Solar Decathlon prototypes and their use as post-competition living labs in higher education

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Abstract

Solar Decathlon (SD) competitions offer to participating universities a unique opportunity for introducing into higher education a learning by building approach, with students as important drivers of the whole process. Making Solar Decathlon projects available for an intense after-competition use in the field of teaching and research multiplies their impact in the field of research and education. Within Annex 74: Competitions and Living Labs of the International Energy Agency's (IEA) Energy in Buildings and Communities (EBC) program 22 living lab projects have been analysed, resulting in a detailed description of their contribution in the fields of new educational methodologies and educational materials, impact on higher education curricula and campus as well as the generation of educational networks. Challenges have been identified regarding organization and management, integration into the established academic settings, or sustainability of projects over time, which need to be addressed to integrate more widely living labs as educational tools in higher education.

Keywords: Solar Decathlon, living labs, higher education, solar houses, prototypes

1. Introduction

Solar Decathlon is an international student-centered competition that challenges the selected teams to design, build and operate highly efficient and innovative housing prototypes powered exclusively by solar energy. The positive impact of the event can be prolonged through a well planned and executed after-competition use of the prototype buildings. Tracking projects of earlier competitions shows that many of the projects lacked a solid after-competition use concept, and as a result or could not be reconstructed, or had only a limited lifespan due to a lack of financing, lack of options for a final location or a lack of use and management concept, among others. Making Solar Decathlon projects available for an intense after-competition use in the field of teaching and research multiplies their impact in the field of research and education, especially when used as educational living labs which showcase sustainability strategies for buildings in the field of efficiency, sufficiency and consistency to a broad public in and outside universities.

Living labs can be defined as interoperable collaboration environments supporting user-driven open innovation processes (European Commission 2009). Whereas innovation has been formally a task of individuals as entrepreneurs, a collaborative approach to innovation with multiple stakeholders seems to be a valid and useful option in a world of increasing complexity (Almirall 2009). Open Innovation is defined as an open process where multiple stakeholders collaborate in the process of jointly developing new products or services (Chesbrough 2006). Schuurman et al. (2013) differentiate living labs that support context research and co-creation from living labs focused on knowledge exchange, focused on exploration and not on co-creation. Nevertheless, a review on case studies of living labs shows a huge diversity of concepts and denominations, e.g. applied research centre, showcase home, research laboratory, demonstration building, experimental platform, community lab, prototype home, and observational research facility among others (Masseck 2016).

In the context of Solar Decathlon competitions and higher education, a living lab can be understood as a place where construction, monitoring and evaluation can happen at one place through a multi-stakeholder approach (students, researcher, companies, administration, general public), in a co-creation or open innovation process. This allows for user-centered research under real conditions of use (house occupancy experiments) with real-time

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feedback about performance data, user comfort, user-building interaction, energy management and energy efficiency among others (Masseck 2017). Therefor living labs deriving from the experimental housing prototypes of Solar Decathlon competitions can essentially support the holistic search for truly sustainable housing concepts.

In result, getting inspired by successful examples of post-competition living labs and learning about related challenges and obstacles is a useful contribution for future teams and their stakeholders. The presented research has been carried out in the framework of Annex 74: Competitions and Living Labs within the International Energy Agency's (IEA) Energy in Buildings and Communities (EBC) program.

2. Objectives

The purpose of this research is to make knowledge available about the after-competition use of Solar Decathlon projects as living labs to those with the intention to participate in a living lab competition and those who are on the way to set up their own living lab. The results should allow a compact overview for future organizers and teams about successfully implemented living labs. Main sources have been the in-depth analysis of former editions of the Solar Decathlon, mainly the European editions, but also case studies from the US and Africa, together with survey results and experts' interviews which summarize the stories and experiences behind the projects.

One principal idea of this focus report is to let the project leaders speak about their personal experience in the post-competition use phase of Solar Decathlon (SD) prototypes. These key players have been asked about which outcomes they can report, which successful actions could be implemented and what has been achieved during this important use phase of SD prototypes. On the other side survey and semi-structured interviews allowed gathering information about the challenges they have encountered, the learnings that could be achieved, and asked for recommendations to be given to future SD participants, teams and project leaders.

This research focuses specifically on living labs which are used for educational purposes in their after-competition use phase, as this allows a prolonged positive impact in the field of higher education, with the possibility to train and educate whole generations of future professionals in and around the prototypes.

