Sustainable Design Experience: The Race to Zero Competition

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Abstract

The architecture, engineering and construction (AEC) industry has become more complex, requiring changes in both design and construction processes and demanding more collaboration among all the stakeholders. Enhancing collaboration in the AEC industry highly depends on changes in the education of AEC professionals to provide an educational venue for students to experience collaborative learning and develop the required professional culture and skills. By using the Purdue Team's experience in the 2018 RTZ competition as a case study, this paper provides insight into the interdisciplinary collaboration experience of designing a zero-energy building (ZEB) and identifies perceived benefits and challenges for the students engaged in the competition. Complementing the report of the team's experience at the 2018 RTZ, this study emphasizes the importance of teamwork collaboration in the present context of the AEC industry while drawing upon concepts of sustainable construction. The study encompasses data collected from: (1) a survey with all the 8 students, (2) interviews with the faculty leader and the student team leader, and (3) the reflections of two of the authors of this paper based on their own experiences and observations as participants in the 2018 RTZ competition team. Three categories emerged from the data and background literature analyzed: teamwork, education and knowledge, skills, and abilities (KSA). Teamwork category clusters the following themes: (a) teamwork quality (TWQ), (b) teamwork in sustainable construction. Education category clusters the following themes: (a) interdisciplinary teamwork in the university, (b) student competitions benefits and challenges. KSA category clusters the following themes: (a) experience in the field, (b) skills required for interdisciplinary teamwork, (c) KSA benefits and challenges. In terms of teamwork, participants acknowledged their overall performance as good. As for education, all the participants emphasized the great learning opportunity presented by student competitions, but they also commented on some challenges resulting from it.

Introduction

Lately, the architecture, engineering, and construction (AEC) industry has become more complex, requiring changes in both design and construction processes [1]. Three new processes are carrying out an important role to manage this increasing complexity: building information modeling (BIM), integrated project delivery (IPD), and lean construction (LC) [1], [2], [3]. In addition to BIM, IPD and LC, sustainable construction has been drawing much attention from the AEC industry due to the growing concerns on climate change, the depletion of the earth's resources, and the widespread pollution [4].

It is important to emphasize that sustainable construction, BIM, IPD and LC are processes that require effective collaboration among team members and a holistic design approach to guarantee the construction of buildings with high overall performance. Holistic design relies on a comprehensive analysis of all the building components and systems during the design phase, considering the entire lifecycle of the building [5]. However, up to date, holistic design is not really "holistic" because it mostly focuses on issues related to energy consumption [5]. This fact is reasonable given the growing concern about power generation and consumption growth verified all around the world.

Many countries are developing codes and tools to promote building sustainability and the construction of high-efficient buildings. In the European Union (EU), the recast of the Energy Performance of Buildings Directive introduced the obligation for nearly zero energy buildings (nZEB) and stated that "Member States shall ensure that (a) by 31 December 2020, all new buildings are nearly zero-energy buildings; and (b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings" [6, p. 153/21]. In the United States, the Department of Energy (DOE) has established guidelines for homes participating in the DOE Zero Energy Ready Home Program [7]. In addition, the U.S. government has mandated "that all new construction of Federal buildings greater than 5,000 gross square feet that enters the planning process is designed to achieve energy net-zero and, where feasible, water or waste net-zero by fiscal year 2030." [8, p. 15874].

The U.S. DOE is also inspiring university students to engage in sustainable building design through a program called Race to Zero, which is an annual competition focused on the design of ZEB buildings (housing or elementary school). The Race to Zero student design competition is opened to graduate and undergraduate students from any interested program of different institutions worldwide [9].

Competitions can be an effective tool for student engagement and collaboration, but it can present some drawbacks or challenges for students, such as worsened academic performance, disappointment and stress [10]. It is important to emphasize that even defeat can benefit competition participants, because they will learn from real-world experiences, dealing with time shortage and learning from losing [11]. The study of student's participation in student competitions is important to evaluate the benefits and challenges perceived through these experiences. [11], [12].

Purdue University participated in the 2018 Race to Zero (RTZ) competition with a multidisciplinary team of AEC graduate and undergraduate students. This was the second time the university participated in the RTZ competition (Purdue University also participated in the 2017 competition). In both opportunities the experience was based on collaboration among participants in a real-world practice, which may benefit students' future academic and professional lives. By using Purdue Team's experience in the 2018 RTZ competition as a case study, this paper provides insight into the interdisciplinary collaboration experience of designing a zero-energy building (ZEB) and identifies perceived benefits and challenges for the students engaged in the competition.

As participants of the 2018 RTZ Team, the authors include their reflections about their experience in the competition. Complementing the report of the Purdue team's experience at the 2018 RTZ, this study demonstrates the importance of teamwork collaboration in the present context of the AEC industry while drawing upon concepts of building information modeling (BIM), integrated project delivery (IPD), lean construction (LC) and sustainable construction.

Background

Teamwork, Teamwork Quality and Knowledge, Skills, and Abilities (KSA)

For this paper, the authors define a team as a group of persons associated to develop a work or activity involving interdependency and shared goals. Teamwork, in turn, is defined as the collective effort of a group of people to solve a problem, involving interdependent components of team performance [13].

Research on teamwork reveals the importance of the interactions among team members and trust is usually mentioned as one of the most important components for cooperation between people and teamwork, because based on values and attitudes of team members, trust can be built in a group, "allowing them to manage the risk associated with their interaction so that they can jointly optimize the gains that will result from cooperative behavior" [14, p.532].

Expanding the topic, Hoegl and Gemuenden [15], argue that the quality of the interactions in teams depends on six facets, which are the base of teamwork quality (TWQ):

- Communication is the exchange of information among the team members, which can be formal and informal, the latter being the most important to evaluate teamwork quality.
- Coordination is related with the organization of the team members and the work.
- Balance of members' contributions refers to the ability of all team members to contribute with significant knowledge to achieve the common goal.
- Mutual support is the collaborative relationship between the team members.
- Effort is related to an equal workload sharing among team members.
- Cohesion refers to the degree of commitment and engagement among team members.

