Building Technology Educator's Society

Volume 2019 | Article 58

3-15-2018

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Introduction

"The 2012 AIA firm survey shows that architecture firms received 42% of their billings from renovation projects. For small firms, renovation projects made up the majority of billings."[1] Retrofits aim to utilize already-established buildings and upgrade them to operate more efficiently. Our Architecture students need to know how to think critically about using resources economically, as ethical professionals of the future. This paper seeks to establish the soundness of retrofits as an ethical architectural practice and, therefore, should hold a more prominent place in the Architecture curriculum. The following points enumerate reasons to include retrofits in architecture curriculum:

- Engaging the present students with past buildings, for the future (educating present students to view older buildings positively and with an eye toward future use);
- Engaging lesson plan exploring the one or two famous structures, why a retrofit was appropriate, and how it turned out, then practice on a campus building;
- Improving efficiency and performance of in-use buildings for the future, thereby extending lifespan of buildings;
- Decreasing environmental impact/moving toward "net zero.

Outcome-based design is mentioned as the future of high-performance buildings, based on American Institute of Architects (AIA). Outcome-based design calls for more case studies and expert building performance simulations. Although building performance outcomes will vary based on the design and location, the study of retrofit solutions could be applied in similar climate conditions. Finding the effective retrofits requires the study of different economically possible solutions and optimization of results. Ardente et al. summarized the results of retrofit actions in six case studies within the European Union projects "Bringing Retrofit Innovation to Application in Public Buildings."[2] This study highlights the importance of life cycle to optimize retrofits. Asadi et al. studied the optimization process to combine retrofit actions;[3] Although, the scientific literature reviewed emphasized that there is a lack of knowledge in retrofit evaluations, using Building Energy Modeling (BEM). US Department of Energy defines BEM as a multipurpose tool for building energy efficiency, which includes retrofit design. This study provides BEM-based retrofit data for a campus building in a hot-humid climate to expand the literature for architects and designers.

Existing buildings are being upgraded at a very low rate, even though the cost of upgrading is most often lower than demolishing and constructing a new building, depending on the condition of the building. Itrad and Klunder compared renovation with new construction possibilities in Dutch urban renewal cases and found that renovation is more environmentally efficient than demolition.[4] Rocky Mountain Institute (RMI) introduces deep (whole building) retrofit steps by identifying opportunities and analyzing options.[5] Opportunities include engaging stakeholders, defining technical potential such as reducing loads (windows, radiant barriers, tenant load), installing efficient systems (chiller, AHU retrofits), and ongoing monitoring of energy systems.[6] After identifying opportunities, the retrofit team analyzes options based on energy modeling and cost analysis tools. Case study examples such as the Empire State Building, Byron Rogers Federal (Denver), and Indianapolis City-County Building could be found on RMI reports for an in-depth retrofit analysis.[7] There are different resources for financial analysis, including the Energy Star financing guide and building cost analysis programs.

Ma et al. categorized building retrofit technologies into Demand and Supply management, and Energy consumption patterns.[8] "*Demand side management* includes heating and cooling demand reduction, and energy-efficient equipment, whereas *Supply side management* focuses on renewable energy, and *Energy consumption patterns* deals with human factors."[9] Ma et al. provided a valuable summary of the findings from previous retrofit studies, indicating the significance of insulation, glazing measures, PV panels, lighting load reduction, and heating system retrofits.[10] Retrofits could be selected based on the economical possibilities and that indicates the significance of energy modeling to evaluate the energy savings and compare them with their cost to optimize retrofit actions.

Conservation is the most common topic, underlying the idea of repair in historical buildings. Aside from theories of Le Duc and Ruskin, this research focuses more on the consumer versus repair mentality in students through the subject of retrofits. The topic of retrofits is included in conservation, and urban planning education, but it is missing from architecture.

Research Methodology

The first part of this research explores retrofit actions on a campus building in hot and humid climate, using simulation method. The next part focuses on the feasibility of this research for graduate master's students in architecture and discusses the lack of retrofit studies in the architecture curriculum.

