Energy performance analysis in interdisciplinary education – Lessons learned from a simulation-based teaching approach

Emilie Nault[1], Sergi Aguacil[2], Emmanuel Rey[2] and Marilyne Andersen[1]

[1] Laboratory of Integrated Performance in Design (LIPID), Ecole polytechnique fédérale de Lausanne (EPFL), Lausanne, Switzerland;
[2] Laboratory of Architecture and Sustainable Technologies (LAST), Ecole polytechnique fédérale de Lausanne (EPFL), Lausanne, Switzerland

Abstract: The education of building practitioners is challenged by the increasing need for interdisciplinary profiles in the professional practice. To progress toward the goal of a sustainable built environment, a common language must be shared among fields such as architecture and engineering, between which persisting barriers remain. This paper presents an interdisciplinary teaching approach that aimed at getting architecture and engineering students to develop – around a unique case study evolving in parallel to the course – an understanding of the relationships between architectural and constructive aspects, simulation parameters, and energy and thermal comfort performance. Lessons learned from this experience include: the (in)adequacy of using an advanced software (EnergyPlus) imposing a steep initial learning curve, the limitations of working on a case study whose scope extends beyond the context of the class, and the conflict between achieving pedagogical objectives and valuing 'real-time consultancy' work in an evolving project. These challenges however seem to have been key to enable students to develop a solid knowledge of the concepts and technical language, as well as strong simulation competences, pushing them to embrace the added value of interdisciplinarity possibly more effectively than if a theoretical exercise had been used.

Keywords: interdisciplinary education, simulation-based exercises, energy performance

Introduction

The evermore demanding requirements in building design have led to the emerging paradigm of interdisciplinarity in the professional practice. As such, education faces a great challenge due to its fundamental role in preparing future professionals, who must acquire an in-depth knowledge in their own domain, while also being able to interact with other disciplines.

Despite a recent shift in the perception that environmental design and energy efficiency fall within the realm of architectural education, as opposed to being reserved to technical/engineering studies, this realization has yet to be reflected in the architectural curriculum (Alsaadani and De Souza, 2012; Altomonte, 2009; Reinhart et al, 2012). To achieve this, Altomonte (2009) argues for an integrated approach combining a theoretical background, empirical knowledge and evidence-based learning, and analytical tools and simulation techniques, to provide students with the ability to translate technical language (based on physical rules) into design concepts.

Future building professionals must, through proper education, assimilate concepts that often remain abstract and theoretical, in order to comprehend the extent of the impact of their design decisions on different facets of a design's performance. To do so, the inclusion of

Building Performance Simulation (BPS) is seen as essential to push the knowledge beyond simple rules of thumb and develop the competences to self-evaluate these impacts using appropriate methods and tools (Alsaadani and De Souza, 2012; Reinhart et al, 2015). In addition to the recurrently stated reasons behind the limited uptake of BPS in architecture practice, i.e. their inadequacies within the design process, Alsaadani and De Souza (2012) highlight a set of non-technical, socio-cultural barriers linked to stereotypes, in turn related to education; *"following elitist philosophical traditions and purist aesthetical paradigms do not allow scope for numerical performance indicators to validate design-decisions"* (about architectural education in the United Kingdom).

Focussing on increasing the uptake of BPS in architectural practice and education, Reinhart et al (2015) proposed a refined version of a simulation game developed earlier (Reinhart et al, 2012) based on the Radiance/Daysim and EnergyPlus tools. They tested it in a semester-long introductory building science class for architecture students. They concluded that this type of evidence-based and self-understanding approach, where students realize they can conduct a simulation-based analysis by themselves, can contribute to the necessary paradigm shift toward integrating sustainability principles from the early design stage.

Sharing these motivations and purpose, this paper describes the lessons learned from a teaching experience in a class mixing graduate students with an architectural and engineering background. The adopted approach, strongly relying on hands-on simulation-based learning, is presented along with its assessment using diverse course outcomes including a qualitative survey filled by the students.

Course curriculum and teaching method

Context

The course which is the object of this paper, called *Architecture and Sustainability: performance studies*, is given to Master's students within the School of Architecture, Civil and Environmental Engineering (ENAC) at the Ecole polytechnique fédérale de Lausanne (EPFL), Switzerland. This course of 4 ECTS credits runs over 12 weeks, with a 4-hour class per week, mixing both lectures and exercise sessions.

