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Developing a Pedagogical Framework for an Integrated and BIM-Based High-Performance Design Studio: Experimental Case Study

Amir Farbod Shahverdi[1]; Fatemeh Mostafavi[2]; Sogand Haghighat Roodkoly[3];
Zahra Sadat Zomorodian, Ph.D.[4]; and Hoda Homayouni, Ph.D.[5]

Abstract: As the current environmental crisis and depletion of our energy resources are pushing the Architecture, Engineering, and Construction (AEC) industry toward the design and construction of High-Performance (HP) buildings, new organizational and technological methods of practice, such as Integrated Design Process (IDP) and Building Information Modeling (BIM), have emerged to facilitate this transition. Consequently, Architecture schools are left with the duty of training practitioners with the required holistic vision and technical knowledge for designing HP buildings, technological abilities to work with new BIM tools, collaboration skills to work with cross-disciplinary team members, and theoretical knowledge to run the new processes. Scholars of architectural education are faced with a significant theoretical and practical knowledge gap on how to add all these new layers of knowledge and skills to what is an already saturated curriculum in architecture schools. To address this need, we developed a conceptual framework for teaching an integrated and BIM-based HP design studio for the MS program in Building Science. The experience was successful in creating an effective systematic method for integrating HP design elements in the students' projects, with all the teams achieving their project performance targets in six distinct HP categories of energy consumption, greenhouse gas emissions, health and wellbeing, water management, and resiliency, while meeting reasonable architectural qualities and economic criteria. The key elements of this pedagogical approach, including teamwork, a structured and iterative design process, decision-making mechanism with a high level of attention given to various performance metrics, the use of related BIM technologies, and the evaluation techniques, are introduced, discussed, and recommendations are proposed for future applications.
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Introduction

The global warming, current environmental crisis, and the rapid consumption of our energy resources are calling for a change in the Architecture, Engineering, and Construction (AEC) Industry toward more environmentally friendly, and energy efficient design approaches. To address this need, many movements have emerged, and related terms were coined such as green buildings, sustainable design, low-impact development, and so forth. While these terms are similar in their approaches to mitigate harm to the environment, we chose to work with High-Performance (HP) buildings, due to their more encompassing scopes. The current approaches to HP buildings suggest that other than the green aspects (e.g., energy efficiency, water saving, land protection), the characteristics of these buildings usually include intelligence (i.e., instrumentation, control and automation of building systems and services, and futuristic design), and resiliency (which may include life cycle costs, fire safety, long-term maintainability, and occupants interaction with buildings' systems) (Lewis et al. 2010; Day and Gunderson 2015; Kalluri et al. 2020). Achieving all these objectives in HP buildings is not feasible using conventional design processes. Instead, a whole building design approach is required in which all HP design objectives can be considered in concert with each other, and the Integrated Design Process (IDP) has proved effective in facilitating this approach (Kanters and Horvat 2012; Jaffe et al. 2020).

IDP has the potential to optimize a project's performance, increase a project's values for owners, decrease waste, improve a building's energy efficiency, and other environmental considerations (7 group, and Bill Reed 2009). These advantages are the results of a shift in the peak workloads compared with the conventional design, as most tasks are done at the initial stages of design, leading to the most effective decisions and lower cost of modifications throughout the process (CURT 2004). The project attributes affecting the success of IDP projects can be organized into four main categories (Ikudayisi et al. 2022): (1) project attributes (e.g., project type, complexity, cost); (2) process attributes (e.g., delivery method, training and education, early commitment to HP project goals); (3) team characteristics (e.g., level of team integration, interaction, and commitment); and (4) client attributes (e.g., commitment to HP goals). While some of these attributes are necessary for project success, others may be combined in different ways to lead to better project outcomes. Thus, planning for success of IDP projects requires strategizing to best match project and process attributes with team and client characteristics (Homayouni et al. 2021).

