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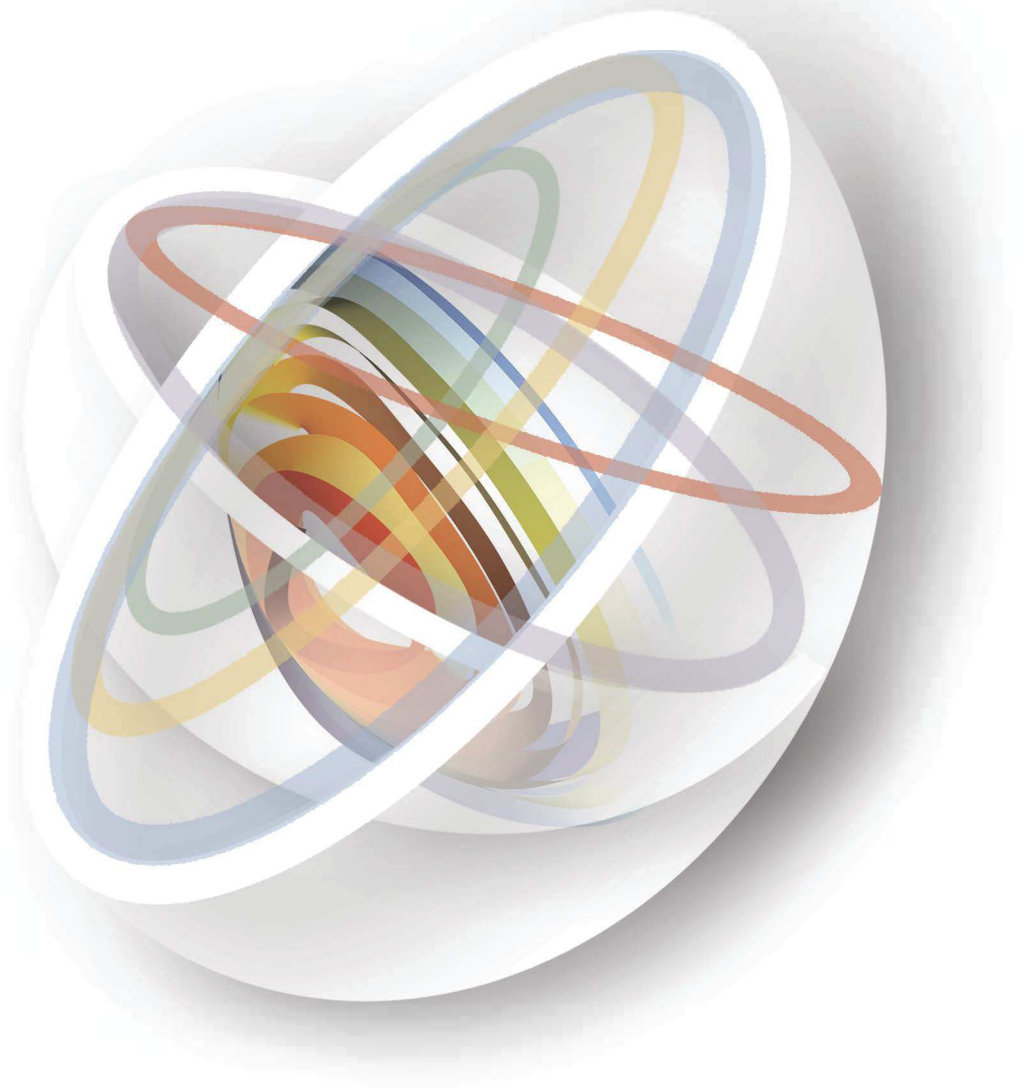

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Teaching about Nearly Zero Energy Buildings in the Architecture curriculum in Havana, Cuba