A specific course curriculum was developed for the fall semester of 2016. For this special edition, it was decided to link the course to the ongoing design of the Swiss pavilion for the Solar Decathlon (SD) competition of the 2017 United States edition (SLC, 2017). The course, structured so as to follow the evolution of the project, focused on three main themes: passive design strategies, followed by construction materials and their embodied energy, and concluding with the active systems (i.e. HVAC). This paper covers the first and last topics, which both relied on the simulation tool and were led by the same instructors.

The group of registered students was composed of 14 architects and four engineers from three different engineering programs – civil, energy and sustainability management, and environmental sciences – for a total of 18 students. Students worked in groups of three, which stayed the same throughout the semester. All students stated not having any prior experience in building performance simulation. Despite the larger number of architects, the fact that both disciplines were present reflects the aspiration for this course to be interdisciplinary. This characteristic was strongly sought through the objectives and adopted teaching method, further described below, and reflected by the interdisciplinary background (in architecture, engineering, and building physics) of the instructors.

Objectives

The goal of the course was two-fold; priority was placed on (i) enabling the students to reach a level of understanding and competences that could, ideally and quasi-simultaneously, (ii) support the decision-making of the competition team during the design of the pavilion. Specifically, we aimed at getting the students to:

- assimilate concepts that are often only addressed through theory and therefore remain abstract in the design context;
- understand and be able to use terms often conceived as being 'reserved' to other disciplines or experts in the field of building performance and simulation;
- grasp the importance of their design decisions by being able to investigate by themselves the impact of such decisions on different performance criteria;
- make links between numerical design parameters (required for simulation) and concrete architectural products and solutions.

These objectives were at the core of our teaching method, which consisted in short theoretical lectures, followed by demonstrations of the concepts using the simulation tool – EnergyPlus (Crawley et al, 2000) through the DesignBuilder (DB) interface (DB, 2017) – which students then had to use to perform exercises using the Swiss pavilion as a case study.

Case study

Figure 1 illustrates the model of the pavilion in its status as of the beginning (left) and end (right) of the semester. This case study is not only particular due to its temporally dynamic status, but also since it will move geographically, from the cold and dry climate of Denver (location of the competition) to the warmer and more humid climate of Fribourg (Switzerland), where it will be rebuilt and will remain. The exercises described below were therefore structured by taking into consideration the evolution of the project as well as the two climates.
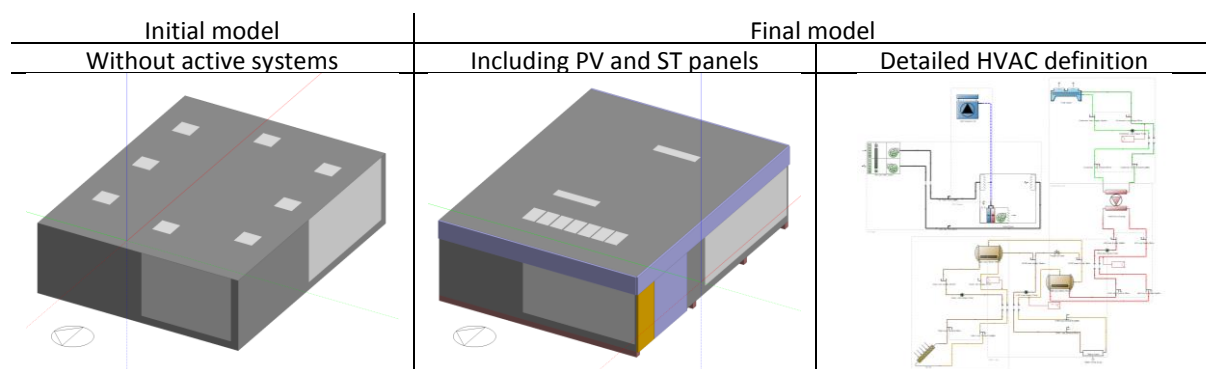
Initial model	Final model	
Without active systems	Including PV and ST panels	Detailed HVAC definition

Figure 1. DB model of the pavilion according to its status at the beginning (left) and end (right) of the course.