3. Methodology

This research has been structured in two parts: Online research regarding the current location, use and ownership of former Solar Decathlon (SD) projects on one side, and a survey and interview-based research on specific projects based on direct communication with their current directors on the other. Projects from the original US competition since 2002, the Solar Decathlon Europe (SDE) competitions since 2010, and the first Solar Decathlon Africa competition (SDA 2019) have been taken into consideration. A total of 152 projects from US competitions since 2002 have been revised regarding their post-competition use as educational living labs. 25 projects have been selected in a first search for current operative living labs related to education. 15 projects have been further analysed and 11 resulted in educational living labs with a high interest for this research. On a European level, competition participants since 2010 have been listed and searched through the corresponding webpages, especially the www.building-competition.org website, supported by the Annex 74 work. 12 potential current operating educational living labs have been identified and after a deeper analysis, 9 have been selected as educational living labs with a high interest for this research. Regarding the Solar Decathlon Africa (SDA2019) competition 4 potential living lab projects have been identified and 2 projects could be further analysed and information about current activities has been facilitated for this research.

After the selection of potential interesting projects and based on the information encountered, a data sheet has been drafted based on previous research of the author (Masseck 2016) with a summarized description of each of the projects, pictures of its current state, contact details to owners or operators, as well as links to publications of current activities. In parallel an educational living lab survey has been designed with 4 blocks of questions. A first block focuses on concepts of each educational living lab, asking for the educational methodologies applied, educational materials generated, target groups who benefit from the project, its impact on higher education curricula and campus, and about new educational networks which could be generated. In a second block of questions project leaders have been asked for a critical view on their living lab project, focusing on the challenges and obstacles encountered in the 3 areas of concept and implementation, costs and maintenance, and operation and outcomes.

Based on the received survey answers, a semi-structured interview has been requested to the project leaders, and 7 interviews could be held, gathering valuable additional information about specific success stories as well as individual drawbacks of projects, which could not be collected through the standardized survey.

4. Results

4.1. The post-competition lifespan of Solar Decathlon prototypes

Project leaders have been asked to estimate the foreseen lifespan of their projects, and answers have been given between 3 years and "no end foreseen", but an average lifespan between all documented projects can be estimated in around 5-6 years, with the oldest ones operating over 14 years and the newest ones recently starting their post-competition use phase.

It is worth to mentions that lifespan is an important aspect for the payback of energy, effort, and money of a project after a Solar Decathlon participation, but the intensity of use must also be taken into consideration for evaluating the overall success of the after-competition use. Some prototypes show very low activity during a longer period after competitions, before being activated and used again. Others get immediately reconstructed and used for ongoing research or dissemination activities. This often depends on how the after-competition use phase has been planned beforehand and important aspects like final location, use rights, maintenance and management have been clarified and corresponding agreements have been closed among partners.

4.2. Educational methodologies and teaching formats applied

Due to the character of the Solar Decathlon competitions as a student-driven event, which allows in-depth learning by planning, building, and operating real prototype buildings, all projects are linking teaching, research and innovation during their development and execution.

In the after-competition use phase some projects seem to focus more on research activities, others foster specifically educational initiatives, and many of them maintain a mix of both. Regarding the specific use for education, online research and survey results allow the following description of the post-competition use of projects:

- Prototype exploration through students (materials, systems, concepts) (20 out of 22)
- Measurements and evaluation of the prototype in-situ (thermal comfort, system performance, bioclimatic solutions, comparison of measurements and simulation) (20 out of 22)
- Seminars/workshops inspired by the special place (18 out of 22)
- Co-creation initiatives for new projects, bringing together different stakeholders (students, researchers, companies, administration…) (10 out of 22)

4.3. Educational materials generated

A major outcome of Solar Decathlon projects are project documentations, monitoring results and results of testing of innovative materials, components and installations regarding their energetic, constructive and aesthetic performance. Beside these technical documents, many dissemination materials are generated like leaflets, video presentations and recorded guided visits, as well as open online courses (MOOCs), virtual or augmented reality presentations among others.

Online research and survey results allow the following description of generated educational materials:

- Documentation of the prototype used regularly as case study for teaching (16 out of 22)
- Articles published about the prototype (5 out of 22)
- MOOC course developed in or around the prototype building (2 out of 22)
- Augmented / virtual reality representations (3 out of 22)

4.4. Positive impact on higher education curricula and campus

Solar Decathlon projects do have a major impact on a faculty due to its duration from start to competition of around 2 years, the intensity of workload for students and teaching staff, as well as the high visibility of the project in and outside university.