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[1] Dept. of Architecture and Urban Planning, Shahid Beheshti Univ., Tehran 1983969411, Iran. Email: A.shahverdi@mail.sbu.ac.ir

[2] Dept. of Environmental Technology and Design, Delft Univ. of Technology, Delft, 2628 RL, Netherlands. ORCID: https://orcid.org/0000-0002-8047-2168. Email: f.mostafavi@tudelft.nl

[3] Dept. of Architecture and Urban Planning, Shahid Beheshti Univ., Tehran 1983969411, Iran. Email: so.haghighatroodkoly@mail.sbu.ac.ir

[4] Dept. of Architecture and Urban Planning, Shahid Beheshti Univ., Tehran 1983969411, Iran. Email: z_zomorodian@sbu.ac.ir

[5] Dept. of Architecture and Urban Planning, Shahid Beheshti Univ., Tehran 1983969411, Iran (corresponding author). ORCID: https://orcid.org/0000-0002-5409-6541. Email: h_homayouni@sbu.ac.ir

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Building Information Modeling (BIM) is considered the technological platform that facilitates IDP from the early stages of design throughout the project lifecycle. Previous studies have shown the antecedents of successful IDP and BIM implementation and have demonstrated how successful implementation of one can facilitate successful operation of the other (Homayouni et al. 2010). The direct influence of utilizing BIM tools on achieving HP buildings has been also demonstrated, especially through BIM attributes such as virtualization of buildings and energy simulation, and still is a subject of more in-depth studies (Mirpanahi and Noorzai 2021; Ur Rehman et al. 2023).

Accordingly, the industry's shift toward IDP and BIM-enabled delivery of HP projects calls for a change in our architectural design education toward approaches that facilitate education of the three interrelated concept. This emerging vision, however, has the potential to fundamentally transform the architectural design education and the way in which design knowledge is gained and used (Ambrose et al. 2008). While many scholars have proposed new pedagogical solutions to incorporate BIM technologies, IDP practices, and designing HP projects in their curriculum, and some have tried to consolidate the two or all three concepts within their design studios, the question regarding the specifics of the implemented roadmap, and the tools and methods used to achieve the most practical and efficient results is yet to be explored.

To address this existing gap, the "Literature Review: Teaching Integrated and BIM-Based HP Design Studios" section reviews the literature on existing pedagogical approaches to Integrated and BIM-based HP design studios; the "Methodology" section discusses the research methodology, its applicability, and limitations; the "Implemented Pedagogical Framework" section presents the development of our pedagogical framework; the "Discussions" section discusses the findings; and the "Conclusion and Future Work" section concludes the paper and offers suggestions for future work.

Literature Review: Teaching Integrated and BIM-Based HP Design Studios

All practitioners within the AEC industry have an obligation to ensure that their buildings are designed with care and respect to their occupants, people affected by the projects, and the environment. A global review of existing architecture programs shows their response to this obligation and a consecutive shift toward assuming a central position for a "sustainable agenda" within their curricula (Dartevelle et al. 2012). Attempts to establish HP architectural methodologies in education include embracing a deep learning approach, such as game-based learning for principles and practices of sustainability and focusing on applying knowledge to new areas and scenarios (Sarhan and Rutherford 2014; Juan and Chao 2015; Solnosky et al. 2020), utilizing virtual situated learning contexts to create simulated experiences of students' interactions with virtual professionals in building science (Eiris et al. 2021), and, HP and green design studios (Altomonte et al. 2014; Sewilam et al. 2015; La Roche 2017; Mohamed and Elias-Ozkan 2019; Grover et al. 2020; Lee and Lee 2021). Strategies to enhance learning experiences in these studios include utilizing design charrettes (Walker and Seymour 2008), conducting living labs in which the proposed HP designs are built and their performances are tested (Dabaieh et al. 2018), and embracing sustainability considerations in digital fabrication (Georgiev and Nanjappan 2023).