The Empire State building is an excellent cold climate example for a successful retrofit based on large capital investments. This retrofit upgraded windows, lighting fixtures, radiator insulation, and ventilation controls. Comparing this example with a retrofit in a hot and dry climate of Arizona State University Health Services shows that the hot dry one benefited from envelope sealing and HVAC replacement. Both of these examples used envelope strategies. About half of the old clinic is renovated and the rest added as new construction.[11] This project also engages the historic palm walk and water conservation as a campus-wide decision. This research provides energy settings used to test retrofits on a campus building in hot and humid climate of florida and lessons learned from applying it in architecture research. Palau de la Música in Barcelona, Catalonia, Spain is a great example for an extension to a historical building, using retrofits and restoration of the old building. The interior of the old building is kept, while framing the facade, using glass.

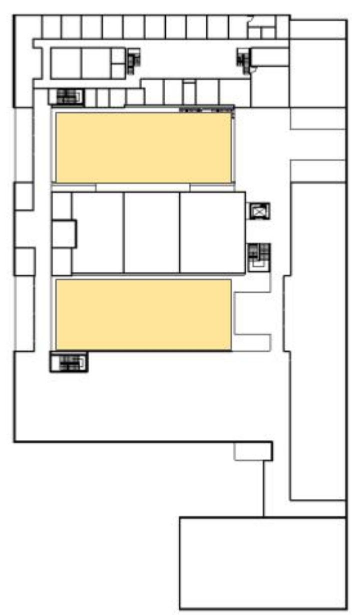


Fig. 1: Building configuration, illustrating the atria, earth berms

In this research, a campus building is modeled in Autodesk Revit with details of building material assemblies and analyzed using Autodesk Green Building Studio.[12] The building envelope is one of the main factors in evaluating the energy performance of an existing building and effective retrofit actions. The simulation in this study is tested, using building material based on the wall sections and architectural detail drawings. The modeling applied details of electricity and HVAC schedules to match the existing conditions. The selected building covers a variety of design features such as different envelope features, earth berming, and atrium (Figure 1). Each atrium measures approx. at 90 ft. (27 m) by 40 ft. (12 m), which is partially covered with a skylight. The following information summarizes the data used for the energy model located in Tallahassee, FL.

- Building type: Educational, Year built: 1985-86, remodeled 2001, with floor area: Approx. 38,000 ft^2 (3,500 m^2)
- Material properties: Bottom-half wall type with U-value: 0.0238 BTU/(h.ft^2.F) = 0.1351 W/m^2.K consists of brick finish (3 ⅝”), and top-half wall type with U-value: 0.0228 Btu/(h.ft^2.F) = 0.1295 W/m^2.K consists of Metal deck finish (3”), Roof U-value: 0.04 BTU/(h.ft^2.F) = 0.227 W/m^2.K, Window typologies and characteristic: Double-glazed U-value: 0.35 BTU/(h.ft^2.F) = 1.987 W/m^2.K.
- Average lighting power: 0.99 W/ft^2 = 10.65 W/m^2 and HVAC system/size: Central VAV, HW Heat, Chiller 5.96 COP, Boilers 84.5 eff.

This paper provides a systematic approach to proper selection and identification of the best retrofit options for a campus building pilot study. Retrofit actions studied include insulation, windows, renewable energy, and efficient lighting. The energy savings are then compared with their cost to provide the most cost-efficient option.

Preliminary Results

The base case results indicate 332,939 kWh electric, 6,912 Therms energy, and 56 EUI. In this case, identifying technical opportunities such as reducing loads, installing efficient systems, and ongoing monitoring of energy systems are studied. The current insulation and window to wall ratio has been studied and resulted in reasonable energy usage, with no need for energy changes. To reduce loads, this research considered renewable energy and lighting efficiency plugs. Since chillers in this case are upgraded by Siemens, there is no need to retrofit efficient systems, although one of the most energy saving retrofit options is high efficiency HVAC. Roof mounted PV system (with medium efficiency 10%) could save 27,000 kwh/yr energy, with an approximate cost of $120,000 to cover 2,000 sq. ft (185 m^2) of a gable roof facing north and south. The next retrofit action focuses on the use of lighting efficiency to 0.3 W/sf (3.2 W/m^2), which results in EUI equals to 49.