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Abstract: Nearly Zero Energy Buildings paradigm is changing the way buildings are designed worldwide. In order to have professionals more prepared to face this goal a design workshop has been implemented for Architecture students at the Technological University of Havana, Cuba. In this paper the background of the environmental design and teaching of nearly zero energy buildings in the architecture curriculum of Havana is explained. The objective of this paper is describe an academic experience with transdisciplinary and integral program designed in order to optimize building`s energy use. From the program consist of a main subject of architectural design, elective and optional subjects, and professional practice. The main subject consisted of architectural design of buildings in urban and rural contexts. The optional subjects were directed towards renewable sources of energy, participation and social impact and the principles of bioclimatic design in hot-humid contexts. The professional practice was aimed at diagnosing energy consumption of different buildings types in real contexts. Finally, the paper discusses the main results and lessons learned from experiences with this educational program through different study methodologies such as historical analysis of sustainability in architecture studies of Havana in last 40 years, presentation of transformations made to program of subject in last two courses as well as exhibition of some results by student work carried out in different contexts.

Keywords: Nearly Zero Energy Buildings, Architecture Education, Havana, Sustainable design, Passive design, low energy design

Introduction

Cuba, as almost all countries, is committed to reduce the negative impact of human activities on the environment, based on agreements within The United Nations Framework Convention on Climate Change as The Paris Agreement. The high CO2 emission on the island is mainly related to the high use of imported fossil fuels as main energy carrier to generate electricity. Furthermore, according to SIELAC-OLADE ("SIER," 2005), major energy consuming sectors in Cuba are linked to the built environment: residential (49%), industrial (27%), as well as commercial and public services (20%).

In the country there is a political willingness to diminish the energy use in buildings as well to increase renewable energy generation. One of the first important actions was the so-called "Energy Revolution" in 2005, intending to decrease energy demand in residential sector, by changing to more efficient appliances. Another goal officially recognized from 2016 in the *"National Plan for Economic and Social Development until 2030",* is to meet 24% of the energy demand by using renewable energy sources (RES). In order to increase the use of RES from the current share of 4% to this 24%, main investments will be located in bio-electricity from sugarcane, solar fields and wind farms. Currently, the decree-law "*Renewable energy development and energy efficiency*" is under discussion, which should allow the use of RES and

other technology to improve building energy efficiency. Furthermore, since 2014 the energy license that approves compliance with the requirements of the energy efficiency standard in the architectural project is established. Regardless of these policies, the building sector is not changing as fast as needed. The current strategies for building energy saving mainly focus on saving costs and materials, and so far a comprehensive policy to improve the energy efficiency of buildings has not been determined.

The European Union has declared (Directive 2016/0382) the intention to achieve for 2030 at least the 27% of energy shared by RES, and it also defined even biggest goals for 2020 to some countries that already have higher use of RES. In parallel to this regulation, the EU has a greater aspiration, by defining in the Directive 2002/91/EC and its recast Directive 2010/31/EU that for 2020 all new building will be nearly zero-energy building (nZEB) what consist on *"a building that has a very high energy performance and the very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby".* On other hand, the building Technologies Program of the US Department of Energy (DOE) has a similar aspiration, declaring that for 2020 the country must have *"marketable zero energy homes"* and *"commercial zero energy buildings in 2025"* (Sartori, Napolitano, Voss, 2012) Currently, implementing the nearly Zero Energy Building (nZEB) concept in Cuba is an indispensable way to improve the energy performance of buildings. Nevertheless, cultural and economic characteristics, tropical climate and social behavior are conditions demanding to adapt and redefine this concept for the Cuban context. Therefore, the discussions about the requirements needed to define an nZEB in Cuba, are ongoing. At the same time, this proves that it is necessary to train professionals better to face this new architecture paradigm.

The importance of designing and building differently to achieve the nZEB goal is recognized by Attia (Attia, 2012). One of the most recurrent requests is to carry out an integrated design approach in an interdisciplinary team working from the early design stage, in order to achieve the optimization of the building's energy performance (Brunsgaard et al., 2014). This is difficult to be achieved in a professional practice, and even more for undergraduate students, because new knowledge about several engineering fields is needed, as well as the competence of integrating this knowledge.

