.

Tools for sustainable material use

Students were asked to use the Trias Materia as a design strategy in combination with material quantity calculations and the NIBE classification system. The simple 'tool' of calculating and evaluating material quantities (removed, reused, recycled and new material) helps students to gain insights in the massive amounts of materials that are removed and added during renovation. For all materials that are removed, students had to discuss end-of-life possibilities (reuse, recycle, disposal,…). This encouraged them to think about construction waste and consult background information on construction waste streams. However, these insights were not always reflected in the choices they made in their own design projects. Therefore, in the next edition of the Zero Pentathlon, calculations on material quantities will be left out of the assignment, so that more time can be spend on the integration of sustainable material use and selecting building materials and elements with a lower environmental impact, already at early design stages.

The NIBE classification system was used to give feedback on the environmental impact of material choices and to avoid that students take uninformed decisions when applying the Trias Materia. The NIBE classification also allows students to consider the availability of alternative materials with a lower environmental impact. However, the students only performed the environmental impact assessment of the materials at the end of the design process when most design decisions were already taken. In this way, the impact of using the NIBE tool on the final design outcome was rather limited. An explanation for this could be that, in contrast to energy performance, where specific targets were set for the building as a whole, this is not yet possible for the environmental impact. Therefore, targets were set on material or element level by means of recommended NIBE classes, but this not always resulted in the use of materials or elements with lower impact.

Conclusion

The Zero Pentathlon is a design assignment which challenges students to develop a holistic sustainable renovation concept for an existing dwelling. Despite the assignment being very intensive, students evaluate it positively, since it is for them one of the rare design assignments in which they have to incorporate and balance so many criteria at once in a real-life project with real clients. Over the years, several supporting methods have been tested, both for the design process and the decision support on energy and materials to avoid that students design and decide in a non-informed, trial-and-error way. The effectiveness is improving and the lessons learned are also used to improve the educational methods in bachelor courses. However, it remains a learning process. Especially the integration of sustainable material use in the students' design process can be further improved.

The combination of the Trias Materia as a design strategy and the use of the NIBE classification for assessing the environmental impact of building materials and elements stimulates students to think about construction waste, critically reflect on material choices and consider the use of alternative materials with a lower environmental impact. However, up to now, most students consulted the environmental impact data only at the end of the design process, when most design decisions were already taken. Along the design process, most material choices were based on aesthetical reasons and on attempts to improve the energy efficiency. Therefore, the induced thinking process on sustainable material use not always resulted in a lower environmental impact of the final design for the Zero Pentathlon

assignment and students need to be further stimulated to integrate sustainable material use along the design process.

The material diaries are found to provide clear insights in the students' design process and their motives for material selection. In last year's assignment, along the design process, ecological motives for material choices were quite limited and no direct references to the Trias Materia or to the information from the NIBE classification were found in the diaries in early design stages. However, the material diaries were only meant for research purposes and students were informed that the diaries would not affect their final score for the assignment. In the next edition of the Zero Pentathlon, more attention will be paid to the material selection process of the students and the material diaries will be used as an instrument to evaluate the integration of sustainable material use throughout the design process. Not only the final design outcome and the report will be taken into account for the final score, but also the material selection itself at specific moments during the design process. Additionally, the diaries will be further developed, so that they can be used as a design-supportive aid. Students will have to demonstrate the implementation of the Trias Materia and the consultation of the NIBE classification or other LCA based data already in early design by means of the diaries. This should further encourage them to take environmental aspects of material choices into consideration already in early design stages.

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