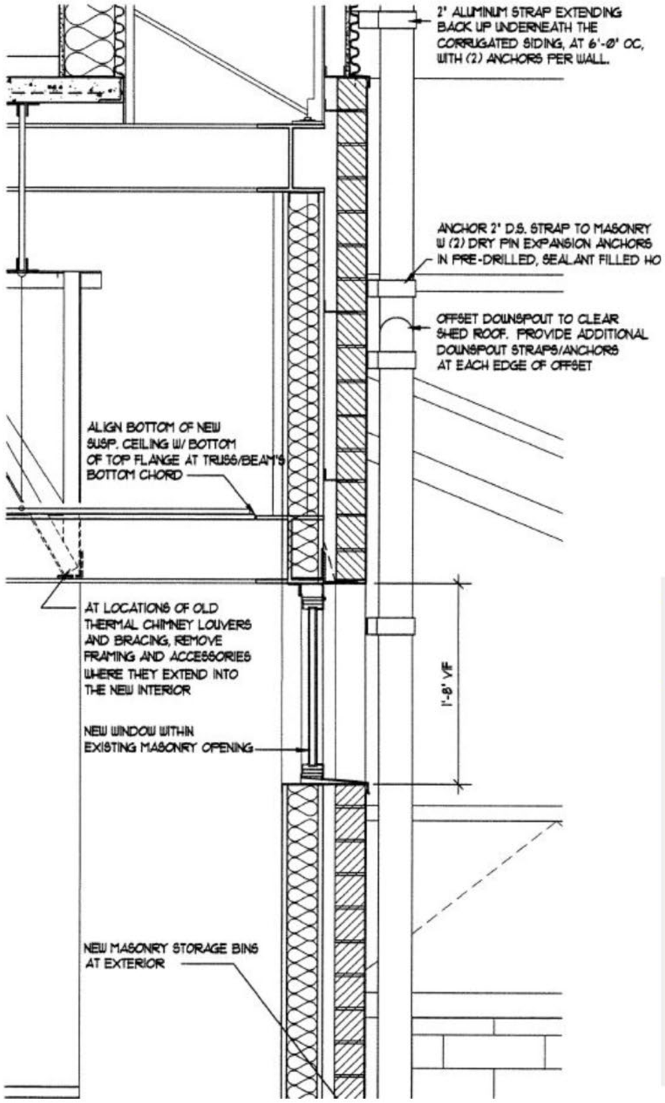
Energy Use Intensity (EUI) is the total energy use (electricity bill) per square foot in a year. Site EUI focuses on the energy usage of the building, whereas source EUI considers the energy generated or transported to the building. U.S. Environmental Protection Agency data state median site EUI for educational buildings as 58.0 kBtu/sq.ft./year (182.967 kW/m^2), with decreased targets using Energy Star portfolio manager.[13] The base case EUI, in this study, represents 56, which could be reduced to meet the target EUI through using renewable energy or combination of retrofit actions. Retrofit actions are different based on climate conditions; for example, PV panels or geothermal might work in a climate and do not have reasonable results in another climate.

One of the constraints in retrofit implementation is the cost and payback evidence for investors. Based on RMI research, in a retrofit retail pilot in Florida (43,000 GSF) that $11/GSF total capital cost and $7/GSF marginal cost could result in 72% annual utility cost savings in 2012.[14] A similar cost basis analysis could be applied to this project in a hot and humid climate. The marginal cost adjusts calculations based on future maintenance needs of not taking actions versus applying retrofits. To make cost-efficient decisions based on budgets, the team should consider the energy saving and life cycle cost for combinations of retrofit action. In this case, for instance, there is a need to compare cost and life cycle payback of including renewable energy, efficient plugs and Air Handling Units and find the right time to retrofit.