Research suggest that good interactions in teams and teamwork quality highly depends on the team members' KSAs [16], [17]. Stevens & Campion [18] define KSAs as the required characteristics of team members to adequately perform their tasks in a team, which can be divided into:

- Interpersonal KSAs – related to interpersonal relations management, they include conflict resolution, collaborative problem solving and communication KSAs.
- Self-management KSAs – related to managerial activities, they include goal setting and performance management, and planning and task coordination KSAs.

In light of the great diversity of stakeholders and the issues related to the planning and construction of buildings and complex real estate projects [1], previous literature suggests "that design and construction activities need to move from a siloed to an integrated approach to improve performance and provide significant benefits for all project stakeholders" [19, p. 36]. This integrated approach is vital to promoting the design and construction of high-performance sustainable buildings and engages collaborative work by requiring AEC industry professionals to develop a holistic view as well as a high degree of expertise and knowledge in the design and construction process [20].

Despite the current push to a more integrated approach, the AEC sector is still facing problems related to information sharing and miscommunication, due to an obsolete design process based on a linear and fragmented approach in which many decisions are made without consulting the

specialists in the field [21]. The AEC industry needs enhanced communication and collaboration among project team members through all phases of the project. Frequently, "relationships within AEC teams are adversarial, lacking collaboration and cooperation" [22, p.70]. This fact clearly shows the existence of a gap between architecture, engineering, and construction "leading to sub-optimal solutions, poor constructability and operability, rework in design and construction, and lack of innovation" [20, p.371].

Architecture, engineering, and construction (AEC), the three main disciplines traditionally related to the design and construction, have recently experienced deep changes to adjust to new processes and demands in the AEC industry: BIM, IPD, LC and sustainability are practices and concepts highly beneficial to the AEC industry, which rely on interdisciplinary collaboration. In fact, collaboration between architects, engineers and construction managers is expected because all these professionals should be working towards a common goal to deliver a finalized built structure. However, an important issue to be overcome lies in the fact that these professionals are prepared to think about their own scope of action, resulting in conflicting goals between AEC industry stakeholders. This adversarial process starts with formal university education, which is most often based on the division of schools and disciplines [23], and research has shown little exposure of students from AEC courses to one another [24].

Enhancing collaboration in the AEC industry highly depends on changes on the education of AEC professionals to provide an educational venue for students to experience collaborative learning and develop the required professional culture and skills [21], [25]. Educational institutions seek to create educational programs that teach students skills such as team working, collaborative decision-making and communication. However, research demonstrates that the current approach is not sufficient to develop student's skills for industry practice [26]. "Effective learning can only take place in larger, multidisciplinary team scenarios" [26]. The best way for AEC education institutions to promote students' professional identity is disseminating cross-disciplinary collaborative courses, projects, assignments and even competitions that simulates real-word experiences [25], [26].

Three Processes Demanding Collaboration in the AEC Industry

Building information modeling (BIM). Building information modeling (BIM) allows the development of a holistic design represented as a virtual information model that can be shared by a multidisciplinary team. This way, each professional contributes with discipline-specific data to the single shared model, reducing information losses and redundancies, as well as providing more comprehensive information to building owners [27]. In fact, BIM can be used throughout the building life cycle, beginning with the planning and design phase of the project, and extending to supporting processes such as project management, cost management, construction management, and facility operation. [28]. BIM is a new approach to design, construction, and facility management involving a process of information management, not a drafting/modelling tool, therefore, the correct way to work with BIM demands professional qualifications beyond drafting-related ones [27], [29].

Integrated Project Delivery (IPD). The American Institute of Architects (AIA) defines IPD as:

> A project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction [30, n.p.].

According to Kent and Becerik-Gerber [1], there is not an accurate definition of IPD accepted by the whole AEC industry, but they suggest that IPD can be defined through three principles: "(1) multi party agreement; (2) early involvement of all parties; and (3) shared risk and reward" [1, p. 818]. IPD requires that all stakeholders come together in the beginning of the building process and have shared risk and rewards, which reduces adversarial relations in the process and encourages a true multidisciplinary collaboration. Based on these explanations it is possible to realize that IPD is a highly collaborative process just like building information modeling (BIM). In fact, IPD as a new project delivery system facilitates the use of BIM and vice versa, since they are complementary processes in construction projects with the objective of integrating the experience of project teams from the first stages of the project to completion construction [1], [31].

Lean Construction (LC). Lean Construction "is a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value" [32, p. 211]. Thinking of a construction project as a temporary production system, the goal of lean construction is to deliver a quality product built on value maximization and waste minimization. In fact, three key concepts are important to better understand lean constructions: value, flow and pull [33]. In LC the meaning of "value" is not only cost, but mainly the customers' satisfaction. Flow refers to the movement of information and materials and through the professionals involved with the project, including the production workflow as well. Pull is related to planning techniques that control the flow of information and materials in a collaborative way, breaking down projects into parts, beginning with the final goal and working backwards to define and monitor the project schedule [2], [33]. Lean construction process is consistent with IPD and BIM processes to stimulate team ability and generate benefits to the AEC industry.

Sustainable and Highly Efficient Zero Energy Buildings Design

The AEC industry is moving towards sustainable building practices in an effort to reduce its a great share of energy, water and materials consumption [34]. However, even if sustainability is an important consideration for the AEC industry today, economic interests are the biggest driver in decisions related to building and construction [34].

Today, buildings are expected to be highly efficient in many ways, such as maximizing usable space and environment comfort for the occupants, while minimizing the generation of waste and pollutants, and resources consumption – water, energy and materials. Highly efficient buildings meet the requirements to be sustainable buildings, since efficiency and sustainability go hand in hand [35]. On the other hand, considering that highly efficient buildings and financial returns are closely linked, energy efficiency in buildings ends up being the most relevant topic related to sustainability. The terms Zero Energy Building (ZEB) and almost Zero Energy Building (nZEB) have become commonly employed in the AEC industry. A ZEB is a building whose total amount

of energy consumption on an annual basis is equal to or less than the amount of renewable energy produced by the building itself.

As a result of the increase in design needs and requirements, buildings are becoming more and more complex, demanding the collaboration of qualified professionals during all phases of their lifecycle, that is, from the design phase to eventual demolition. It is important to emphasize that in the AEC industry the most effective actions occur during the design phase; that is, decisions made during the early stages of design strongly impact the performance of the building throughout its life cycle, which reinforces the need to promote interdisciplinary collaboration during the design phase of the construction process [23].