All HP design studios benefit from some level of disciplinary integration to optimize attributes that play a part in HP buildings. Different levels of disciplinarity can be defined as (Stember 1991; Kocaturk and Kiviniemi 2013): (1) intradisciplinary – working within the professional boundaries of a single discipline, that is, Architecture or Engineering; (2) cross-disciplinary – using concepts of one discipline within another from own's perspective; (3) multidisciplinary – using the knowledge of more than one discipline (i.e., Architecture and Engineering), but not drawing on each other's knowledge; (4) interdisciplinary – integrating knowledge and methods of one discipline within the other (i.e., Architectural Engineering); and (5) transdisciplinary – reaching a unified and commonly accepted understanding among multiple disciplines, which is beyond any individual disciplinary perspective (i.e., focusing on an issue, such as sustainability, within and beyond disciplinary boundaries of architecture and engineering with the possibility of finding new perspectives). Kocaturk and Kiviniemi (2013) argue that all these levels of disciplinarity need to be addressed in architectural education. Although HP building design requires a high level of disciplinary integration, only by realizing one's own disciplinary roles and responsibilities in the first place can we utilize the knowledge of other disciplines and contribute to their scopes of work successfully. Thus, all these concepts are valid pedagogical approaches and can be used at different stages of education.

In recent years, several universities have defined IDP studios, with different levels of disciplinarity integration to design HP buildings. The participating disciplines range from architectural design, interior design, mechanical engineering, electrical engineering, construction management, and so forth. Strategies and principles reported by these cases as contributing to successful pedagogical approaches to integrated HP design studios include the following: (1) clearly defining learning outcomes (Altomonte et al. 2014); (2) implementing a self-directed, problem-based approach which provides educational materials that are highly interactive, problem-based, and enables students to control their own learning pace in addition to gaining knowledge through coursework (Rachke 2003; Vassigh and Spiegelhalter 2014; Martínez et al. 2022); (3) inclusivity of disciplines, that is, sufficient breadth of coverage of topics, with their complex interrelationships, which is not always feasible within the already busy curriculum of architecture (Altomonte et al. 2014; Kostopoulos 2022; Martínez et al. 2022); (4) having an integrated/ nonlinear process instead of a step-by-step approach in teaching design studios, in which the design process is broken into smaller segments, which have nonlinear interactions with each other (Bashier 2016); (5) entailing self-evaluation, in which all aesthetics, performance, and sustainability related factors are taken into consideration using qualitative and quantitative target benchmarks and explicit criteria for assessment, which is reached by consensus through weighing different performance criteria in comparison with each other (Graham 2009; Larsson 2009); (6) embracing holistic thinking in which students should be exposed to more holistic aspects of sustainability and develop understanding of multidisciplinary problems that transcend sustainability issues (Altomonte et al. 2014); (7) taking an explicit design approach in which students test generated solutions and modify their design. The process should be explicit to enable rational decision-making (Bashier 2016); (8) establishing team communication protocols including timing, means and methods of collaboration, decision making and dispute resolution plans (Ibrahim et al. 2007; Homayouni 2015); (9) develop inspiring delivery methodologies that support and reinforce dialogue to emphasize integration and joined-problem solving (Altomonte et al. 2014; Martínez et al. 2022); (10) promoting the application of tools and techniques that are appropriate to the various stages of design development (Ewenstein and Whyte 2009); and (11) measuring each technical decision against its spatial effect on the design product to pursue aesthetics and HP-related objectives at the same time (Dunay et al. 2006).

To establish BIM-related courses within architectural curriculum, several methods and techniques have been proposed. Examples include flipped classrooms for education of software tools (Monson et al. 2015), BIM-enabled design collaboration processes in remote architectural practice and education (Lee et al. 2023), transnational education for practicing virtual cross-disciplinary and cross-border coordination with BIM tools (Dossick 2015), and BIM-based studios to perform detailed analysis and design modifications (Uzun and Çakır 2022), some interdisciplinary with the goal of improving building performance, cost, and constructability (Holland et al. 2010). Successful implementation of BIM courses within higher education institutes requires overcoming challenges such as: (1) cultural change management; (2) curricula and content limitation; (3) educators problems; and (4) disconnect with the industry (Pradhananga et al. 2021).