Retrofits in Pedagogy

The idea of providing architecture students with a "repair" vision defines the underlying didactics of this graduate research project. There are a few schools of architecture across the U.S. that offer Facilities Management as their business side of architecture as a graduate level degree. Facilities Management programs provide a clear vision about the future career path for students; however, joint-degree programs such as M.Arch/ MBA are quite broad as a graduate program, since most graduate students have already decided about the future career path. Most of the students in this Master of Science degree programs (such as Facilities Management) have architecture backgrounds, while undergraduate architecture students usually do not take Facilities Management or preservation courses. Examples of curricula that include retrofitting as preservation include Master of Science in Preservation Studies offered at University of Notre Dame, University of Oregon, Columbia University, Clemson University, and University of Minnesota. Historic Preservation courses at University of Oregon offer promising course material, such as Experimental Course: Principles of Adaptive Reuse and Building Pathology: Masonry and wood. While it's important to provide the opportunity for undergraduate architecture students to take some elective courses in preservation, Historic Preservation programs are offered mostly as graduate level programs. As a result, there is a need to have the subject of "repair" added to current design studio and technology courses in undergraduate architecture courses.

National Architectural Accrediting Board (NAAB) covers financial issues in one of the accreditation criterion, which can be met through professional practice lecture course in addition to upper level design studios. Finances and contract management is one of the important aspects that an architecture firm expects students to know, entering the firm. Schools of Architecture play a significant role in conveying this knowledge, in addition to the Architectural Experience Program. Including retrofits started with a graduate Research Assistant modeling and analyzing an existing campus building in Revit. The students used the energy analysis results to understand the building performance and find out appropriate retrofit actions. The analysis of cost and combinations were then added by the Principal Investigator. One of the examples for integration of different courses such as material and methods with student's research is when students translated construction assemblies to Revit for the energy model (Figure 2).



Family: Basic Wall
Type: BOTTOM HALF
Total thickness: 1' 0 1/2"
Resistance (R): 42.1033 (h·ft²·°F)/BTU
Thermal Mass: 7.2126 BTU/°F

Layers

EXTERIOR SIDE

	Function	Material	Thickness
1	**Core Boundary**	**Layers Above Wrap**	**0' 0"**
2	Finish 1 [4]	Brick, Common	0' 3 5/8"
3	Thermal/Air Layer [3]	<By Category>	0' 0 3/4"
4	Membrane Layer	Vapor Retarder	0' 0"
5	Substrate [2]	Gypsum Wall Board	0' 0 1/2"
6	Structure [1]	Metal Stud Layer	0' 6"
7	Thermal/Air Layer [3]	EIFS, Exterior Insulation	0' 1"
8	Finish 2 [5]	Gypsum Wall Board	0' 0 5/8"
9	**Core Boundary**	**Layers Below Wrap**	**0' 0"**

Fig. 2. Student's interpretation of wall section into the envelope assembly for simulation.

This experience brings up the question of the extent to what educators focus on retrofits in architecture education. It is an issue of ethics in technology to consider providing students with retrofit solutions and adaptive reuse, as case studies to convey the sustainable design techniques. Budget is one of the controversial parts of design studios, which is covered in lecture courses. However, there seems to be a need to combine every aspect of design for graduate students as a holistic action to have more efficient design deliveries. This research was a unique opportunity based on graduate researchers, while case studies of adaptive reuse could be combined in Introduction to Technology courses, to make students familiar with the concept. If other majors such as Facilities Management take the course, this will provide them with an opportunity to learn solutions that can be applied later in their career as facility managers. This research has also considered and tested including retrofit case studies and energy modeling as part of Environmental Systems course. The students were given an exercise to revisit one of their design studios with an energy efficient vision and improve its performance. Students used Autodesk energy simulation and evaluated their base case, then applied and tested changes to improve their building in a workshop. The results of this exercise showed that students learned about possible passive design strategies and how to integrate the strategies either at the beginning stages of design or as retrofits. The other benefit of this exercise was to make students familiar with the concepts used in energy modeling and parameters that affect the efficiency of a building. To summarize, including retrofits in architecture education provided the students with better understanding of building cost and design, more efficient retrofit solutions, integration of energy modeling in design, and solutions to improve the building performance.