The processes related to sustainable construction and building efficiency follows the overall design process, but in this case collaboration among team members is even more important and not only during the early stage of the project, but during the whole project lifecycle. Beginning with an outline, as a holistic system, the building design is then gradually detailed in design iterations with the multiple team members, and sustainability requirements, first defined at highly abstract level, become more specific. A sustainability benchmarking, that is, a comparative assessment of the sustainable definitions adopted, shall be made at the end of each project phase to refine the proposed solutions [20].

Research Context

The U.S. Department of Energy Race to Zero Student Design Competition is an annual competition that challenges students to create zero energy buildings (ZEB). In the 2018 Race to Zero, teams could choose between two different types of ZEB: residential (single or multi-unit) or institutional (elementary school) buildings. The 2018 RTZ Purdue team comprised seven student team members, one student team leader (STL), two faculty advisors and one faculty leader. Six student team members were selected jointly by the faculty leader and STL. The seventh member (landscape architect) was chosen after the development of the project had already been initiated. The team also counted on the collaboration of industry advisors, according to the RTZ competition requirements.

The chronology of the Purdue team participation in the 2018 RTZ is presented as follows:

1. Mid-September 2017 – Purdue team began to be formed in with the initial participation of two members and the support of an advisor from the School of Construction Management Technology, which are the authors of this study. Following, the two team members began the work of defining the type and the location of the building.
2. End of September 2017 – the team decided on developing an elementary school zero energy building in Indianapolis; two faculty advisors and four more students had joined the team.
3. Beginning of October 2017 – another member joined the team and the conceptual design began to be developed.
4. November 7, 2017 – the Project Introduction was submitted encompassing some preliminary data and technical information of the ZEB project, such as project type,

location, area, and technical concepts, in addition to the team information. After that, the team evolved with the building design, detailing and technical specifications, evaluation of energy performance and costs.

5. Beginning of December 2017 – the last member joined the team to develop the landscape design which was very significant for the project.
6. February 20, 2018 – the Project Progress Report was submitted, encompassing plans, 3D renderings, the project's highlights and the architectural goals. The team kept working after this submission.
7. March 6, 2018 – the Purdue team leader was informed that the project was not selected to participate in the final competition.
8. March 21, 2018 – one of the researchers sent the survey to the RTZ Purdue team. All Purdue team student members and the faculty leader agreed to participate in this study.

Soon after the 2018 RTZ announcement of the teams selected for the final competition, the group split, but two of the original team members still decided to attend an internal Purdue exhibition promoted by the school of Ecological Environmental Engineering (EEE). The Undergraduate Environmental Programs & Research Expo was held on April 12th, 2018 and the two former members of the 2018 RTZ Purdue team presented a poster showing the main aspects of their project.

Methodology

Research Questions

Our purpose is to explore the participants' perception of their experience in the 2018 Race to Zero competition by using the following research questions:

1. How do participants perceive their interdisciplinary teamwork experience in the 2018 RTZ competition?
2. How do participants perceive their skills to participate in the 2018 RTZ competition?
3. What are the academic, professional and personal benefits and challenges perceived by the participants in the 2018 RTZ competition?

Research Design

In this exploratory research, we use a case study to answer the research questions. The case study suits very well for this study, especially because we want to investigate “a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident” [36, p. 18]. Thus, to answer the posed research questions, we studied the 2018 Race to Zero competition Purdue Team (defined as the unit of analysis) in relation to the concept of interdisciplinary teamwork.

We have adopted some procedures defended by [37], [38] to enhance the quality and credibility of this study:

1. Systematic data analysis – search for alternative themes, divergent patterns, and rival explanations; constant comparison of quotations and codes; analysis connected to the research design and purpose.
2. Triangulation – use of two different sources of data (survey and interviews) to integrate and triangulate data; use of another analyst to review findings.

Data Collection

The data used in the study was gathered from a survey with the 2018 Race to Zero competition Purdue team students, interviews with both faculty leader and the student team leader (STL), and the experience of the authors as participants in the 2018 RTZ competition Purdue Team.

We obtained prior exemption of this study from the Purdue Institutional Review Board (IRB Protocol # 1803020364). Participation in survey and interviews was optional and all the participants were aware that data from the surveys would be anonymized prior to analysis and reporting. The participants names were substitute by a randomized key (P1 through P8).

The survey consisted of an online questionnaire, with standardized multiple-choice and open-ended questions, developed and distributed through Qualtrics platform. All the 8 students participated in the survey, including the STL. In addition to the questionnaire, one of the authors conducted two face-to-face semi-structured interviews, which posed open-ended questions, focused on interpretative answers, allowing the participants express their opinions, feelings and experiences. The two interviewees were the faculty leader and the student team leader, because their leadership position in the Purdue team ensured a different view of the experience to be explored through interviews. The interviewing process involved asking questions, listening to and audio recording answers from the two respondents. A manual transcription of the audio-recorded interviews was made, which was later used for the data analysis.

The reflections of two of the authors of this paper are based on their own experiences and observations as participants in the 2018 RTZ competition Purdue Team. The student team leader and the architectural designer registered their reflections between the end of July and the middle of August of 2018, focusing on the three research questions. The faculty leader, who is also an author in the present paper, reviewed the reflections provided by the students and prompted students to give more details if needed.

Study Participants

The first phase of the study consisted of a survey conducted with the 2018 Race to Zero Purdue Team, a group of eight students, including two authors of this study.

The interview participants were both the faculty leader (FL) and the student team leader (STL) from the 2018 Race to Zero competition Purdue Team, who are both collaborating with this paper. Table 1 shows a description of the eight student participants' academic profile. In addition, the faculty leader is an Assistant Professor of Construction Management Technology and holds a PhD in technology, with a focus in construction management.

Table 1. Participants' academic profile

Academic level	Major
Graduate - PhD	Construction Management Technology
Graduate - PhD	Civil Engineering - Innovation Science
Graduate - Master	Ecological Environmental Engineering - Building performance
Graduate - Master	Building Construction Management
Undergrad	Civil Engineering – Architecture Engineering (Team Leader)
Undergrad	Construction Management Technology
Undergrad	Interior Design
Undergrad	Landscape Architecture

Data Analysis

Survey. We analyzed the survey data separately and before the interview data. The answers to the multiple-choice questions were tabulated and quantified. The answers to the open-ended questions were coded according to the thematic analysis and based on the concepts discussed on the literature review, which captured important patterns and themes related to the research questions [39].