Yet, there are some untouched areas in pedagogical approaches to integrated BIM-based design studios which will be addressed in this study.

1. Few studies have presented a pedagogical framework for teaching HP buildings that can be used in different climatic/ social/ and economic conditions. One example of such a consideration is SBTOOL (Larsson and Bragança 2012), which was designed as a generic framework, in which weighting and benchmarking are expected to be determined by local noncommercial organizations. While this system helps students to gain a general understanding of a wide range of HP building issues, the work process is quite different from the industry in which projects pursuing HP design usually choose to pursue a particular set of green building goals and assessment systems.
2. While some management support tools and guidelines for IDP processes, such as IDP-Tool and Integrated Whole Building Design Process (IWBDP), are presented (Ministry for the Environment, New Zealand Government 2008; Larsson 2009), which show the generic steps that need to be taken in an IDP process and are adaptable to regional conditions and project characteristics, not many studies have clearly addressed how IDP processes can be integrated into studio projects.
3. To the best of authors' knowledge, the specifics of how HP building principles, IDP framework, and related BIM roadmap can be integrated within a design studio, with the required level of attention given to the performance metrics involved in the process, has not been addressed in previous studies.

To cover these gaps, this paper provides a step-by-step guideline for instructors to create integrated, BIM-based HP design studios that can be incorporated in different climatic, social, and economic conditions.

Methodology

This study aims to present a case study report on teaching an integrated and BIM-based HP design studio, using a pedagogical framework developed for third semester graduate students of MS in Building Science program in Shahid Beheshti University (SBU), Tehran. The design process was planned based on IDP to use the relevant BIM tools, with defined decision-making processes and evaluation schemes based on available green building rating systems and HP related building standards. The studio included a group of 23 students and two instructors conducting the design studio as a team, with the help of a teaching assistant. The study consisted of 19 weeks, and 6 working hours per week. Due to the covid-19 pandemic, it was run virtually at the time of study, although the framework was not particularly developed for virtual education, and the course has been offered in person ever since. All the students participating in this studio had a bachelor's degree in architecture and had received a wide range of training in related areas such as green building, passive and active environmental control systems, and building performance simulations since starting of the MS program.

The assigned project was an HP resort complex consisting of a hotel, a convention center, a sports facility, and a commercial building in a 20,000–30,000 m^2 site, with 30% building coverage. The students were divided into six groups, each working on a different climatic context as assigned by instructors in the cities of Rasht, Tabriz, Urmia, Shiraz, Kerman, and Kish Island categorized as Cfa, Dsa, Dfa, BSk, BWk, and Bwh, respectively, based on Koppen–Geiger climate classification. As all the team presentations and crit sessions happened in virtual studios, the students had a chance to observe all project discussions, and therefore they were provided with the opportunity to learn about challenges and opportunities of working on different climatic settings. The follow-up of the planning and the revision of the design products were conducted weekly.