Campuses are excellent places to practice retrofits, because the buildings are generally long lasting and need periodic retrofitting. As a result, including topics about retrofits in architecture technology courses and explaining case studies is necessary to prepare students for their careers. The present study provided an applied example for retrofit actions in architecture on a campus building in hot and humid climate, the results are applicable in similar conditions. The methodology to use energy modeling to recognize optimal retrofit actions makes it easier to include retrofits in architecture education.

This research was an attempt to include avenues of improvement for teaching building performance in existing buildings in architecture education. The comparison of benefits and costs helps students with more logical design decisions based on the factors that are taken into consideration. Facility managers play an important role in decisions regarding retrofit actions on campus buildings. As a result, there is a need for educators in schools of architecture to provide students with more practical life cycle cost analysis studies. Life Cycle Cost Analysis (LCCA) is a method to assess building cost, which takes into account construction, maintenance, and personnel salaries. There are codes and formulas to calculate LCCA, such as the Building Life-Cycle Cost (BLCC) Program, which is a tool developed by the National Institute of Standards and Technology for the U.S. Department of Energy. The understanding of LCCA in studio teaching would make students think about the life cycle of a building and give them an in-depth view of the scale and materiality of their design. To conclude, the goal of focusing on energy analysis and understanding the LCCA in design education is to have students critique and revise their decisions in the early stages of design. This should lead students to be more cognizant of their design options as professional architects, and, ultimately, more efficient and ethical building construction in the future.

This research concludes with the fact that Energy Modeling and Life Cycle Cost Analysis should play a significant role in architecture undergraduate education. On the one hand, practical aspects of the profession could be more emphasized throughout design studios, by inviting architects for jury sessions to comment more on financial aspects of the projects. On the other hand, retrofit examples could be explained to undergraduate students as case studies in courses such as Introduction to Technology in Architecture. The retrofit subject is a touch on the more critical issue of replacing the mindset of consumerism with “repair” by increasing the collaboration between architecture schools and practice.

Retrofitting could be discussed through a broader lens than energy and life cycle analysis, such as bringing back the meaning of preservation into architecture studios or urban design projects. Usually students in architecture are only focused on designing a new building that sometimes they forget the role of their architecture to the urban context and to what extent their design could maintain the existing fabric. As an example, in a fourth-year design studio, students were given a project to redesign an urban courtyard in Lisbon, Portugal. The results that faculty received from students work were impressive in the sense that students initially struggled to find ways to preserve and couple the new intervention with the urban fabric. Simon Burton and Hyde in Sustainable Retrofitting of Commercial Buildings values the idea european perspective and the idea of resilience [15,16]. One of the successful points in applying this idea in a design studio was to have the students think cautiously about the occupants, space planning, and the use of space in the context.

Sustainability rating systems are the next approach in retrofit discussion in architecture education. LEED has adopted certain criteria and credits for material reuse and space adaptations, while european rating systems take the lead on more advanced measurement methods and solutions. For instance, LEED Building Design and Construction provides credits for protecting and restoring sites, storage of recyclables, and demolition waste management. The familiarity of students with these ideas in design and technology courses will play a positive role in their future designs. There are various approaches to integrate retrofitting in architecture education, including design studios, technology courses, design competitions, sustainability rating systems, etc. This paper reviewed examples to apply retrofit education in technology, sustainability discussions and studio classes, with a focused research study approach towards energy modeling. Interaction with students during this process and research demonstrated the need to make student's knowledge of material and methods more practical and integrated with the holistic vision of their design.

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