The coding method was based on Saldaña's [40] coding manual for qualitative researchers. The in vivo coding method was used in the first cycle, then the eclectic coding method was used prior to the searching for themes [40]. One of the researchers coded the responses to the open-ended questions of the survey shortly after coding the interview responses. Then, after identifying and reviewing the themes, the themes from the survey were compared to the themes from the interviews and all of them were clustered into categories. Once the categories were defined, the tabulated data from the survey were divided into categories.

Interviews. Firstly, we analyzed each interview separately. The data was analyzed using the thematic analysis method previously described. In a second moment, we analyzed the two interviews together, and compared the identified themes. The themes which emerged from the interviews were compared to the themes from the survey open-ended questions and they were clustered into categories.

Results

Based on what is described in the methodology, three categories emerged from the data and background literature analyzed. They are:

1. Teamwork – this category cluster the following themes: (a) teamwork quality (TWQ), (b) teamwork in sustainable construction.
2. Education – this category cluster the following themes: (a) interdisciplinary teamwork in the university, (b) student competitions benefits and challenges.
3. Knowledge, skills, and abilities (KSA) – this category cluster the following themes: (a) experience in the field, (b) skills required for interdisciplinary teamwork, (c) KSA benefits and challenges.

We present the results associated to each research question and within each category the themes are discussed and the data that support the results – tables and anonymized direct quotes – are presented. In the tables all the participants are identified by a number and in the quotes only the 2018 RTZ Purdue faculty leader and team leader are identified.

1. Participants' perceptions of teamwork in the 2018 RTZ competition

Teamwork

Teamwork quality (TWQ). This theme is based on the participants' evaluation of the performance of the Purdue team in the 2018 RTZ competition. Table 2 shows the level of collaboration between Purdue team members, as perceived by the participants, on a scale of 0 to 4 with 0 being very poor and 4 excellent. The overall performance in terms of collaboration was considered between good and excellent (mean = 3.3).

Table 2. Collaboration between Purdue team members (n=8)

	Involvement	Responsibility sharing	Respect among members	Collective input and interaction	Information exchange	Mutual encouragement and support	Problem solving ability	Innovation and creativity	Motivation
P1	4	4	4	4	4	4	4	4	3
P2	4	4	4	3	3	4	3	3	4
P3	3	3	4	2	2	4	3	2	4
P4	3	2	3	2	2	3	2	2	3
P5	4	3	4	4	4	4	4	4	3
P6	3	3	4	4	3	4	3	1	3
P7	4	4	4	4	4	4	3	3	3
P8	2	3	4	3	3	2	2	2	2
Mean	3.4	3.3	3.9	3.3	3.1	3.6	3.0	2.6	3.1
Overall collaboration level (mean)									3.3

Scale: 0 = Very Poor / 1 = Poor / 2 = Average / 3 = Good / 4 = Excellent

When questioned about the chance to start over their collaboration in the RTZ competition, all the 8 students (from both the survey and interviews) highlighted aspects of their teamwork experience that could be improved to enhance the TWQ. P5 affirmed: "I [would] try to organize internal team deadline more efficiently and distribute work more evenly." P6 said: "I would have devoted more time to the group." STL's comment is related to her leadership role: "I think the first thing that I would change is advise everyone to watch the videos before starting any work because that would give the same base for everyone, at least the same base."

The faculty leader commented on her role as an adviser and commented on some points that would improve the TWQ: "Maybe the other thing I would do more as an advisor would be to really have biweekly meetings […]. We did maybe a couple of them. Maybe more would be helpful."

Teamwork in sustainable construction. The 8 survey participants, one of them being also an interviewee, were unanimous in asserting the importance of teamwork for AEC professionals. STL commented:

> I think the building industry requires very precise work in all the areas and one single person can't master every area. You [need] specialists […] to work in collaboration with everyone, so everything is done in excellence, and […] you have to trust your teammates [will] have their work done and you have to trust in their abilities to do the work.

The faculty leader explained her point of view:

A building project requires a team because there is no way that one person can do it at all, there is no way one team can do it at all, so actually multiple teams that are involved with the project.

Table 3. Aspects of the project benefited or hindered by the multidisciplinary team (n=8)

	Getting started	Engagement	Communication	Working flow	Productivity	Quality	Project definitions	Brainstorming more solutions	Flaws / review detection	Accomplishment of complicated tasks	Deadlines
P1	4	3	4	3	4	4	4	3	4	4	1
P2	2	4	4	3	3	3	4	4	4	4	4
P3	-	4	1	3	3	4	2	4	2	2	1
P4	2	3	2	3	3	3	2		2	3	2
P5	4	4	2	2	3	4	4	4	3	4	3
P6	3	3	2	2	3	4	3	4	2	3	3
P7	4	2	3	4	4	3	2	3	4	4	2
P8	4	3	2	3	3	3	3	3	3	3	2
Mean	2.9	3.3	2.5	2.9	3.3	3.5	3.0	3.6	3.0	3.4	2.3
Overall evaluation (mean)											3.0

Scale: 0 = Much worse / 1 = Worse / 2 = About the same / 3 = Better / 4 = Much better

All the 8 students were also asked if they considered that high-efficient zero energy building projects require more collaboration from the AEC professionals working on them. Six of eight participants from the survey agreed that ZEB projects require more collaboration: "Yes, any Zero Energy building cannot be successful without cross discipline collaboration. Integrated design and construction is key to Zero Energy Building projects." (P2)

According to the faculty leader:

> Yes, they do require more collaboration because, there are more subject [areas] […] So, the project is much more complex. More complex, more projects, more iterations to make the project work as a whole and not have a lot of coordination issues.