Online research and survey results allow the following description of positive impact on higher education curricula and campus:

- Creation of new infrastructure (19 out of 22)
- Creation of new forms of teaching focused on real project and construction (12 out of 22)

Project leaders describe the impact on HE curricula as following:

- *As I have presented the projects in my lectures at the faculty, most students now know them. What works particularly well are three films we have made: two mini-documentaries and a mini-film. Students and people across the world love these and share them in social media.*
- *The main impact on our curriculum is an increased ratio of practical studies and experiments with a real building. The SD prototype is now used as a seminar room, in which we can descriptively discuss with the students about building energy efficiency, indoor climate and the usage of renewable energy for buildings.*
- *Our school is focus on acting on the reality. This kind of projects allows us to inspire to the students in order to go further than the typical classes.*
- *The project helped us to identify the strengths and weaknesses of the different courses of the faculty, highlighting the need for more in-depth interdisciplinary teaching. For this purpose, the teaching staff must be trained or have an interdisciplinary background. This is one of the best ways to give the different classes and respond to the questions and concerns of students.*
- *In general, the project has reinforced the idea of mixing students from different disciplines (architecture, civil engineering and environmental engineering) under a single course type workshop.*
- *There is more room now for collaboration between different disciplines and more collaboration with companies*
- *Our university is convinced of the educational value of teaching by project.*
- *The students and professor of the project continue to work together within the framework of an association they created and new research subjects related to the theme are launched: PVT, Phase change materials, ...*

4.5. New educational networks generated

A Solar Decathlon participation is for universities a major opportunity for building up networks of students, researchers, companies and institutions, which support the project during development and construction through contribution of material and know-how, participation in linked research projects or funding, among others. These networks across disciplines are useful for education, research and market-uptake objectives, according to the interest of each partner. Networks often persist in the post-competition phase and are valuable outcomes of the competition for universities on medium and long-term.

Online research and survey results allow the following description of positive outcomes regarding the generation of educational networks:

- Creation of student networks which persist in the post-competition phase and often result in a common professional project like a start-up or a cooperative (15 out of 22)
- Creation of research networks which allow generating research and innovation outcomes in and around the prototypes (6 out of 22)
- Creation of institutional networks which keep supporting the project in the post-competition phase, a new participation in a later competition or a similar project on local or regional level (7 out of 22)

In this context it is worth to mention the specific UPC experience during Solar Decathlon Europe Competitions since 2010. The UPC prototypes LOW3 (SDE 2010) (Figure 1), e(co) (SDE 2012) (Figure 2), Ressò (SDE 2014) (Figure 3), and TO (SDE 2019) (Figure 4), resulted in the generation of cooperatives of former team members, creating sustainability focused architecture practices, as well as prolonged collaboration as operators of the respective prototypes together with public administration and university as stakeholders.

LOW3 (SDE 2010) allowed to generate a first collaboration of second- and third-year students at the Vallès School of Architecture (ETSAV) of UPC. 2 years later these students formed a new competition team for SDE 2012, using LOW3 as on-campus infrastructure for their meetings and networking activities.

E(co) (SDE 2012) has been the core project that initiated the foundation of the Arqbag cooperative (www.arqbag.coop), which at the date of this report states of 7 founding members and 3 collaborators, developing sustainable architecture projects with a specific focus on the social innovations like neighborhood facilities and co-housing projects. Some Arqbag members are also part of the current teaching staff at ETSAV (UPC), and through this link transmit their knowledge, attitude and experience gained in the last years to following generations of students.

Ressò (SDE 2014) gave place to the association Accio-Ressò, constituted by former SDE students, which after the competition in 2014 directed the re-building and implementation process of Ressò as a neighborhood facility at Sant Muç (Rubí) in cooperation with the city council of Rubí. Ressò since then has served as a platform and space for multiple activities which contributed to improve the living quality of the neighborhood. It has served as a multifunctional space for educational activities regarding energy efficiency, it supported the implementation of energy efficiency projects in the neighborhood, and it hosted other activities like yoga classes or similar offers for a neighborhood which lacks this kind of offers. Administrative issues led to the temporary closure of the installation at the time of writing, but according to the drivers of the project, a re-activation is planned.

TO (SDE 2019) is the newest project at UPC and has been rebuilt at the UPC Campus South Diagonal in the beginning of 2020, with the aim to start activities as a Living Lab that allows guided visit and educational initiatives for UPC students and the general public. The project has received support for this post-competition use by the city council of Barcelona and the Barcelona Energy Agency. Due to the pandemic outbreak, specific activities could only start from early 2022 onward. Currently the house is occupied by students who live and evaluate the house under real conditions of use.