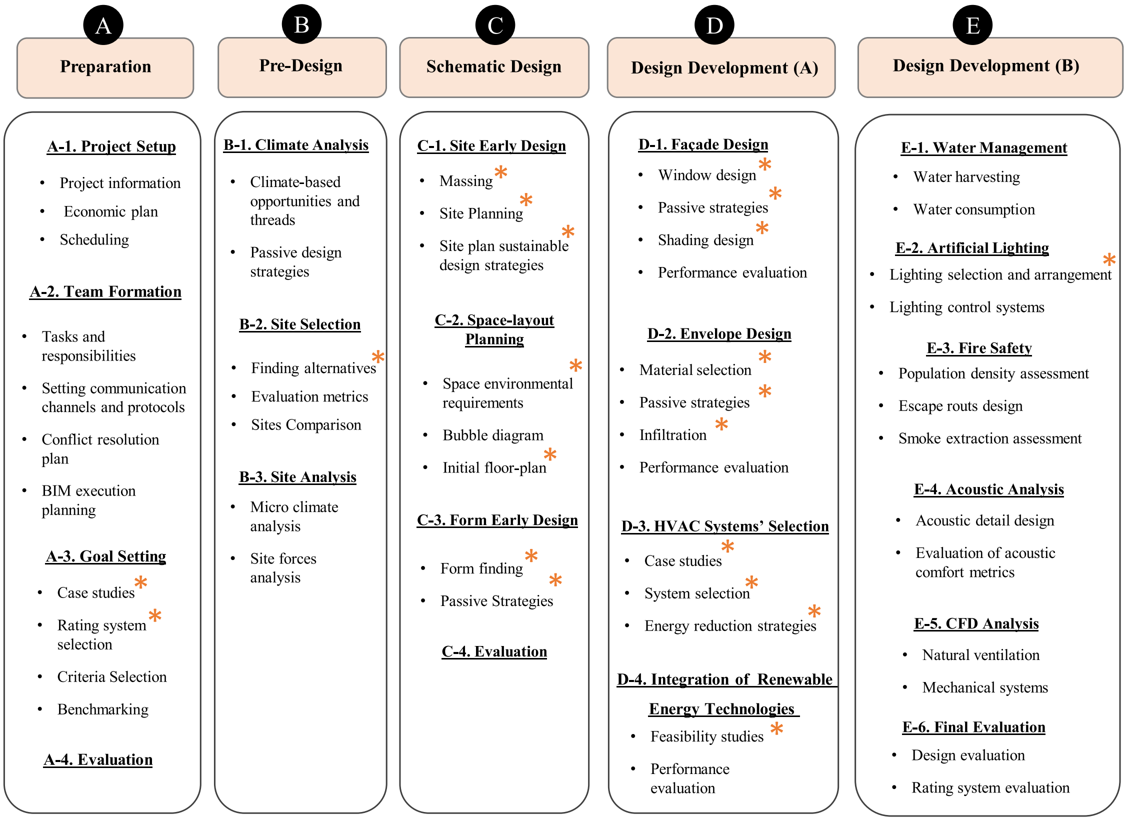
The overall project goal was to design the complex with exceptional performance in six areas of energy, greenhouse gas emissions, health and wellbeing, water management, economic efficiency, and resiliency while paying attention to the architectural qualities of the project. The students defined the specific qualitative criteria and quantitative performance metrics to evaluate performance of their projects, based on local and HP building codes (e.g., IgCC and ASHRAE standard 189.1), as well as building certification, rating, or labeling programs (i.e., LEED), and benchmarked them based on the case reports they had studied. The instructors then evaluated the goal setting and the benchmarking of each group and made sure they were ambitious and reasonable at the same time. We deliberately put an emphasis on HP criteria that focused on the measurable performance metrics that could be influenced during the schematic and design development stages.

The final project deliverables included: (1) project goals and objectives, baselines for main HP-related performance metrics; (2) design development documents; (3) selection of HVAC systems; (4) renewable energy production methods; (5) indoor environmental quality evaluations; (6) water management and fire safety strategies; and (7) final evaluations of all the identified criteria and performance metrics in comparison with the defined baselines and benchmarks.

Implemented Pedagogical Framework

In this section, we present the implemented framework of the Integrated BIM-based HP design studio. The 19 weeks of the semester were divided into a modulus system that allowed students to focus on the process rather than the result. As illustrated in Fig. 1, the design process was divided into five main modules, each covering several design stages, each stage with its own defined steps: 4 weeks for the preparation phase, 3 weeks for the predesign, 3 weeks for the schematic design, 3 weeks for the design development (A), and 3 weeks for the design development (B). The students then had 3 weeks for their final presentations (including their final exam weeks).