Two participants from the survey did not think high-efficient ZEB projects require more collaboration than traditional projects from the professionals involved in them: "I do not see how

net zero projects differ from any project when it comes to benefiting from collaboration. All projects have design and execution phases, and therefore collaboration is important in all projects equally." (P4)

2. Participants' perceptions of their preparation and skills to participate in the 2018 RTZ competition

Education

Interdisciplinary teamwork in the university. The students' answers to both survey and interview reveal that their current formal university education mostly foster collaborative work between classmates and between courses within the same Major. However, as 4 out of 8 students evaluated that their courses do not encourage interdisciplinary collaborative work, it is possible to identify a gap in formal university education, since the AEC industry requires a high level of interdisciplinary collaboration among professionals in the field. Table 4 summarizes the assessment of students in their current formal education in terms of collaborative work.

Table 4. Collaborative work in students' current education (n=8)

	Teamwork between classmates	Teamwork between courses within the same Major	Teamwork between disciplines of different fields
P1	No	Yes	No
P2	Yes	Yes	Yes
P3	Yes	Yes	Yes
P4	Yes	Yes	No
P5	Yes	No	No
P6	Yes	No	No
P7	No	No	Yes
P8	Yes	Yes	Yes

As an interviewee, STL talked about her own experience as an undergraduate student at Purdue:

> I think in my first years at Purdue I didn't do much teamwork, it was more design or learning the math and physics, so it was very individual, […] but, this semester I'm in a class that the goal is to communicate sustainability and work with the team for the entire year, or the entire semester, and they fostered the skills necessary to work together…. This class is an interdisciplinary course.

The faculty leader commented on her view of education as a professor in the School of Construction Management Technology in Purdue and expressed a desire to see more interdisciplinary collaborative work in the school's programs:

> In this case I must say that our program [currently] does not foster interdisciplinary [or] encourage interdisciplinary collaboration. We are getting better at this, we are getting better at encouraging students, but I think there [are] miles to go.

Responding a question about working collaboratively and preparation of students from AEC related disciplines to enter the AEC industry, STL was not very enthusiastic about the current scenario.

> … Because seniors have to take this senior design class and that [in this] class you work with one single group throughout the semester, they will learn a little bit about working together because it requires them to work together. But I think one experience is not enough to prepare you for the industry […], so that's why I think it's good to have extra-curricular [activities] like competitions and organizations, and stuff like that.

And the faculty leader reinforced STL's voice:

> So, if the student really wants, especially here, they can take classes [outside their major] that they can […] find other students. But if you don't want to go the extra mile, then you will stay in silos. So, I don't think most of the students will be prepared. But if they do […] these competitions, then they will be a little more prepared.

Knowledge, skills, and abilities (KSA)

Experience in the field. Seven out of the eight students have some experience in the AEC industry, including volunteer work, internship and formal job. Table 5 summarizes the findings.

Experience	Field
Volunteering	Research Group
Formal Job	Building Services
Internship	Multidisciplinary civil engineering firm
Formal Job	Structural and architectural design, construction
Internship	Owner representative companies and General Contractors
None	-
Internship	Consulting firm for sustainable construction
Formal Job	Architect / Design Manager

Experience in the field can be considered a good way to enhance the required skills to interdisciplinary teamwork. The participants' voices show that prior experience is an important factor in conveying self-confidence to students, such as one of the participants commented: "Yes, having 4.5 years of experience in the AEC industry gave me good fundamentals on Net Zero Energy buildings which helped me a lot in participating successfully in competition."

When questioned about influential experiences to prepare her to work collaboratively, STL highlighted her experience in the Race to Zero competition in the previous year as paramount in terms of interdisciplinary teamwork:

> I think, in terms of experience, the competition helped me a lot to understand how some strengths in some areas can help your teammates and how your weaknesses can open your mind to learning from other people in your team. […] I learned a lot from Polytechnic

> students and how to communicate with industry and professors and something like that, so I think that was good.

The faculty leader commented on the importance of working in the industry: "For me, I think it was my years in industry when I did coordination work. […] So, I think that prepared me for the collaborative work."

Skills required for interdisciplinary teamwork. When students were asked if they find themselves prepared or if they have the required skills to participate in the 2018 RTZ Competition, all the 8 students affirmed they felt prepared. A survey participant, P3, said: "I did feel prepared, having worked on projects with people in different majors before. This was my first time working with company sponsors as part of the project, however."

As interviewees, both the faculty leader and STL emphasized the importance of communication and trust, but they also listed other skills: empathy, caring or thinking about the group, and mutual support. STL said:

I think we have to able to communicate very well […], you have to learn how to communicate what you know in a way that doesn't offend the other person, […] so I think that makes you seem not arrogant and they'll respect you and trust you. Besides communication, […] you realize you can make mistakes but there are people there to help you […].

3. Academic, professional and personal benefits and challenges perceived by the participants of the 2018 RTZ competition

Education

Student competitions benefits and challenges. This theme considered the students' perceptions of the general benefits and challenges that resulted from their participation in the RTZ 2018 competition, not focusing on the benefits directly related to KSA.

All the 8 students agreed about the importance of competitions to foster interdisciplinary collaboration among students and emphasized the great learning opportunity. Overall the student's comments were very positive, P2 said: "I got good hands on experience on working [collaboratively] across cultural environment." Another student, P1, noted: "More solution for the same questions has been learned from the teammates [through competitions]. And they let me know how to work as a real team for a real project." And STL commented:

> I think it's a good tool because not in all classes you get the opportunity to work in a team of different backgrounds. So, introducing this type of competition in a college, especially in a college that have different majors is a good way to make people work together and understand each other.

And she added:

> I got a lot closer with the industry and with the products that they have […] I started to realize how the design process applies to the actual work because for design we can do all of

> the assumptions with fake numbers and it will work, […] and that is something that you don't experience in class with fake design projects.

Some challenges were identified by six of nine participants (from both survey and interviews). Students commented on time management as a challenge related to teamwork faced during the competition. P6 mentioned problems to attend demanding classes while working on the competition issues:

> […] designing a building this size in a few short weeks is very daunting and I would have not been able to design [it] as beautiful as I would have wanted on top of the very demanding classes already required in [my] major.

In the interview STL also commented on problems to keep up with her courses:

> Because I had more motivation to work on the competition than in my courses, and for me it was more important, […] my GPA was not as high as the other years because I was putting less time in [my] classes, […].

The faculty leader commented on the challenges to set up the team: "I think we had challenges to define, you know, exactly how many people we need, so this is something that we have to refine for the next time, […].

