Introducing regenerative design and circularity into architectural and engineering curriculum

S. Attia[1]

[1]Sustainable Buildings Design Lab, Department ArGEnCo, Applied Sciences, Université de Liège, Belgium

shady.attia@ulg.ac.be

Abstract

Looking today to the challenges for planning and design of sustainable built environment including, carbon emissions, climate change, human health, water problems, biodiversity, scarcity of resources, depletion of fossil fuel, population growth and urbanization; sustainable architecture will play a key role for the sustainable development of society as a whole. In the context of an architectural design studio, this paper presents the experience of introducing the concept of regenerative design within a Belgian engineering faculty. The regenerative design objective and principles are used as a method to develop engineers' capabilities to design within a circular economy paradigm. The aim of the study is to evaluate the adoption of circular economy principles and their influence on the decision making and final outcomes on third-year architectural engineering students at the University of Liege (Ulg), Faculty of Applied Sciences in 2014 and 2015. The paper utilizes two design studios outcomes in the form of projects evaluation and students feedback, in the form of interviews and surveys, in order to assess the students' knowledge uptake, learned skills and design capabilities. Students completed a knowledge, skills, and attitudes questionnaire before the curriculum, after the final learning experience, and one year later. The paper provides results that shed light on the opportunities, challenges and architectural engineer's needs to engage in a circular built environment.

1 Introduction

The radical changes necessary for our planet require a vision that is rooted within an ecological paradigm. The tendency of urban sprawl and resource intensive built environment during the last decennia is contradicting with the need for positive impact development and the principles of sustainability. The urban sprawl is not only consuming large areas of land but is associated with negative environmental impacts, social and cultural disparities beside the overall decreasing incremental environmental cost.

In order to face these challenges the architectural design studio of the third year architectural engineering students at Liege University (Ulg) is playing a central role for challenging its students to generate a built environment that is dense, accessible by public transport, and based on positive impact buildings and sustainable construction technologies, following the principles of circular economy and regenerative design for a collective housing project in Belgium. The key question of the studio is: How can architects construct buildings with positive impact for the environment while addressing the materials, energy, water and biodiversity challenges.

In this context, the study aims to assess the students' learning experience using qualitative and quantitative evaluation methods. The importance of this study is significantly highlighted in the studio's ability to achieve an informed decision making process regarding regenerative design and circularly in the built environment. Secondary, the study provides a reflection on the assessment of learning outcomes, expected knowledge, skills, attitudes, competencies and habits that student acquired during the studio's learning process. With its focus on the design experience and knowledge uptake this article will be of interest to engineers, architects, educators and researchers concerned with engineering education of sustainable development (EESD). The article determines the needs for pedagogical and educational project oriented engagement to ascertain and quantify the effort needed to understand and apply those sustainability principles in future curricula. This paper is organized into five sections. The first section identifies the research topic. The second describes similar studios and courses that have been presented at previous EESD conferences aiming to describe the state of the art. The third section identifies the research methods and studio evaluation metrics and setting. The analysis of the results and the self-reported survey and questionnaires findings are presented in Section 4. The final section discusses the research finding and study limitations along with implications for future teaching and education.

2 State of the Art

2.1 Past research

There is an extensive body of literature examining the effects of introducing sustainability in the engineering curricula on the students' knowledge and skills and final learning outcomes. The international conference on Engineering Education in Sustainable Development (EESD) proceedings include several examples of integrating sustainable principles as a framework for a redesign of engineering education and of engineering education institutions. Also the International Journal of Sustainability in Higher Education and the Journal of Architectural Education provide a series of valuable publications related to introducing sustainability into engineering curricula. In the local Belgian context we looked in the Proceedings of the Doctoral Seminar on Sustainability Research in the Built Environment (DS2BE 2016). Three screening criteria were used to reduce the initial pool of 60 conference and journal articles to a focused set of 15 representative studies: (a) review articles; (b) empirical studies (c) studies with an educational assessment or intervention with learner outcomes measured quantitatively or quantitatively; and (c) research that focus on architectural and engineering curricula due to the specific nature of our architectural engineering students.