Simulation-based exercises

Through a series of exercises, out of which the three main ones (in terms of scope and weight) are here detailed, students were asked to investigate the impact of passive design strategies, before working on the active systems, including solar technologies. This hierarchy was motivated both by the project's natural evolution and by the principle put forward that passive strategies should be considered first to minimize the energy demand, before deciding on how to best supply the required energy.

In the first exercise, students were provided a prepared DB model, an Excel file containing template tables and a Word document with a simple report template. They had to analyse, through an iterative, one-at-a-time parameter modification procedure, the effect of

passive design strategies on the annual energy performance and hourly thermal comfort over one month (October, time of the SD competition) in the climate of Denver. The pavilion and the variations in the design parameters are depicted in Figure 2.

In the second exercise, they were asked to propose a compromise design scenario for the two climates, starting with a new version of the DB model, updated to reflect the status of the project from the competition team's side. By the third exercise, passive design aspects had been defined and students were asked to investigate the link between the settings of the active systems and the performance in terms of energy consumption and thermal comfort. Once again, the simulation model, integrating a base case active system, was provided.

a	10 – 15 – 25 – 30 – 35 cm
b	Incandescent – LED (with and without control)
c	Single – Double – Triple (with and without blinds) for horizontal and vertical windows
d	0 – 90 – 180 – 270°
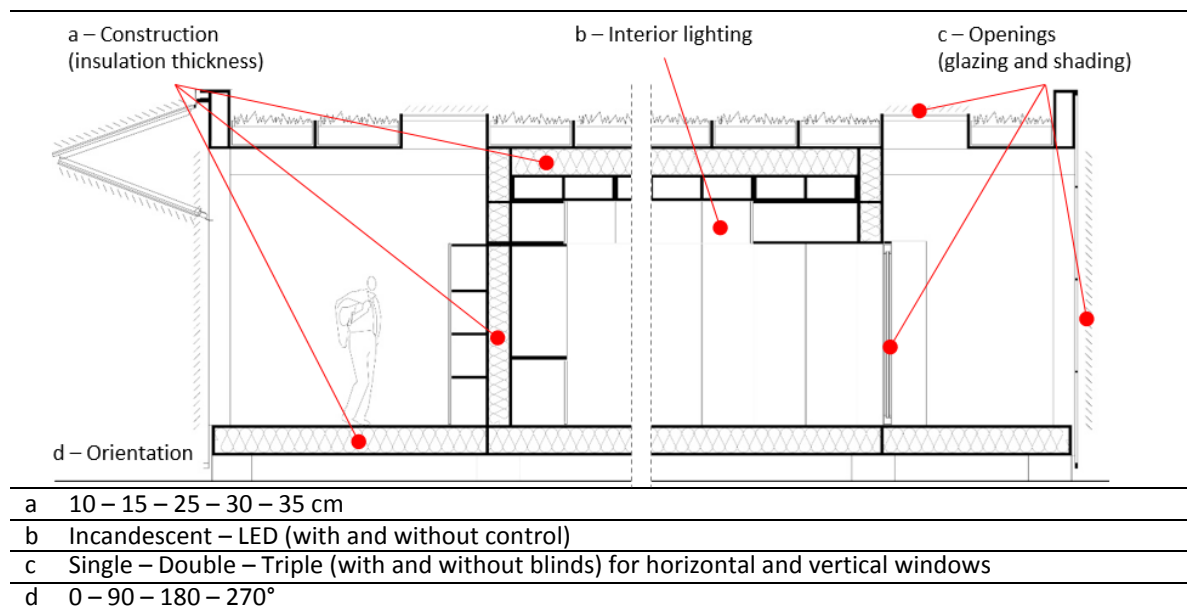
Figure 2. Design parameters modified (one at a time) in exercise 1, according to the options listed.

Assessment of the teaching method

To gather some insights on the level of success of this teaching format, three different outcomes were analysed: (i) the exercise-related reports submitted by throughout the semester, (ii) results from a knowledge quiz administered to the students near the end of the semester, and (iii) responses to a survey aiming at gathering their feedback on the course. Although not detailed in this paper, it is to note that students were evaluated not only on their reports, but also on two oral presentations (related to the exercises) given at the middle and end of the semester. Moreover, an informal exchange between instructors and students following the first presentation was useful in getting an intermediate feedback on their experience and, in reaction, adjust our approach for the remainder of the semester.