Another important aspect, which can be identified as a drawback of competitions, refers to the frustration of not going to the finals, as commented by STL:

> I think because we didn't go to the finals we have to deal with frustration. […] So, sometimes I guess you can do your best and everyone works hard and do their best work but… For your experience it was perfect, but for the goal of the competition it was imperfect but still you learned a lot.

The faculty leader emphasized the importance of student competitions to encourage interdisciplinary teamwork: "I think those opportunities [competitions] are great and I wish there were more of them".

Knowledge, skills, and abilities (KSA)

KSA benefits and challenges. In terms of KSA, participants' perceptions of the benefits and challenges were positively evaluated by 7 of 8 students from the survey. Table 6 shows the results (mean = 2.1, considering a scale from 0 to 3). Diversity (mean = 2.6) is evaluated as the skill best developed by participating in the 2018 RTZ competition.

While answering some open-ended questions from the survey, students presented a number of other KSA that have resulted of their participation in the 2018 RTZ competition, some of them are closely linked to sustainable construction. P5 emphasized his gain of knowledge: "[I got] a good knowledge on Net Zero energy construction practices." And added:

> It was a big learning curve for me because coming from a construction background, I had little to no knowledge of Green Building and passive construction techniques and though our team did not make to the finals, I am pretty sure […] we all learned a lot, especially me.

Challenges were also presented by 4 of 8 participants (from both survey and interviews). Answering a survey question, P1 commented on challenges related to specific skills and knowledge: "I [would have to] learn more details about the system working and how the modeling tool works. Just like at this time, it was hard for me to create a new model without any help." And P5 highlighted planning as a challenge to be overcome: "I will try to organize internal team deadline more efficiently and distribute work more evenly".

Table 6. Personal KSA developed or improved by participating in the 2018 RTZ (n=8)

	Diversity	Communication	Critical Thinking	Evaluation	Conflict Resolution	Higher Moral
P1	3	3	3	2	2	2
P2	3	3	2	3	3	3
P3	3	1	3	2	2	1
P4	1	1	1	1	1	1
P5	2	3	3	3	3	3
P6	3	2	2	2	2	2
P7	3	3	3	3	3	1
P8	3	0	0	1	1	0
Mean	2.6	2.0	2.1	2.1	2.1	1.6
					Overall evaluation (mean)	2.1

Scale: 0 = About the same / 1 = Somewhat better / 2 = Better / 3 = Much better

Authors' reflections as participants in the 2018 Race to Zero Competition

As participants of the 2018 Race to Zero competition Purdue team, two of the authors, who were also student team members in the RTZ 2018 competition, considered important to reflect on their own experiences and observations to answer the research questions.

1. How do participants perceive their interdisciplinary teamwork experience in the 2018 RTZ competition?

Author A: As a participant involved with the building design, I experienced a good level of collaboration with most of my teammates. However, in my opinion, not all the team members got an adequate degree of engagement with the project because, according to the project planning, some team members would get more involved in the project in a second moment. However, due to our premature elimination in the competition they did not have the chance to work as planned.

Considering my own performance, I should have encouraged some team members to work more collaboratively in the project. In some moments I felt overwhelmed, trying to cope with some project issues which were too complicated for me, such as defining more sustainable construction materials and methods, defining technical spaces, etc. I realized then that our team

was missing someone with more technical knowledge of mechanical, electrical and plumbing systems. Our team tried to deal with this situation, but I think this fact has negatively impacted our performance because we spent some time trying to find an industry partner to help us.

The decision to go for a school project and the site selection didn't involve all the participants, especially because the team was not entirely formed. I felt some discomfort among some team members due to not having participated more in those important front-end decisions, but the entire team respected the decisions made.

Author B: My engagement with the diverse group of students involved struggle and success within our team communication since the beginning of the competition. I had a very insightful communication with each team member at the stage in which the team was being formed, we discussed the relevance of the project for our academic and professional careers as well as the excitement of participating in competitive design. I felt the need to present each prospect team member my motivation for entering the competition and motivate them to join. Along with that, I tried to interpret their level of commitment and technical competence for the future stages of the project to make sure that we were entering the RTZ Competition with a solid team.

I perceived this as a success in the conceptual formation of the team. However, as the hands-on stage of the competition approached, I realized that we were facing struggles with varying levels of commitment, aspiration to learn and teamwork interaction.

I personally felt connected to the team members and competition goal, and for this reason it was relatively easy for me to maintain myself motivated, but I noticed that not everyone felt the same way. It is possible that this happened because although all members respected and acknowledged each other's diverse expertise areas, they didn't provide a net of support and motivation for each other, which I think is crucial for a good interdisciplinary teamwork interaction and stellar professional performance. In my opinion this could be achieved if we had conducted social informal gatherings to bond with each other.

2. How do participants perceive their skills to participate in the 2018 RTZ competition?

Author A: Due to my experience in the AEC industry, which included designing buildings with LEED certifications, I found myself prepared to develop a good work in the 2018 RTZ competition. However, I can say the experience was challenging because I had to learn to deal with 3 important design issues: (a) use of some construction materials and methods unfamiliar to me, (b) weather conditions very different from the ones I knew, (c) remarkable time constraints, due to the need to keep up with my courses and work.

The choice to design a school was challenging, as it involved a large building with many requirements related to the comfort and safety of the users, besides being a zero-energy building.

Author B: In my opinion, the RTZ Competition organizers provided many resources to develop basic skills for a ZEB project, but I admit that I did not exploited them as fully as I wanted to. I had had experience with ZEB codes and standards, design guides, and specialized organizations, and the building science training developed by the Building Science Corporation specifically for the 2018 RTZ Competition, gave me other insights to what entails to design a ZEB. However, I

felt that I did not have the industry experience to conceptualize and produce the design and construction professional drawings as fast and efficiently as we were required to.

I also recognize that I had a good background of project design skills due to the strict Purdue University curriculum. Although the project scope was very challenging, I tried to maintain an optimistic view of each challenge during the competition.

3. What are the academic, professional and personal benefits and challenges perceived by the participants in the 2018 RTZ competition?

Author A: I think the experience offered me a good opportunity to learn more about American construction systems and technologies, building design in cold climate regions and collaboration with people from different cultures, since 6 of the 8 students were international students from different countries. On the other hand, I realized that I still need to improve my knowledge of American construction materials and methods to evolve both in my academic life and in my career.