The Cuban University has been recognized by the government as the main resource to carry out research works about regional problems. Influences of urban microclimate and low energy building design on energy consumption are issues discussed for years at the Architecture Faculty. A research group at the Architecture Faculty of the Technological University of Havana, José Antonio Echeverría (CUJAE) set during the last two academic courses a *nearly Zero Energy Building* design workshop. This action is also undertaken as part of the international VLIR USO TEAM project, "*Renewable energy and bioclimatic architecture improving sustainability and development in Eco-touristic settlement: Las Terrazas*". In the project the Architecture Faculty and Renewable Energy Technology Study Center (CETER, according to its initial letters in Spanish) of CUJAE, and the Architecture and Engineering Faculty of Ghent University (Belgium) are joining forces.

The present paper analyzes the main strategies and lessons learned from these experiences with transdisciplinary and integral program designed in order to optimize building`s energy use. The environmental and sustainable design teaching on the Havana Architecture Faculty in the past 40 years is also evaluated. Finally, the transformations made to the program of subjects in the last two courses, as well as some results for the work of the student carried out in different contexts are exposed.

National background

In the Architecture curriculum in Cuba, knowledge is structured into different disciplines incorporated in diverse subjects in two semesters along five years. *Urban and architectonic Design* constitutes the main discipline that integrates the contents of seven other disciplines in seven exercises or design projects, taught in workshops. These workshops are guided by a professor although, currently, in the fifth year they are guided by a research group, in order to work related to more complex matters and multidisciplinary teams (Figure 1).

Year	1st Semester	2nd Semester	
1	Introduction to Architecture and Urbanism (IAU I)	Introduction to Architecture and Urbanism (IAU II)	FIRST CYCLE
2	Architectural and Urban Design (AUD I). URBAN HOUSING	Architectural and Urban Design (AUD II). SERVICES AND FACILITIES FOR HOUSING	
3	Architectural and Urban Design (AUD III). NEW URBANIZATION	Architectural and Urban Design (AUD IV). MEDIUM COMPLEXITY BUILDING	
4	Architectural and Urban Design (AUD V). URBAN REHABILITATION	Architectural and Urban Design (AUD VI). ARCHITECTURAL REHABILITATION	SECOND CYCLE
5	Architectural and Urban Design (AUD VII). DESIGN OF HIGH COMPLEXITY PROGRAMS	DIPLOMA THESIS	

Integrated conception of research (same project topic with different degrees of scope and depth of research). Work in research groups with multidisciplinary teams.

Figure 1. Design subject in the Architecture curriculum in Havana for years and semester. Source: Authors

To include the *nearly zero energy building* workshop as a part of Architecture curriculum is a new challenge to be reached. Even though this matter has not been tackled before, it's a continuation of the teaching tradition following the goal to reach a be suitable architecture making a better use of natural resources.

Issues related to environmental design have been included in the study programme as specialized contents since the early sixties. New tools for environmental assessment were designed as part of the results of the faculty research works. The *stick or shadow method* to study the thrown shade in horizontal surfaces realized by professor Joaquin Rallo was one of these pioneer works (González Couret, 2004).

From the seventies, several studies were developed about thermal comfort in the Cuban context, thermal performance of building typologies and diverse urban morphologies, as well as performance of building materials and technologies (González Couret, 2004). These works were supported by measurements using measurement equipment from the former Soviet Union. These results were considered as basis for the Cuban standards about environment and energy in buildings design developed from the eighties, including natural ventilation and lighting, solar control, and thermal loads. Furthermore, the developed methodologies were also taken into account to improve teaching methods about environmental architectural and urban design. However, more quantitative methods based on calculation and numerical ranges were predominant during the 70's and the 80's (Alemany Barreras et al., 1986), which provoked certain negative reaction from the architecture students against mathematical approaches.