Student reports

Students were asked to submit a written report in association to each of the three main simulation-based exercises conducted throughout the semester. Reports contained a description of their analysis and thought-process along their iterative simulation-based workflow. A thorough review and correction of these documents by the instructors revealed the level of assimilation and understanding of the students about the specific material covered in each exercise and related theoretical lecture. The fact that these reports were submitted all along the semester provided us with a temporal view of their learning process.

Knowledge quiz

During the penultimate class, students were asked to answer an anonymous online quiz, containing questions related to the material covered, excluding the themes falling outside the scope of this paper (such as the embodied energy, as mentioned earlier). The quiz progressed, in accordance with the course's structure, from passive design aspects to questions related to active systems. A sample of the questions along with the students' answers is presented in the results' section. Once all students had completed the quiz, the instructors went over each question with the whole class, graphically displaying the answers that had been collected in real-time using the Google Forms service. Through this exercise, the instructors could simultaneously identify and clarify the topics that were misunderstood by the students.

Survey

The third means for collecting information on the course and its format was a qualitative survey, defined in collaboration with a counsellor from the Teaching Support Centre at the EPFL. It consisted in a series of 23 statements with which students had to specify their level of agreement on a 5-point Likert scale with the following options: strongly agree, agree, no opinion, disagree, and strongly disagree. The statements included generalities applicable to any course, for instance about its organization, the resources provided, and the students' attendance, as well as more course-specific affirmations on its interdisciplinary nature and on the adequacy of the software and case study employed. Examples are presented in the next section. The survey was given in paper form during the last class, which is when students had to give their final presentation. Results were collected and analysed by the counsellor before being transmitted to the instructors in a report and during a face-to-face discussion.

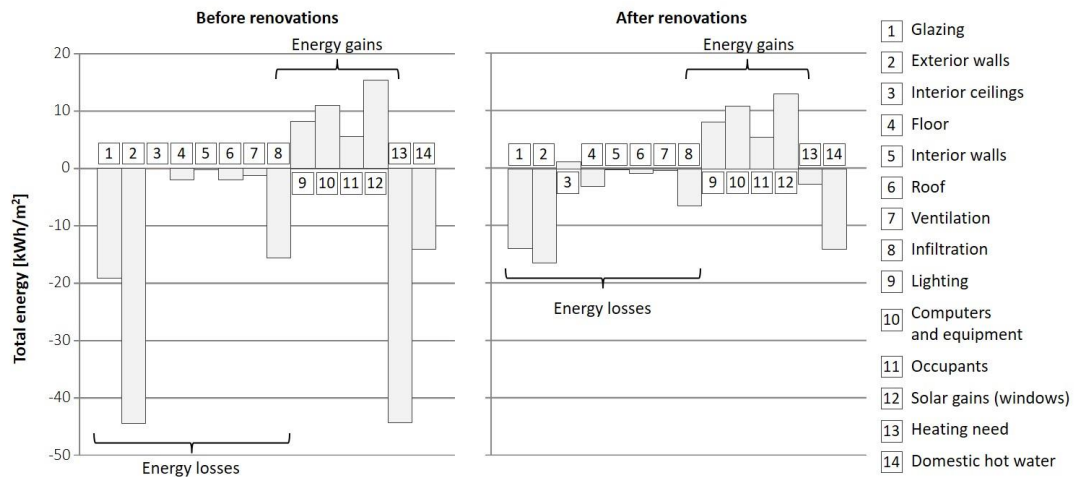## Results of the assessment

Student reports

Throughout the semester, we observed improvements in the reports regarding the exactitude of the terminology used (e.g. technical terms) and the rigor and depth in the explanations of specific simulation results. Moreover, despite being given a detailed template of the simulations cases only for the first exercise, students quickly adopted this structured workflow in the subsequent exercises, which demonstrated their understanding of the need for (and benefits from) following a clear protocol when conducting simulation iterations.

Their proposed solutions were systematically better, in terms of energy and thermal comfort performance, than the provided base case model. Depending on the level of freedom given in each exercise, the strategies put forward by the groups differed, with some pushing their analysis on a specific concept (e.g. thermal inertia) beyond what had been covered in lectures and to a level that challenged the instructors' own knowledge of the simulation tool. Given the progress and interest of the students, the initially planned scope was extended to cover advanced concepts related to active systems and renewable energy technologies, such as the temperature and size of the hot water tanks on the demand- and supply-side.