As for the academic benefits, I emphasize the fact that this experience created conditions for this study, allowing me to write and reflect on it.

Author B: The competition has brought me many benefits that could not be obtained in traditional college courses. With respect to the professional benefits, I am grateful to have had the opportunity to work on a sustainable building project, a topic that is trending worldwide. This is also true because I know that there is a strong demand for competent professionals with sustainable building science and technology experience, and it is still difficult for students to obtain this type of experience and feedback in real-world projects.

As for the academic benefits, I think the competition created a space for me to collaborate with students in different disciplines and to improve my communication skills and team work. This type of collaboration is rare among different colleges since the courses are conducted separately for each department and do not allow interaction.

The personal benefits are countless, because the competition resulted in thinking sustainable design, working hard towards a challenging goal, and learning how to behave in a diverse community (or team). These are extremely important for the AEC industry and have become part of who I am as a citizen, a student, and a future engineer.

Discussion

The 2018 Race to Zero competition may be considered an important tool to enhance interdisciplinary teamwork among undergraduate and graduate students from AEC related disciplines. Student competitions can play an important role in the academic training of students and enhance their preparation for the industry [11]. Participants' responses confirm the importance of competitions for preparing them for future full-time jobs in the AEC industry.

The role of education in the training of students who will became whole professionals was briefly discussed in this study, and, based on the participant's responses, it is possible to identify

that most AEC university programs fail to promote interdisciplinary teamwork, which is currently one of the topics most valued by the AEC industry [21], [24], [25], [26]. In addition to finding some gaps in formal university education, the participants of this study recognize the importance of extracurricular activities in the preparation of students for the professional life. To minimize this lack of formal collaboration, student competitions, participation in research groups and student organizations are cited as important tools to enhance interdisciplinary teamwork.

All the 8 students perceived the benefits of this experience. However, these benefits are not restricted to the students' interdisciplinary teamwork, but also to the experience of developing the real project of a high-efficient building, a ZEB project, with all its complexities. As suggested in current research, building projects, and more specifically, ZEB projects require a lot of collaboration during their whole lifecycle, but even more attention is required in the initial phases of the project, when the most important decisions are made [1], [20]. In the 2018 RTZ competition the Purdue team worked on the initial project development, which increases the importance of their work and the value of this experience for their academic, professional and personal life.

Challenges were identified as well, but as emphasized by the faculty leader “students learned from the challenges”. In addition, research has also demonstrated that competition’s challenges can contribute with positive aspects for the students’ experience [11]. The present study participants acknowledge the importance of interdisciplinary teamwork, so they are aligned with the requirements of the AEC industry today, which considers teamwork as the point linking sustainability and the three major processes leading the AEC industry – BIM, IPD, and LC [1], [2], [3].

Conclusion

In this study we explored the perceptions of the 2018 RTZ competition Purdue team related to three categories: teamwork, education and knowledge, skills, and abilities. The 2018 RTZ competition Purdue team engaged multidisciplinary AEC students in an experience that fostered interdisciplinary teamwork among participants through a real-world practice, potentially benefiting student’s future academic and professional lives. The work on the competition lasted for 6 months during the 2017-18 academic year, and students’ skills to work collaboratively were tested through this experience.

Teamwork category encompasses two themes: teamwork quality (TWQ) and teamwork in sustainable construction. Education category encompasses two themes: interdisciplinary teamwork in the university and student competitions benefits and challenges. Knowledge, skills, and abilities (KSA) category encompasses three themes: experience in the field, skills required for interdisciplinary teamwork, and KSA benefits and challenges.

As researchers, we based our analysis on previous literature, the participants' responses to the survey and our own perceptions as participants of the RTZ experience, which were registered in the responses to the interviews and in the reflections. We are aware of potential biases that could affect the present study’s results, such as researcher’s bias, wording bias, as well as social desirability bias by participants.

Future research can analyze more in depth some important issues that emerged in this study, such as (1) the importance of student competitions that simulate real-word experiences for the AEC students; (2) the role of extracurricular activities promoted by universities in the preparation of future AEC professionals; and (3) changes in the academic AEC programs to enhance effective learning and interdisciplinary teamwork among students.

References

[1] D. C. Kent and B. Becerik-Gerber, "Understanding Construction Industry Experience and Attitudes toward Integrated Project Delivery," *Journal of Construction Engineering and Management*, vol. 136, no. 8, pp. 815–825, 2010.
[2] L. Koskela and G. Howell, "The Underlying Theory of Project Management Is Obsolete," IEEE Engineering Management Review, vol. 36, no. 2, pp. 22–34, 2002.
[3] R. Sacks, L. Koskela, B. A. Dave, and R. Owen, "Interaction of Lean and Building Information Modeling in Construction," *Journal of Construction Engineering and Management*, vol. 136, no. 9, pp. 968–980, 2010.
[4] C. Manoosingh, B. McMakin, and D. Ghosh, "The Pathway to Net Zero Energy Buildings: A Practical Practitioner Guide," *International Journal of Current Engineering and Technology*, vol. 6, no. 6, 2016.
[5] J. Sabin, "Transformative Research Practice: Architectural Affordances and Crisis," *Journal of Architectural Education*, vol. 69, no. 1, pp. 63–71, Feb. 2015.
[6] *On the energy performance of buildings (recast),* Directive 2010/31/EU of the European Parliament and of the Council, European Union, 2010. [Online]. Available: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF
[7] "Guidelines for Participating in the DOE Zero Energy Ready Home Program | Department of Energy", Energy.gov. [Online]. Available: https://www.energy.gov/eere/buildings/guidelines-participating-doe-zero-energy-ready-home-program [Accessed: 14-Mar-2018].
[8] Executive Order No. 13693, 80 FR 15871, March 25, 2015. [Online]. Available: https://www.govinfo.gov/content/pkg/FR-2015-03-25/pdf/2015-07016.pdf
[9] "U.S. Department of Energy Race to Zero Student Design Competition," Energy.gov. [Online]. Available: https://energy.gov/eere/buildings/us-department-energy-race-zero-student-design-competition. [Accessed: 01-Mar-2018].
[10] P. Schuster, A. Davol and J. Mello, "Student Competitions The Benefits and Challenge," in *2006 ASEE Annual Conference & Exposition, Improving ME education: Broad Topics,* Chicago, IL.
[11] B. F. Bigelow, S. Glick, and A. Aragon, "Participation in Construction Management Student Competitions: Perceived Positive and Negative Effects," *International Journal of Construction Education and Research*, vol. 9, no. 4, pp. 272–287, 2013.
[12] C. Kasier, and W. Troxell, "Student Design Competitions in Undergraduate Engineering Education," in *35th ASEE/IEEE Frontiers in Education Conference*, Indianapolis, IN, 2005.
[13] E. Salas, N. J. Cooke, and M. A. Rosen, "On Teams, Teamwork, and Team Performance: Discoveries and Developments," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 50, no. 3, pp. 540–547, 2008.