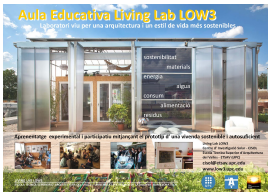

Fig. 1: LOW3 (SDE 2010) (Picture: Torsten Masseck)

Fig. 2: (e)co (SDE 2012) (Picture: Arqbag)

Fig. 3: RESSÒ (SDE 2014) (Picture: Torsten Masseck)

Fig. 4: TO (SDE 2019) (Picture: Torsten Masseck)

Learnings for a successful after-competition use of SD prototypes can be especially achieved through a critical review of processes, obstacles and success stories linked to specific projects. A critical analysis by project leaders themselves and specific recommendations out of their experiences made, are most valuable in this context.

4.6. Concepts and Implementation

The after-competition use of Solar Decathlon prototypes requires a concept for the implementation of prototypes, especially a place where to rebuild the house, with the possibility to stay for a certain period. Also, entities must be linked for this new phase of operation and exploitation through agreements and contracts.

Project leaders reported the following aspects and experiences through the survey and personal inter-views:

- *Getting it rebuilt after the competition has proved to be very hard compared to the speed of construction during the competition, because everyone was tired and busy again with other things, and the weather was bad during winter. It was a struggle. We have also had trouble getting things arranged regarding the hand-over.*
- *It is very hard to find a building site on the university campus where a SD prototype can stay for several years (this process had a duration of 3 years in our case)*
- *To re-build it again was an achievement itself. And we started pretty well with neighbors. But city hall did not allow them to self-manage the space.*
- *The main difficulty is the situation (the use of the land) and the creation of a convention with the owner of the land. In this case the convention defines that the cultural exploitation of the prototype is in the hand of one entity, and the maintenance (with associated costs) is of … the two institutions that use it as research infrastructure.*
- *It requires a different attitude from teachers*

- *Here are some obstacles and drawbacks when using our SD prototype post-competition as an educational living lab: the project is too far from our university, there is a lack of operating budget and also a lack of a regulatory framework for the operation of the project: after two years an agreement is still being prepared*

These quotations and the additional information given through interviews, as well as the knowledge about projects which suffered from the lack of adequate location for their after-competition use and therefore had to be dismantled, show that a clear planning for location and after competition use is essential.

4.7. Costs and Maintenance

Cost and Maintenance of prototypes in the post-competition use phase are critical aspects. After competition end resources are often limited, many teams even have accumulated debts during the whole process of development, construction and competition, and new funding is necessary to cover cost for reconstruction at a new location.

Project leaders reported the following aspects and experiences through the survey and personal interviews:

- *Arranging well that one party can do the maintenance, operation and eventual demolition was a struggle. The money has gone and parties taking over usually want to be paid for it, which in our case came down to dodgy arrangements for which the faculty eventually paid the bill. Better to have this arranged beforehand with people who are trustworthy.*
- *The SDE competition format doesn't really consider the necessary costs for the reconstruction in the post competition phase.*
- *The maintenance is a big issue because city hall does not want to spend money regularly. The re-assembly was relatively easy. The maintenance is much more complicated.*
- *Who takes care of it and who pays are the key questions. A usage convention has solved this.*
- *It is difficult to find a viable business model.*
- *Lack of operating and maintenance budget for the project.*

These testimonies focus on the importance to secure financial resources for re-construction forehand. Estimating the maintenance costs of the prototype in the post-competition phase and clarifying who will take them over and for how long are key questions to be approached as early as possible.

4.8. Operation and Outcomes

Operation in the post-competition phase might be critical. New agents might have taken over the responsibility of the project, or shared operation is agreed among several entities. Daily operation also requires personal and material resources as well as knowledge about the prototype itself. All this leads to critical situations of the operation and exploitation of prototypes which must be handled and solved.