Even though major research results were not immediately applied in practice, their introduction in into design solutions awarded in several competitions contributed to the demonstration of their validity. Some of such successful projects are The Habitat of Tomorrow in 1983 (project awarded in the international competition carried out by UNESCO), Bioclimatic Solar House in 1985 (National Award for Scientific Result), Three Designs to improve Leaving Conditions in the Mountainous Regions in 1989 (project awarded in a National Design

Competition), A sustainable Community Design in 1993 (project awarded in the international competition promoted by IUA in Chicago) and Bioclimatic and Progressive Social Housing in 1999 (Great Award in a National Design Competition) (González Couret, 2000). Likewise, these exercises have proved the benefit of using professor and student partnership method, to obtain in a limited period more holist and comprehensive solutions (González Couret and Portero Ricol, 2004).

The implementation of the fourth edition of architecture programs started in the nineties, addressing a wider character of the architects' profile than the previous ones. However, a gradual change in content of environmental subjects became evident and the investigations in these fields were decreased. This change was due to numerous factors such as the deterioration of the measure equipment and the move of the specialists to the teaching activities. In addition, it was evidenced that the contents were not sufficiently apprehended in the students and neither were they applied in their entirety in the design exercises.

Two the reasons for not applying this knowledge in academic or real architecture projects, despite it was taught since the early sixties, has been the rejection of complex calculation methods and the generally existing dichotomy between design studio professors and specialised professors in scientific disciplines such as underestimate essential environmental requirements in design. While on one hand the design studio professors didn't have this knowledge, on the other hand, the specialized professors used to consider these issues as the most important. Therefore, the assessments related to environmental design tended more to qualitative and perceptual analyses, and proved to be very complex to demonstrate scientifically.

Currently, knowledge and abilities of environmental design are acquired by the students mainly via a discipline 'Environmental Design and Conditioning'), given during 5 semesters between the 2nd and 4th year of the curriculum. The integration between this knowledge and the main integrative discipline has been better than in previous periods. One of the reasons is that one half of the programmed hours is taught together with design workshop professor and it is evaluated in the same project exercise. This experience is developed not only between these two disciplines, but with most disciplines that intervene in each level from 3rd year of the Career.

The more frequent professional discussions about climatic change, environmental impact and sustainable development, have contributed to an increased recognition of environmental matters in teaching Architecture. For instance, the sustainability paradigm a has been included in the discipline *Theory, Critique and History of Architecture and Urbanism*, as well as in *Technology and Structural Design*, encouraging the use of local materials and technologies.

Integration of key processes of university studies (teaching, research and university extension) has been strengthened at CUJAE University, where students carry out their thesis and then, master and PhD investigation as a part of a research group, and achieved results are implemented in practice by the university extension, contributing to improve people quality of life.

Despite of the advances achieved in teaching and investigating these matters, at present there are still limitations to surpass. The knowledge and evaluations integration conceived from the curriculum conception depends on a highly collaborative and consensual work between the different professors involved in the designing exercise. Otherwise, the student may have the confusion of not knowing what point of view to assume in the face of different requests. In addition, in spite of the rescue of scientific analysis in the environmental design

discipline, very qualitative assessment persists and the teaching of related matters with equipment and technologies as air conditioning, artificial lighting and renewable sources of energy proves to be insufficient. Regardless of the international development in environmental simulation software, its use is very limited, mainly due to the high cost in the international market. The Faculty does not yet have measurement equipment to continue the investigations that had begun in previous decades.

The role of the University, of going in the vanguard as to the analyses of society problems, has caused the architectural paradigm that academic aspirations differ from those projected and executed in the professional context. In addition, some studies have to begin without enough starting information, or this information is not quite much managed, registered or processed. This entails besides that most of the paradigmatic examples of sustainability and energy efficiency, come from developed countries, that have different economic situations, weather and cultural traditions. This problem at has been discussed likewise in similar contexts (Benkari, 2013) for the importance of recognizing the socio-cultural sphere at the same level as the economic and environmental assessment are considered in sustainability discussions.