[14] G. R. Jones and J. M. George, "The Experience and Evolution of Trust: Implications for Cooperation and Teamwork," *The Academy of Management Review*, vol. 23, no. 3, p. 531, 1998.
[15] M. Hoegl and H. G. Gemuenden, "Teamwork Quality and the Success of Innovative Projects: A Theoretical Concept and Empirical Evidence," *Organization Science*, vol. 12, no. 4, pp. 435–449, 2001.
[16] M. J. Stevens and M. A. Campion, "Staffing Work Teams: Development and Validation of a Selection Test for Teamwork Settings," *Journal of Management*, vol. 25, no. 2, pp. 207–228, 1999.
[17] D. J. Leach, T. D. Wall, S. G. Rogelberg, and P. R. Jackson, "Team Autonomy, Performance, and Member Job Strain: Uncovering the Teamwork KSA Link," *Applied Psychology*, vol. 54, no. 1, pp. 1–24, 2005.
[18] M. J. Stevens and M. A. Campion, "The Knowledge, Skill, and Ability Requirements for Teamwork: Implications for Human Resource Management," *Journal of Management*, vol. 20, no. 2, pp. 503–530, 1994.
[19] C. M. Clevenger, R. Valdes-Vasquez, and M. Abdallah, "Implementing a Collaboration Activity in Construction Engineering Education," *New Developments in Engineering Education for Sustainable Development World Sustainability Series*, pp. 35–44, 2016.
[20] D. Forgues and L. Koskela, "The influence of a collaborative procurement approach using integrated design in construction on project team performance," International Journal of Managing Projects in Business, vol. 2, no. 3, pp. 370–385, 2009.
[21] P. P. Charles and C. R. Thomas, "Four approaches to teaching with building performance simulation tools in undergraduate architecture and engineering education," *Journal of Building Performance Simulation*, vol. 2, no. 2, pp. 95–114, 2009.
[22] S. Mollaoglu, A. Sparkling, and S. Thomas, "An Inquiry to Move an Underutilized Best Practice Forward: Barriers to Partnering in the Architecture, Engineering, and Construction Industry," Project Management Journal, vol. 46, no. 1, pp. 69–83, 2015.
[23] I. Kovacic, M. Filzmoser, and F. Denk, "Interdisciplinary Design: Influence of Team Structure on Project Success," *Procedia - Social and Behavioral Sciences*, vol. 119, pp. 549–556, 2014.
[24] L. Debs, M. Shaurette, and D. Wilder, "Undergraduate Opportunities for Construction Students Multidisciplinary AEC Collaboration and Awareness," *2017 ASEE Annual Conference & Exposition Proceedings*.
[25] T. Selman and T. Westcott, "Interprofessional Issues in Construction Education," *Construction Research Congress 2005*, 2005.
[26] A. J. W. Maclaren, M. Wilson, R. Simmonds, A. Hamilton-Pryde, J. Mccarthy, and A. Milligan, "Educating Students for the Collaborative Workplace: Facilitating Interdisciplinary Learning in Construction Courses," *International Journal of Construction Education and Research*, vol. 13, no. 3, pp. 180–202, 2017.
[27] C. Eastman, P. Teicholz, R. Sacks, and K. Liston, BIM handbook a guide to building information modeling for owners, managers, designers, engineers, and contractors, 2nd ed. Hoboken, NJ: Wiley, 2008.
[28] C. Eastman, R. Sacks, and G. Lee, "Strategies for Realizing the Benefits of 3D Integrated Modeling of Buildings for the AEC Industry," in *Proceedings of the 19th International Symposium on Automation and Robotics in Construction (ISARC)*, Gaithersburg, MD, 2002.

[29] M. Shelbourn, J. Macdonald, T. Mccuen, and S. Lee, “Students’ perceptions of BIM education in the higher education sector,” *Industry and Higher Education*, vol. 31, no. 5, pp. 293–304, Aug. 2017.
[30] "Integrated Project Delivery: A Guide", AIA.org, 2018. [Online]. Available: https://www.aia.org/resources/64146-integrated-project-delivery-a-guide. [Accessed: 03- Mar- 2018].
[31] R. Ghassemi and B. Becerik-Gerber, “Transitioning to Integrated Project Delivery: potential barriers and lessons learned,” *Lean and Integrated Project Delivery Special*, pp. 32–52, 2011.
[32] L. Koskela, G. Howell, G. Ballard, and I. Tommelein, “Foundations of Lean Construction,” *Design and Construction: Building in Value*, 2002.
[33] G. Ballard and G. A. Howell, “Competing Construction Management Paradigms,” *Construction Research Congress*, 2003.
[34] K. Keeler, C. M. Clevenger, and R. Atadero, “Framework for Sustainability Challenges within the Building Industry,” in *49th ASC Annual International Conference Proceedings*, San Luis Obispo, CA, 2013.
[35] D. Kolokotsa, D. Rovas, E. Kosmatopoulos, and K. Kalaitzakis, “A roadmap towards intelligent net zero- and positive-energy buildings,” *Solar Energy*, vol. 85, no. 12, pp. 3067–3084, 2011.
[36] R. K. Yin, “Case study research: Design and methods,” p. 18, 2009.
[37] M. Q. Patton, “Qualitative research and evaluation methods,” 2001.
[38] M. Q. Patton, “Qualitative research & evaluation methods: integrating theory and practice,” 2014.
[39] V. Braun and V. Clarke, “Using thematic analysis in psychology,” *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, 2006.
[40] Saldaña J, “The coding manual for qualitative researchers,” 2016.