Knowledge quiz

Example multiple-choice questions included in the quiz can be seen in Figure 3, along with the selected answer(s) from the students. Blue and red bars respectively represent correct and incorrect answers. Although students were not graded on the quiz, marks were attributed to compute the success rate for the purpose of the current assessment.

The average grade for the class is of 79.4%. Students were slightly more successful in questions related to passive design aspects (86.5%), than those about active systems (74.7%). We believe these results reflected well the level of understanding of the students, given the fact that possibly influential factors, such as time limit and stress related to being judged, were not present in this evaluation format.
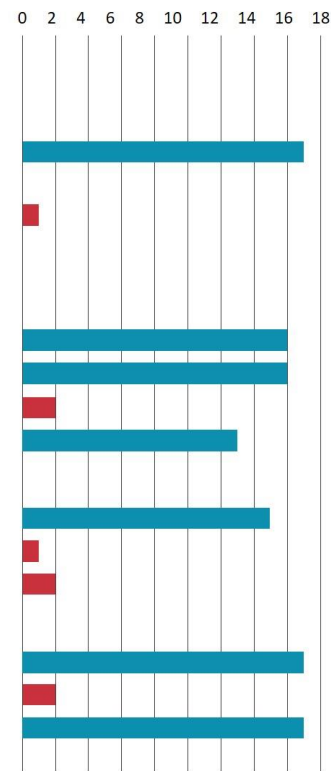

Figure 3. Students answers to four example questions from the knowledge quiz. Blue and red bars respectively represent correct and incorrect responses. Overall, a high success rate was observed.

Survey

A sample of the survey questions – the main course-specific ones – and the corresponding distribution of answers are shown in Figure 4. A majority of students agreed with the adequacy of the simulation software as a tool that enabled them to better assimilate the concepts (Q1), and with the added-value of learning through a real and complex project (Q2). However, they were split over the belief that they would have learned better by working on

a case study 'frozen in time' (Q3). It is to note that for that statement, responses should be interpreted as inverted, disagreeing being considered as positive in this context.

The following two questions (Q4-Q5) both concerned the interdisciplinary aspect of the course. While over 80% of the students agreed with the usefulness, for their professional future, of having been exposed to other disciplines, almost 40% thought the interdisciplinary aspect had not been well integrated in the course. The relevance of the course as well as it's distinction from others were highlighted by the spread of answers to Q6 and Q7. Finally, a majority of students thought the work load to be too important given the allocated credits.
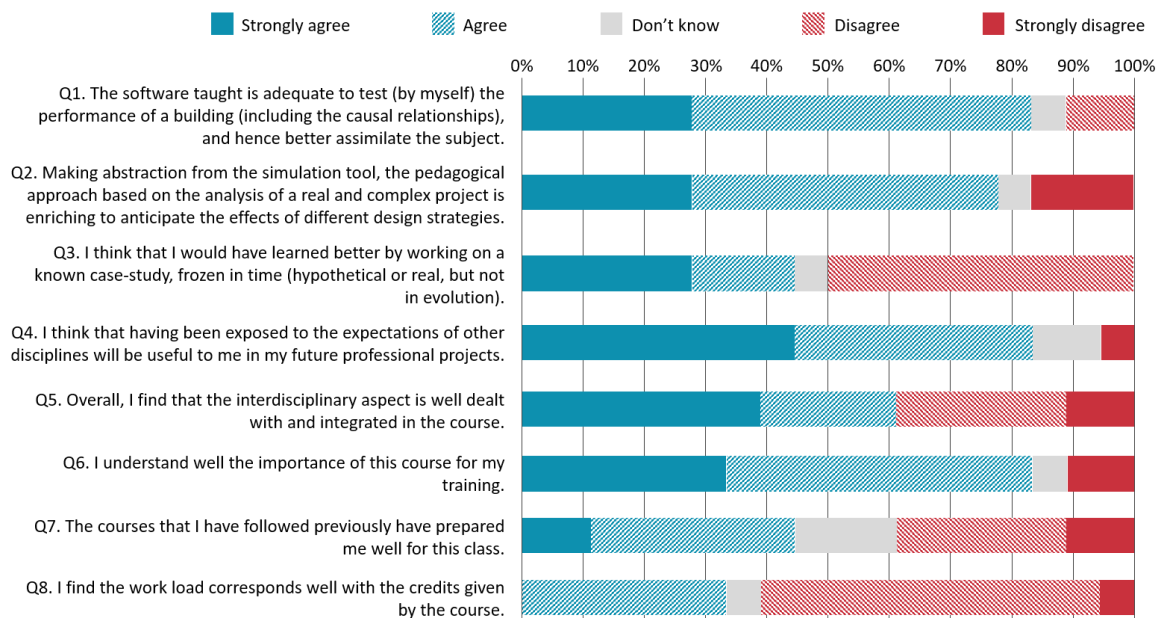