Project leaders reported the following aspects and experiences through the survey and personal inter-views:

- *You definitely need partners in the administration of your institution which love the project.*
- *The operation was thanks to good will from the team members and illusion from neighbors.*
- *Ensuring that the prototype is operational for research purposes and that the sensor data is correctly uploaded to the database etc. is a special challenge. In general, the facility management of the prototype created for a temporary competition is not an easy task due to the "test" component of its creation.*
- *Finding a balance between the needs of education and the needs of companies.*
- *Lack of a regulatory framework for the operation of the project: after two years an agreement is still being prepared.*
- *Overall, it can be stated that the following aspects are most relevant: Plan operation beforehand and clarify administrative support as early as possible to avoid de-lays due to necessary negotiations and missing framework. Consider that technical challenges might appear, as prototypes are student built and might need improvement for long-term operation and monitoring.*

According to the testimonies it results key to plan operation beforehand and clarify administrative support as early as possible to avoid delays due to necessary negotiations and missing framework. Furthermore, it must be considered that technical challenges might appear, as prototypes are student built and might need improvement for long-term operation and monitoring.

4.9. Integration in academic curricula

Solar Decathlon prototypes in their post-competition use phase con be valuable objects and places for new teaching formats, interdisciplinary educational formats, and innovative experience-based learning initiatives. Nevertheless, existing higher education curricula are generally little flexible regarding innovations in form or content.

Based on the survey and personal interviews, project leaders described their experience regarding the integration of Solar Decathlon prototypes into the academic curricula as following:

- *The Idea is to integrate the prototype in some specific subjects, but COVID postponed all.*
- *I use the prototype examples in my lectures, and they are used for tours of new students coming in in August, but furthermore, there is no embedding in the curriculum. We do ask students to connect graduation projects to the prototypes, which has been done regularly.*
- *This worked very, very good in our case. No challenges.*
- *Not much. One studio was focus on this reassembly for a year and it helps to do the next SDE edition.*
- *The prototype has been very much exploited during its elaboration so at a curricular level the interest has decreased, but the willingness to make use of the prototype for a facility management via digital tools such as the BIM is now up to date.*
- *It takes time.*
- *The project is too far from our university.*

These testimonies allow drawing the conclusion that it is important to integrate new teaching based on living labs in academic curricula as early as possible, as little flexibility exists generally for adapting higher education curricula to new academic formats or contents. It is also mentioned that reconstruction of SD prototypes requires time and resources which might delay the readiness for post-competition uses, but also opens the possibility to consider reconstruction and operation itself as an academic activity to be embedded in HE curricula. Finally, digital tools (MOOCs, BIM) might open up possibilities for additional use in higher education curricula when academic interest in the SD prototype itself decreases over time due to loss of novelty.

5. Conclusions

The explanations given by project leaders about the post-competition phase and resulting initiatives and activities give testimony about the prolonged positive influence of Solar Decathlon prototypes, when implemented properly for a post-competition use as living labs.

It shows that the generation of networks among the huge diversity of participants is one of the most interesting outcomes which benefit all type of stakeholders of a project. Companies get into touch with potential future collaborators, Higher Education Institutions (HEI's) build up or improve their university-industry relationships and their collaboration with public institutions, students build up interdisciplinary networks that often allow generating a core group for a start-up initiative, or any other type of cooperative enterprise linked to the project, but also beyond. Educational networks based on a university project evolve many times towards professional relationships over time.

After describing the diverse impacts achieved, obstacles encountered, and conclusions drawn by the interviewed project leaders it can be stated that there also exists a certain pressure for teams to convert SD projects into high impact post-competition labs and only a view really succeed in achieving a high visibility and high impact through a holistic implementation and a strong concept.

Nevertheless, beyond the visible part of a post-competition use as living lab, almost all projects generate a huge number of distributed, small-scale benefits, which are difficult to detect and to document, but which exist, like new professional projects, e.g. cooperatives or students getting employed by companies which supported and collaborated in SD projects, or simply the human networks generated.

Solar Decathlon projects are generally milestones for faculty advisors which have a high component of stress, risk, but also rewards as researchers and lecturers. Struggle with after-competition use seems to be typical, with conflicts to solve regarding the available work force, because students are exhausted or leaving university, lack

of financial resources with many teams come back from the competition without resources left or even with some debts to deal with, and a lack of organizational support e.g., for finding appropriate location and operational support at university.

The analysis of 22 projects allowed a detailed description of their contribution in the field of new educational methodologies, educational materials, impact on HE curricula and campus as well as the generation of educational networks. Projects often generate participatory teaching and learning processes in interaction with many other relevant societal stakeholders. The analyzed living lab projects show the diversity of possible approaches and their potential to create impact, but also allow identifying a series of challenges of the concept regarding organization and management, integration into the established academic settings or sustainability of projects over time, which need to be addressed to integrate more widely living labs as educational tools in higher education.

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