Under the review articles we grouped the manuscripts under two groups. The first group is focused on integrating sustainability into engineering curriculum and second group is focused on integrating sustainability into architectural engineering curriculum. The first group of manuscripts include the study of Davidson et al. (2014) that discussed some efforts taken place in the United States, namely the activities of the Centre for Sustainable Engineering operated by a consortium of universities. The paper describes an initiative to develop a community oriented platform to serve as a repository for educational materials. Similarly McPherson et al. (2015) compared engineering programs in Canada and review and analysed the sustainability integration in curricula but with a focus on sustainable energy. The undergraduate programs reviewed by the authors were classified as conventional engineering programs with a sustainability add-on courses and did not embed sustainability fully in the curricula. Likewise, the study of Vargas, L. et al (2015) reported embedding sustainability in the curriculum of engineering school but only for the University of Chile.

The second group of manuscripts has an architectural focus including the work of Álvarez et al. (2016) who compared the presence of sustainability in architectural education is Asia with a focus on professional degree curricula. The study provided an overview of 20 selected influential schools in 11 countries according to contents, intensity and teaching modalities. Sustainability design studios received a special attention by the study and were examined against the three sustainability areas of ecology, society and economy. The study provided qualitative and compared the curricula without describing their sustainability thematic content in detail. Similar to this study is the study of Olweny

(2013) who investigated the presence of environmental sustainable design and energy efficiency in architecture education in East Africa. His study highlighted the basic integration of sustainability with at least one course in the studies curricula and the need for more integration efforts. Moreover, Wright (2003) provided a brief review on introducing sustainability into the architecture curriculum in the United States. The paper is out-dated and focused on the integration of sustainability in architectural programs. However, the publication of Iulo et al. (2013) provided an interesting overview of six architecture programs in the United States considered to be leaders in sustainability education. The study findings highlighted consistent approaches to promote sustainability core values to undergraduate architectural education by supporting courses fulfil needs for sustainable education and encourage students' choice and specialization to sustainable design.

The most important manuscripts in this group are the COTE and EDUCATE reports. The Committee on the Environment (COTE), which serves as the community and voice on behalf of AIA architects regarding sustainable design works, together with the Association for the Advancement of Sustainability in Higher Education (AASHE) provides a more recent assessment of the state of ecological literacy and the teaching of sustainable design in architecture education as part of a proposal for a large-scale, long-term effort, led by the AIA COTE, to inject ecological literacy and sustainability principles into architecture education in the United States. The COTE mapped the strengths and gaps in teaching methodologies and identified top ten measures of a definition of sustainable design that are developed as a framework for different types of courses and studios. COTE reported that at many architecture schools, the mentor model is still firmly in place; students are "filled up" by the knowledge of a professor. The report (2006) indicate the use of other teaching modalities involving multidisciplinary, participatory, iterative, designing for place, designing across time and involving students to become more involved in framing the questions, shaping courses, and interacting with practitioners and in the community. Also a similar project took place in Europe in 2009, where Altamonte (2009) investigated environmental design in University Curricula and Architectural training in Europe. The European review identified mainly the status quo of integrating sustainability across most European member states and encouraged the holistic approach to architecture education (Attia 2010ab).

3 Method

3.1 Curriculum design

The first three year Bachelor curriculum of architectural engineers of the Faculty of Applied Sciences of Liege University are built around project-based learning cases but also include basic science lectures and an introduction to engineering courses. The Bachelor Program curriculum focuses on developing students' architectural design skills, increasing their understanding of architecture and construction and introducing technical issues. The program is divided into 6 blocks over three years and covers architectural design methodology I-III, sustainable building construction technology I-III, History of Architecture, Graphical Composition, Architectural Studio I-III, Chemistry I-II, Calculus, Algebra, Physics I-II, English, History of Urban Planning, Computer programing, Fluid Mechanics, Building Materials, Solid Mechanics, Geology, Heat transfer, Structural Design, Project management, Structural Engineering, Metallic Structures, Statistics and probability, Thermodynamics and heat engines, Geotechnics and infrastructure (Architectural Engineering 2016).