It is in this context that the *nearly zero energy buildings* design workshop is developed, it could contribute to solve problems that arise. To achieve this objective with the students, it could involve conceiving different complementary subjects that provide specific tools and knowledge, establish more interdisciplinary methods of teaching and design, simulate the architect's profession through team work and role plays, as well as define specific and integral solutions, aspects that are complex to achieve in the academic field.

Teaching improvement. Working methods in nearly Zero Energy Building workshop

Different subjects as part of the same project design was conceived to develop knowledge and skills more integrated into same Evaluation System

The design workshop was developed during the last academic year, due to the need to work with students better trained about specialized issues. Likewise, this was possible as a result of the enabled flexibility of the analytical program of the 5th year design subject to generate workshops related to ongoing investigations. The first experience developed during the academic course 2016-17 consisted of a workshop with 12 students working on nearly zero energy buildings used as touristic lodge in different central areas of Havana. During the second occasion (academic course 2017-18) the same amount of students were involved, but related to a wider subject, with the objective to improve sustainability in a rural community related to ecotourism (“Las Terrazas”, Cuba).

For both experiences, the program was structured from one design project for each semester, combined with four complementary subjects conceived in order to obtain a full integration. Although the design exercises are in different context, they present the same conceptual objective aimed at obtaining more training in the students. The design project of second semester constitutes furthermore the final diploma work, which the students have to present, discussing the theoretical framework and a detailed assessment from the initial stages. The other two complementary subjects consist of 54 optional hours and 32 elective hours related to technologies for renewable energy and environmental design in warm and humid climates, besides learning about the use of simulation software such as Energy Plus, for the architectonic assessment, and ENVI-met, for urban analysis. Additionally, 124 hours for practical semi-professional activity are also conceived as part of the student’s comprehensive formation which is why they were inserted in some entities and project companies to evaluate

the energy consumption and to know the energy efficiency strategies that have been planned (Figure 2).

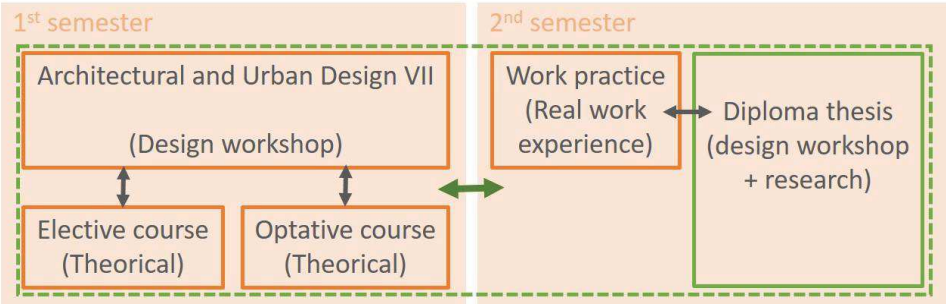

Figure 2. Relationship between different subjects of 5th year. Source: authors

Even though both courses had a similar programme, the experiences from the first year modified the initial program for the second one. The elective course about renewable energy was given during the 4th year, so that the students arrive in the 5th year with this knowledge. As well, an elective course about tools of participative design was offered during the second course, to be applied by the students when working with the community.

Interdisciplinary discussions with professors from different specialties and community actors

The subjects were directed by full professors and PhD students. The professors were architects and mechanical engineers, specialized in renewable energies. The workshop was conceived through seminars to evaluate the partial stages and ending of the project with the participation of stakeholders. This conception seeks to break traditional teaching approach, facing a problems based design in a multidisciplinary team. In the second step, the projects were also developed with the communal actors: population, leaders of the civil organizations, as well as executives of territorial institutions. Participative design techniques learned in the workshop were used for that (Figure 3).