As will be explained in this section, to create a better chance of approaching the optimized solutions, the steps that are marked with asterisks have exploratory natures, in which students opened their search fields and explored new ideas. The stages defined as "evaluation" are where whole system thinking happened, and all the parameters and performance metrics considered throughout the design up until the evaluation stage came back into play, and



* The steps at which alternative design ideas are explored

Fig. 1. Implemented design process steps.

with the holistic vision that students gained by working with numerous parameters and performance metrics (as listed in Table 2), they adjusted their designs to better optimize them with respect to the objectives and performance metrics involved. To check the students' models for accuracy throughout the semester, the teaching assistant would check the details of the students' simulation periodically, while the instructors would point out the more obvious discrepancies in the students' performance reports during the crit sessions. This section presents a summary of the implemented pedagogical framework.

Phase A: Preparation

The Preparation phase is where the project is defined, the teams form, and project objectives are set. This phase was divided into three main stages in our framework.

A-1. Setup. The design process began by introducing the project and providing the students with information regarding the project goals, conditions, scopes, and limitations, accurately specifying all sustainability-related terms and the project deliverables. Next, the students considered a target cost for their project, a payback period, and identified the government subsidies regarding HP buildings in their regions. The instructors also provided a general roadmap for the students at this stage and required them to review the roadmap and plan a detailed schedule accordingly.

A-2. Team Formation. The project setup followed by teaming and team-building activities, where the students divide into groups of three or four, based on their previous relationship, skills, knowledge, work ethics, and familiarity with project needs. Each group then conducted a meeting to define their working relationships, communication channels, and protocols, as well as a conflict resolution plan. They also conducted a BIM execution planning, determining the software programs to use, the details of file transformation mechanism, and the level of development (LOD) at each stage. From a list of software tools appropriate for each design step, listed in Table 2, the students chose the ones to use according to their own familiarity with the programs, interoperability, and other technical considerations such as the software tools' reliability and comprehensively. However, ultimately, the determining factors in choosing the software programs in our studio were the programs' accessibility, applicability during the design stages, and reliability of the simulation engines (i.e., Energy plus and Radiance).

A-3. Goal Setting. At this stage, students specified the aims and objectives of their projects more specifically at two different levels of district and building scales. This happened through four procedures of case study, rating system selection, criteria selection, and benchmarking. At the case study stage, students found and studied cases that were similar to the project in terms of their type, scale, and climate. After reviewing the cases, they categorized the learned lessons based on different specialization areas (e.g., architecture, landscape design, HVAC, energy efficiency, passive design). Using the lessons learned and familiarity with one's own project, the students discussed the six main identified HP goals of the studio (i.e., reducing energy use, reducing greenhouse gas emissions, promoting health and wellbeing, water management, economic efficiency, and resiliency) and prioritized these goals for their projects. Next, they performed research on various sustainability rating systems and chose a district-level as well as a building-level rating system that best aligned with their goals and objectives. For instance, the Kish Island team decided to use LEED-ND, for their site evaluation and LEED-NC for their buildings due to the importance of reducing energy use and attention to human health in their projects and these rating systems. Next, within the selected rating systems, the students identified the credits to pursue, based on their feasibility and the project objectives, determining the level of their desired certification. To be able to specify a measurable target and benchmark for the building performance in areas such as the building's energy demand, carbon emission, and water consumption, students used online tools such as EDGE, Energy Star Portfolio Manager, and RETScreen (as listed in Table 2).

A-4. Evaluation. At the end of the preparation phase, the students conducted an evaluation meeting, discussing the decisions made at this stage and their tradeoffs, revised their decisions accordingly, and prepared a presentation summarizing the undertaken process to the class.