We identified opportunity for introducing regenerative design and principles of circular economy in the Architectural Studio III. The Architectural Studio III was chosen because of the maturation of the students and the need to develop and crystalize the fundamental knowledge and skills through an integrated project. The existing curriculum was based on introducing a design project of middle sized housing in the third year and we found that it could be linked with a new content. The studio's curricular goals and learning objectives focus on analysing issues specific for the transformation of a European post-industrial city from a perspective of circularity. The studio focused on developing third year students' knowledge, skills, and attitudes relevant to regenerative design and circularity of the built environment. Several references guided our development of the studio curriculum. A body of literature informed students about the regenerative design and circularity in the built environment (Lyle, J. 1996, McDonough, et al. 2010, McDonough, W. et al. 2013, Mulhall, D., et al. 2010 and Rifkin, J. 2008). We implemented and taught the curriculum, which was approximately 4 ECTS equivalent to 120 hours in the fall of 2014 and 2015. The curriculum was taught by the author and a teaching assistant, with the assistance of volunteer jury members and guests for the site visits, role playing based debate, jury panel and small discussion groups.

The studio content addressed seven main themes listed and described in Table 1. The activities in this design studio were a synergy between sustainability and regenerative design theory and their integration in an architectural design project. This approach allowed us to address issues of conceptual coherence, spatial and expressive design while exploring simultaneously the possibilities for sustainability as an essential element for the design; which will become an important and essential task in the field of architecture. The studio focused in particular on studying the interaction between questions of density, mixed functions, quality of life in buildings, while in the meantime integrating the principles of bioclimatic architecture. This included the development of construction details in accordance with a basic understanding of sustainable buildings concerning energy, water and materials. The project design case was based on a study of solutions adapted on the development of plus energy and Passive House complying collective housing cluster. Solutions are successively developed throughout the different scales from the urban form, the ensemble of buildings, the building itself its envelope and materials.

Table 1: Regenerative design and circularity in the built environment curricular content and educational modality by theme, Liege University, Faculty of Applied Sciences, 2014-2015.

Theme	Content	Educational Modality
Theory and Principles	Sustainable architecture and regenerative design	Lectures
	Bioclimatic design and Passive House Standard	Lectures
	Human well-being and quality of life	Lectures
	Construction systems and materials	Lectures
	Energy conservation and production	Lectures
	Water management + Biodiversity and air quality	Lectures
Philosophy	Cradle to cradle: Remaking the way we make things	Reading
Case Studies	Wijk van Morgen (Heerlen), Park 2020 (Amsterdam)	Site Visit
Reasoning	1. How far to go with technology?	Debate
	2. So where should be set targeted minimum performance?	+
	3. To certify or not sustainable buildings?	Role Playing
Application	Concept development follow up (weekly)	Table Critiques
Assessment	Evaluating the design and project dynamics	Pre-Jury
	Provide individual Feedback	Panel Discussion
	Support and motivation for creation and design development	
Evaluation	Evaluating the design and project dynamics	Jury
	Provide individual Feedback	Panel Discussion

3.2 Assessment of students' knowledge, skills, and attitudes

We developed a 15-item questionnaire to evaluate the impact of sustainability of the curriculum on architectural students' knowledge, skills, and attitudes. Item development was informed by our literature review. The questionnaire included items modified from existing questionnaires assessing i) the knowledge concerning regenerative design, ii) the decision-making attitude and behaviour (reactions to design uncertainties), the jury evaluation, as well as items based on our curricular learning objectives. We selected items for the questionnaire based on the like hood that they would demonstrate change after students participated in our studio. Five multiple-choice items assessed students' knowledge, five items measured their comfort with skills (using a five-point ordinal scale where 1 = very uncomfortable and 5 = very comfortable), and 18 items measures attitudes (using a five-point ordinal scale of agreement with statement where 1 = strongly disagree and 5 = strongly agree). Based on our experience from a previous research (Attia 2013) we pilot tested the questionnaire for comprehensibility with second-year architectural engineering students and for applicability with one Master student with prior involvement with regenerative design.