Figure 3. A feedback meeting with stakeholders and students to present initial ideas project design. Source: authors

As part of the VLIROUS international project, the PhD students involved accomplished research stays at Ghent University, in order to update the available bibliography, to deepen the developed investigations, to learn simulation software and to use measurement equipment. This knowledge and abilities were quickly transmitted to undergraduate students by the given courses. Amount of student per professor (4:1) was lower than the traditional design studio in the Faculty (20:1), what allowed deeper discussion and analysis and more personalized attention.

The teaching and learning process in the design studio was developed in three stages: first to discuss essential theoretical concepts and to define the main requests of the projects; second, to design a general proposal, and third, to detail the main technical solutions and to analyze energy performance of buildings.

Simulation of interdisciplinary professional practice in design workshop from role play and teamwork

Team work was used as methodological resource during the first phase, where a specific task was assigned to each group for deepening and updating the collective knowledge. Among the assigned issues were: renewable energies, building equipment, passive and active design, touristic standards as well as urban assessment. The collective discussion of each aspect allowed to forge the main principles and leading concepts for the posterior design stages.

The designing proposal was carried on in an individual way in two last stages during the 2016-17 course, although the projects were discussed based on the role played by each student during the intermediate evaluation, in order to simulate the multidisciplinary team approach for the building design. In this sense, each student played a role according to the research task carried out during the first stage, even though they were not specialist in this issues, but they were the ones that developed more deeply into the study.

During the first design stage (2017-18 course), the students made proposals by groups, for the whole community or a particular component system while the last design step was developed individually. Groups were created combining students that analyzed different issues in the documentary first stage. During this experience, discussions with communal actors were essential. This entailed to transform the scope, because although at the beginning the goal was to delve mainly into energy issues, the discussion with the involved actors allowed to confirm that it was necessary to accomplish proposal related to key sectors in the community as landscape, dwellings, and public services.

Results and learned experiences

Academic exercises. 2016-2017 course.

In the exercises developed during the first year, the students worked up in three central zones of Havana: Old Havana, North Area of Havana Center and Vedado, which have a high touristic potential as well as diverse urban morphologies. The aim of the exercise was the design of a nearly zero energy building used for a cultural and city tourism market located on these central urban areas. Developed analysis and proposals allowed to define recommendations for this kind of projects.

Priority was given to natural ventilation complemented with roof-fans in all the spaces, although bedrooms were envisaged with air conditioning to fulfill the Cuban standards. The selected option was to design much more permeable buildings in such a way that they would not constitute a barrier to air flow inside the spaces. Among the used suitable design resources are fret-history, inner courtyards, in addition to include public services as snack-bar in the middle or last floor. These public services were generally designed including photovoltaic panels in order to allow ventilated roofs and in turn, propitiating the educational diffusion of this technology to the guests. The traditional spatial distribution was transformed in order to reach a better contact between indoors and outdoors in compact urban areas, by organizing bedrooms around a courtyard with an inner corridor.

Appropriate solutions for buildings in warm and humid weather were used, such as flexible windows and shadow protection, as well as hybrid system for power generation based

on renewable energy as solar thermal and photovoltaic systems. Small wind turbines were also incorporated in areas with high wind potential, even though this technology has not yet been used for buildings in the country (Figures 4-5).

Figures 4-5. A student `s design that use small wind turbine and photovoltaic roof as essential elements of the building conception. Source: students of last course 2017.

According to the Cuban standards, the architectural program for the touristic lodge was fitted with the aim to decrease energy consumption without affect regular performance. This type of building used to have minimum services additional to lodge, so restoration and recreational services are found on the surrounding urban context. It also included technical areas for renewable energy technologies and automation, not totally included in current standards.