Phase B: Predesign

In the predesign phase, the students evaluated the site and its climatic context, gathering any prerequisite information for the schematic design phase, through the following three steps.

B-1. Climate Analysis. In this step, the students analyzed the climatic context of the project using related tools and the EnergyPlus Weather (epw) file of the project's location (Table 2) to create graphic charts of dry and wet bulb temperature of air, relative humidity, direction and velocity of prevalent winds, radiation, heating and cooling degree days, ground temperature, and so forth (Table 1). Since in this framework students selected their own sites based on sustainability criteria, they were instructed to start studying and considering potential passive design strategies of their climates in this phase and to use that information in the site selection process as well.

Table 1. Recommended performance metrics to be considered at each design step

Design steps	Recommended performance metrics
B-1. Climate Analysis	Relative humidity, Air temperature, Direct and diffuse radiation, Cold Degree Days (CDD), Hot Degree Days (HDD), Wind velocity, Wind direction, Ground temperature
B-2. Site Selection and B-3. Site Analysis	Distance from public transportation, Main streets and squares; Number of accessibility types; Width of roadways and sidewalks; Distance from hospitals, educational centers, shopping malls, and so forth; Distance from fuel stations; Underground water level; Distance from natural faults, Floodplains; Site Renewable energy potential; Noise pollution; Concentration of volatile Organic Compounds (VOC); Distance from historical landmarks and city center; Population density of the neighborhood; Economic condition of the vicinity; Quality and number of attractive views; Obstructions' height and distance; Solar right (maximum and minimum building height); Floor area ratio; Urban heat island, Sea level rise predictions.
C-1. Site Early Design	Buildings' distances from each other; Consideration of B-1, B-2, and B-3 parameters; Green area coverage; Fire truck accessibility; Architectural functionality; Number of parking spaces; Landscape permeability; Percentage of area with high solar energy potential; Solar reflectance of walkway and parking material reflection; Outdoor thermal comfort/ Universal Thermal Climate Index (UTCI)
C-2. Space Layout Planning	Spatial organization functionality; Visual comfort (Acceptable Task plane illuminance range); Acceptable Vertical illuminance/ Glare index range; Acceptable view factor; Thermal comfort: Operative Temperature, Predicted Mean Vote (PMV), Percentage of dissatisfied (PPD); Indoor air quality: Ventilation rate, Air Change Per Hour (ACPH), Minimum fresh air requirements; Acoustic comfort: Equivalent Continuous Sound Pressure Level (LAeq), Impact Insulation Class (IIC) or Weighted Normalized Impact Sound Pressure Level (Ln,w) acceptable range, Acceptable noise range
C-3. Form Early Design	Heating and cooling loads; Energy demand; Daylight Autonomy (UDI, DA, sDA); Annual Sunlight Exposure (ASE); Natural ventilation potential; Daylight availability/ Daylight Autonomy (DA); Envelope Solar heat gain; Thermal comfort autonomy
D-1. Façade Design	Improvement of C-3 metrics; Daylight Glare Probability (DGP); ACPH; Initial Cost; Maintenance cost; Constructability; View factor; Spatial Disturbance Glare (SDG); Primary energy; Energy Use Intensity (EUI); Embodied carbon; Simple payback
D-2. Envelope Design	Improvement of D-1 metrics; Sound Transmission Class (STC); Ln,w; Fire resistance hours; Condensation risk
D-3. HVAC System Selection	Socioeconomic factors: Initial cost, Operational cost, Installation time, Space requirement, Maintenance cost, Availability; Environmental factors: Energy efficiency; Health-related factors: Air filtering, humidification dehumidification CO_2 controller; System performance: System control, Air distribution, Ducted/ductless; User-related factors: Noise level, Safety, User friendliness, Aesthetics
D-4. Renewable Energy	Percentage of consumption coverage; Levelized Cost of Electricity (LCOE); SPB; Percentage of energy saving; Percentage of carbon emission decrease; Income; Energy generation.
E-1. Water Management	Collected wastewater; Harvested rainwater; Tank volume; Percentage of water saving; Indoor water demand; Water use intensity; Outdoor water demand; Process water demand.
E-2. Artificial Lighting	Number of lighting fixtures; Efficacy; Input power; Correlated Color Temperature (CCT); Color Rendering Index (CRI); Luminous flux; Standby power; Light distribution; Layout of fixtures; Operating hours; Initial cost; Maintenance cost; Visual comfort; Unified Glare Rating (UGR); Mean illuminance; Lighting energy.
E-3. Fire Safety	Evacuation time; Available Safe Egress Time (ASET); Required Safe Egress Time (RSET)
E-4. Acoustic Analysis	Sound Reduction Index (R); Reverberation time; Sound Pressure Level (SPL); Speech Transmission Index (STI).
E-5. CFD Analysis	PMV and PPD; Air pollution distribution; ACH
E-6. Final Evaluation	Total energy; Water management; Greenhouse gas emission (GHG); Resiliency; Health and wellbeing; Economic efficiency.