3.3 Assessment of students' self-reported behaviours

On the one-year post-test, we also asked students to report their behaviours since completing the curriculum. Students responded 'yes' or 'no' to items about whether they used what they learned in the curriculum, design errors, and disclosure and reporting experiences. We calculated the percentage of students responding 'yes' to each item.

3.4 Curriculum Evaluation

We developed studio evaluations to measure students' reactions to the curriculum. Student used five-point ordinal scale to rate how well the curriculum met learning objectives, its usefulness in their architectural education, its future benefit to their architectural career, and if it should be continued. We also invited students to describe the most important thing they gained from the curriculum and to offer suggestions for improvements.

4 Results

4.1 Assessment of students' knowledge, skills, and attitudes

36 students answered the questionnaires before and after the studio. Our analysis of paired comparisons of pre-test to post-test was based on these responses. No students indicated that they had had prior experiences with regenerative design or circularity in the built environment. These results can be divided into three categories: students' responses with improvement, those without change, and those with change in an undesired direction.

4.2 Responses with improvement

Table 2 presents the pre-test means, mean paired differences, and confidence intervals for items with improvement both immediately after students participated in the curriculum (pre-test to post-test). Students' responses to one attitude item addressing the inevitability of regenerative paradigm, another about the effectiveness of this approach to create a positive impact versus the efficiency paradigm, and a third reflecting perceptions about competence and design errors improved immediately after attending the studio. These improvements were sustained after the studio. Four skills items also improved immediately after students took the curriculum: supporting a peer involved in a design error, analysing root causes of an error, accurately estimating the building energy consumption and generation, and disclosing an disclosing an error to a professor or assistant. Although not improving immediately, students' responses to one attitude item about architects routinely admitting and sharing information about errors and their causes improved at one year. Students' responses to an additional attitude item on the effectiveness of design errors, as well as the composite knowledge score, improved immediately following the curriculum, but these changes were not sustained at one year.

Table 2: Questionnaire items with improvement

Item	Mean Change (95% CI)		
	Pre-Test mean response	Post-Test mean response	Post-Test after Two-Years
Attitude Questions*			
Making errors in design is inevitable	68.75	31.25	21.5
After an error occurs, an effective design strategy is to work harder to be more careful	62.5	65	61
Competent architects do not design errors that lead to quality decrease	6.25	25.5	22.1
Architects routinely share information about design errors and what caused them	12.5	56.2	53
Design assessment types (weekly meeting with professor, debate, jury) do little to reduce future errors	16.25	3.0	4
Skills Questions**			
Supporting and advising peer who must decide how to respond to a design error	18.5	72	66
Analyzing a design to find the cause of an error	50	48	45
Defend the design successfully in a design assessment	31	56	33
Disclosing a design error to a professor	81.25	12.50	8.5
Knowledge Items			
Knowledge uptake score	37.5	74.5	61

* Scale: 1 strongly disagree, 2 = disagree 3 = neutral, 4 = agree, 5 = strongly agree

** Scale: 1 very uncomfortable, 2 = uncomfortable, 3 = neutral, 4 = comfortable, 5 very comfortable

4.3 Curriculum Evaluation

At the completion of the curriculum, 31 (86%) of students agreed that the studio content improved their ability to meet the learning objectives either well or very well. Eighty-five percent, on average, agreed strongly that the curriculum and learning modalities were useful in their architectural education. Ninety-two percent, on average, agreed or strongly agreed that the curriculum would be of benefit to their future career, and on average 78% recommended that the curriculum be continued for future architectural school classes. Topic mentioned as the most important thing students gained from the curriculum were an understanding that everyone makes design errors, how to address those errors at the root cause, and the mistake reporting and disclosure are important. Suggested improvements included changes in the timing of the curriculum, shorter sessions, fewer lectures, more personal follow up sessions, more feedback and more guidance on communication issues.