The proposed architectural solutions reduced conventional energy consumption in between 30 and 40% respect to other similar buildings. One of the research results is the definition of the appropriate energy consumption range, as well as the identification of the main reasons for high energy consumption, based on 12 studied urban hotels. Nevertheless, energy balances and validation of these results by means of more precise simulations are pending tasks for later stages.

Even though proposed designs looked for a new esthetics trying to achieve that new technologies are not perceived as an addition, they also intended to be consistent with the patrimonial and contextual existing values. Design resources as the height of indoor spaces, design of windows and doors as well as shadow elements, were reinterpreted from the urban context, looking for endogenous solutions as the main energy saving strategy.

The need to develop studies beyond the building scale with the objective to evaluate potential and restrictions from the rest of the urban context to take advantage of renewable energies, became evident.

Figure 6-7. A student`s design that cover the terrace snack bar with a photovoltaic roof as well as it was simulated the envelope design performance. Source: students of last course 2017.

Academic exercises. 2017-2018 course.

The second academic experience was aiming to improve the energy performance and sustainability parameters for a community as a whole. The selected case-study was "Las Terrazas", a rural community located in a biosphere reserve, 60km from Havana, with high landscape values. This settlement was founded in the sixties, based on forest recovery as the main economic activity, and turned in the nighties to nature tourism.

The exposed results correspond to the work developed up to the first semester of the year, since the last diploma work step has not been concluded. Based on a diagnosis of problems and opportunities, a general development strategy include proposals as: to achieve a better use of the tourist resources through more accessible solutions and oriented route; to improve gastronomic and recreational services; to promote food production by permaculture techniques; to reuse and recycle solid wastes; to collect and use rainwater for domestic functions; the indoor spaces realignment to utilize new productive functions in the houses, and to improve housing living conditions. Community participation, as well as involved actors on each step has been one of the main achievements.

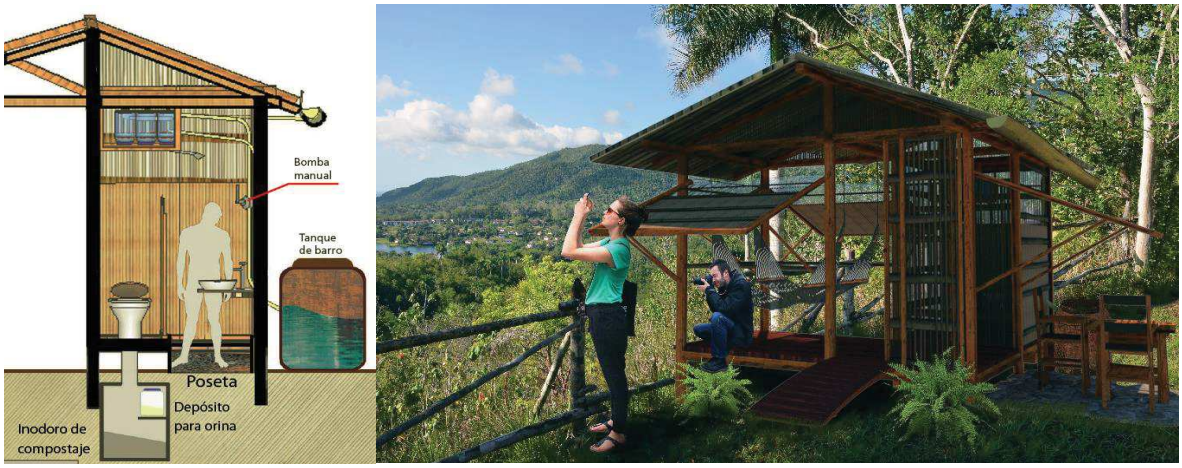

Figure 8-9. An eco-lodge design in Las Terrazas area. It was conceived the rain water use, photovoltaic system and composting toilet. Source: students of last course 2018.

Academic experience

Nearly Zero Energy Building is a new issue in Cuba, in such a way that discussions between students and professors allowed to touch this paradigm for the first time. Access to updated information as well as the generated discussion supported by the international project has contributed to consolidate and to deepen knowledge with regard to this matter.