Figure 4. Sample results from the survey. These 8 questions (out of 23) are some of the most course-specific.

Discussion

From the above outcomes, we observe that a large majority of students were able to reach a deep level of knowledge and understanding of the concepts and associated language, more so than in previous editions of the course according to the instructors also involved then. However, the attempt at bridging an educational curriculum and a consultant-like activity generated a challenging situation for the students, who seem to have 'suffered' from the dynamic feature of the case study and the heavy work load associated to the iterative simulation tasks, exacerbated at times due to changes in the project. A certain frustration caused by the lack of perceived impact on the design process could also be detected. Certain hindrances should therefore be anticipated if a similar teaching approach was to be adopted in a future edition of a comparable course.

We believe that the combination of an evolving case study and a complex simulation tool generated a context in which students were able to reach a deep level of understanding of the taught (and self-taught) concepts, as well as develop advanced simulation capacities. The complex capabilities of the software proved to be essential to allow students to conduct the analysis of a project beyond its early-design stage and to get an understanding of the impact of specific design decisions. We believe a simpler and more closed (i.e. black-box-like) software would have prevented this level of fine-tuning, which was also achieved due to the dynamic characteristic of the case study. This outcome strongly defies the often preconceived idea that BPS is out of the realm of architects. It however remains conditional to a high level

of knowledge and support from interdisciplinary instructors. The preparation for anticipating a variety of simulation pitfalls and bugs should moreover not be underestimated.

Although the model of the pavilion was systematically updated throughout the semester, discontinuous communication between the instructors and the competition team about design decisions made led to occasional mismatches between the 'real' project and its educational counterpart. These circumstances in turn affected the potential of the students' work to effectively influence and support the decision-making process. Measures should therefore be taken to mitigate the risks of communication barriers and of a relative lag in the timelines and scopes.

Conclusion

This paper presents the outcomes from a simulation-based teaching experience with students from different disciplines working around a multi-functional pavilion, itself evolving in parallel to the course. Our interpretation of the student reports, knowledge quiz, and qualitative survey of the course highlight a strong level of achievement of the pedagogical objectives. By assimilating the technical, performance-related language and concepts, students were able to surpass the boundaries traditionally instilled by their specific backgrounds.

Further work within educational programs should be made to establish links between such classes and design studios, promote an interdisciplinary curriculum, and fully integrate performance considerations throughout the creative design decision-making process. Greater attention should be placed on teaching students to 'justify' their design intentions, while fostering a climate of respect between architects and engineers through shared competences and language.

Acknowledgments

References

Alsaadani, S., De Souza, C. (2012). The social component of building performance simulation: Understanding architects. In: *Building Simulation and Optimization Conference 2012*, Loughborough, UK, 10 - 11 September.

Altomonte, S. (2009). Environmental education for sustainable architecture. *Review of European Studies*. Vol. 1, No. 2.

Crawley, D.B., Pedersen, C.O., Lawrie, L.K., Winkelmann, F.C. (2000). EnergyPlus: Energy Simulation Program. *ASHRAE Journal*. 42, 49–56.

DB (2017). DesignBuilder Software v5, Available: http://www.designbuilder.co.uk/ [15 March 2017].

Reinhart, C.F., Dogan, T., Ibarra, D., Samuelson, H.W. (2012). Learning by playing – teaching energy simulation as a game. *Journal of Building Performance Simulation*, 5, pp. 359-368.

Reinhart, C.F., Geisinger, J., Dogan, T., Saratsis, E. (2015). Lessons learned from a simulation-based approach to teaching building science to designers. In: *Building Simulation Conference*. Hyderabad, India, 7 – 9 December.

SLC. (2017). Swiss Living Challenge. Available: http://www.swiss-living-challenge.ch/en/ [15 March 2017].