5 Discussion and Conclusion

All members of the engineering academic world, including architectural engineers, should be able to recognize the importance of applying the regenerative design and circularity concept in their curricula. Students should be able to systematically apply those concepts and principles in a project oriented format with a thorough understanding of students problem solving and creativity skills. Our results demonstrate regenerative design and circularity in the built environment curriculum was well received and led to some changes in third-year architectural engineering students ‘knowledge, skills, and attitudes. However, not all of these changes were for the better, nor were all of the positive changes sustained after the design studio or supported by students’ self-reported behaviours on the long term.

We believe there are several sets of factors that contributed to these results. The first is the curriculum itself, including the course content, instructor effectiveness, educational modalities, timing and integration topics within the overall curriculum, planned redundancy, and evaluation methods. The second comes from other formal or informal learning experiences within the pre-architectural and architecture study years, including hidden curriculum. The third set of factors includes the study design, questionnaires, and evaluation tools used. We discuss each of these three areas below.

5.1 Curriculum characteristics

Our analysis identified aspects of the curriculum that worked well for our third-year architectural engineering students. We believe that presenting the studio content at Bloom's (1956) taxonomy of higher order thinking skills (understand, apply, analyse, evaluate, create) and the interactive nature of the learning modalities contributed to the improved responses after students participated in the curriculum and after two years. For example, the most improvement was seen in items addressed by interactive sessions, such as the debate and the weekly follow up corrections, where students applied knowledge and practiced skills. Conversely, students' improved mastering of content delivered solely by lecture, such as design principles and guidelines reported in the body of literature, but this knowledge was not sustained at two years. These results and the curriculum evaluation suggest that application-focused learning and case-based interactive or narrative sessions may achieve more lasting impact of students' knowledge, skills, and attitudes, as well as improved student satisfaction with the curriculum. In addition, when we covered topics multiple times using several educational modalities during the curriculum, as in the inevitability of design errors, students' learning was sustained.

On the other hand, several topics let to no change in students' knowledge, skills, and attitudes. For many of these topics, students were already familiar with the concepts that were taught, such as the quality gap between ideal regenerative design philosophy and actual application limitations and it takes more than architects to determine the causes of design errors. Students' prior experiences and baseline knowledge may eliminate the need to cover this material in a curriculum. Alternatively, this lack of change in students' responses might indicate that curricular timing and integration should be improved for these topics. For example, the curriculum did not convince students that regenerative design and circularity in the built environment is a priority at Ulg. This may be due to a lack of clear messages and planned redundancy with the curriculum about our institutional focus on regenerative design. Based on these results, when we presented the curriculum to the next class of third-year architectural engineering student in 2014 and 2015, we decreased the amount of time spent on introductory material, substituted a required reading for a background lecture, and focused more on the interactive, application-based aspects of the curriculum, including the time allotted for students to apply the project requirements in the project design.

5.2 Other learning experiences

Calling to mind the effects of the informal and hidden curricula, our study shows that students' responses to the two items describing secrecy about architectural design errors weakened after one year of architectural practice. Additionally, responses to two items on the value of learning about improving design quality during the study period and working to improve design quality as part of their professional life.

5.3 Study design, questionnaire, and evaluation tools

Limitations in our study design, questionnaire, and evaluation methods also may have blunted the effects of our curriculum on student's learning. A stronger study design would have included a control group of Ulg students or students from similar institutions. However, we thought strongly that all Ulg students should be exposed to this content and thus integrated it into the core curriculum. As this was a novel curriculum and likely to be adapted further, we did not seek to implement it at another institution during this phase of the study. Although the response rate was adequate at each time period, our core analysis focused only on those students who completed the questionnaire at all three administrations. The survey instrument was new and therefore limited by its lack of formal validation and reliability testing. Some attitude items were confusing in that they required the students to respond in a way that reflected both what we taught (i.e., in general architects do not report errors routinely) and what we demonstrated to contrary. Ultimately, our study is limited by reliance on students' self-reporting their comfort with skills and behaviours, rather than our using observational methods to determine their actual performance or measuring design-related outcomes with respect to regenerative design and circularity on the built environment. In addition, students completed the curricular evaluation after the last session, thereby requiring them to recall sessions presented several weeks ago.

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