While this was worked out with a small group of students (around 15 % of the total in this level), the energetic aspects were also included in others workshops for the majority of the architecture students. This fact became evident in the second course, when was started the work with students from 4th year of the career. It has put in practice the inclusion of students from inferior years to take part in the main group discussions, with the aim of achieving transmitting experiences and knowledge.

The evaluation with simulation software was still very preliminary, due to the fact that it was not possible for the researchers to develop the skills of using it. Based on the measurement equipment coming from VLIROUS project, it will be possible to validate simulation results by measurements in real cases in the near future.

Even though, it was conceived a design workshop with subjects that complement the formation with a total integration between them, the need to update own curricular subjects with the aim of achieving a better preparation of the students has become evident. In this

sense, it is advisable from the first years of the career to include all determining issues for a better building energy use, starting with fixed or very general elements, and gradually rising the level of complexity. This experience is part of the process of curriculum improvement, which is being developed at present to begin implementation in September 2019.

Transdisciplinary work between professors from the Study Center for Renewable Energy Technologies (CETER) and the Faculty of Architecture has been developed, despite the need to incorporate more specialists such as electric and automatic engineers as well as experts in air conditioning. In includes the convenience to develop multidisciplinary diploma works by students and professors of mechanical engineering and architecture and other specialties, despite the expected integration does not yet turn out well.

This is a complex process, because despite the recognition of its necessity, the structure and management system of the university is still organized by specialties, which make difficult to manage or schedules integrated academic activities and evaluations involving students from different faculties.

Working with two designing exercises with the same objective, let that students train in the subject matter and make their abilities perfect. The proposals in the second semesters were solutions that managed better to integrate technologies implicated in the buildings, including the RES, and the own design of the building with its surroundings.

Figure 10-11. Transformation of Las Terrazas housing looking for better solar protections and incorporate renewable energy technology. Source: students of last course 2018.

The communication between students and professors, together with the actors involved in the process, proved to be favorable. The proposals adapted to the concrete needs they had, but at the same time, they began to discuss problems not previously considered by the community, as water reuse, the use of renewable energies, and others.

This work also had made possible to improve the access to information, and involved actors are now more aware about importance of having more truthful data base to analyze their problems. Nevertheless, such experience is only possible if involved parts show a total interest about the process, as in ”Las Terrazas” community. The university extension project developed with the community participation will enable to raise the environmental conscience of the population, and in turn, divulging knowledge that enables dialoguing more diaphanously to discuss proposals (Figure 12 and 13).

Figure 12-13. Socio-cultural work of university students with primary students. Identification of community values from drawings. Source: students of last course 2018.

Conclusions

In Cuba, the integration of sustainability in the teaching of Architectural designbegan more than 40 years ago, and from the very beginning it was characterized by the application of scientific results.

Energy efficiency and use of renewable energy constitutes a priority due to their impact on climatic change and the economic restrictions in Cuba. Some subjects from the architecture curriculum have been updated to this end, although even they still prove to be insufficient.

Design workshops with participation of professors from other fields and the integration of different disciplines involved in planning and designing processes now allow to improve the students' knowledge about sustainable buildings.

The experience showed the need to make integrated designs, in which the main energy saving strategy consists on the passive building design according to the features of its surrounding area. The use of renewable energy sources as well as considering the energy efficiency of equipment, must be a condition from the early stages of design, as one of the main guidelines for the building envelope. Decreasing energy consumption of buildings and using renewable energy sources imposes the design of a new architecture that at the same time, must respect heritage values of the local environment.

The validation of concepts and results by using measurement equipment and simulation software should be a part of the research processes and formation. To carry on international projects makes the acquisition of infrastructure possible, which is fundamental for southern countries.

The present work will continue in later stages that will enable to evaluate and correct the proposed solutions.

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