	Criteria	WI	Site 1	Site 2	Site 3	Site 4
1	Height restriction	2	1	1	3	3
2	Drainage infrastructure	1	1	1	1	1
3	Groundwater table	2	2	1	2	1
4	Being located on agricultural land	1	3	2	3	1
5	Future flood possibilities or impacts on neighboring buildings	2	2	2	2	2
6	Threat to endangered plants or animal species	1	2	2	2	1
7	Stormwater or wastewater management potential	2	2	1	1	3
8	Impact on availability of parkland	1	1	3	3	3
9	Need to complete any environmental impact reports	3	2	2	2	2
10	Public transportation potential	2	1	2	3	3
11	Community service accessibility	2	1	3	2	2
12	Restore or reuse of an existing building	2	1	1	1	1
13	Being located on the national register of historic places	1	1	3	3	3
14	Local or state government tax or development incentives	2	2	2	1	1
15	Brownfield redevelopment site	1	3	3	2	2
16	Supporting existing transit and urban settlement patterns	3	1	1	3	3
17	Existence of natural features to be protected, maintained, or restored	3	2	1	1	3
18	Existence of renewable energy sources on or adjacent to the building site	3	2	2	2	3
19	Matching with renewable energy sources in the region	3	2	2	2	2
20	Ability to enhance established neighborhood ecological patterns	2	2	2	2	3
21	Existence of off-site areas that could be used as part of the project	2	1	3	3	3
22	On-site and off-site features hindering renewable energy use	3	1	1	3	3
23	Solar collector using potential	3	2	2	3	3
24	Heliostat using opportunity	2	1	1	3	3
25	Adjacent buildings with dissimilar programs providing shared parking	2	1	3	1	3
26	View potential	3	1	1	3	3
27	Proximity to waste heat source	2	1	2	3	2
28	Harvesting rainwater from the site	2	2	2	2	2
29	Proposed regional access	2	1	2	3	3
30	Neighboring land use/ adjacent	2	1	1	3	2
31	Topographical features	3	2	2	2	2
32	Visual exposure	1	3	2	3	3
33	Availability of adjacent land for expansion	2	1	1	3	3
34	Daily traffic flow	1	1	1	2	2
35	Heat island effect	3	1	1	2	2
			108	121	163	173

1	2	3	Weighting index (WI) ranging from 1 to 3
1	2	3	Criteria scoring ranging from 1 to 3

Fig. 2. Site comparisons; Tabriz team.

B-2. Site Selection. In the site selection process, the students compared alternative sites with respect to the metrics such as accessibility and mobility, proximity to amenities, environmental and resiliency related conditions, economic and social circumstances, visual attractiveness, and so forth, as listed in Table 1. The students assigned weights to these categories based on the consensus reached at their goal-setting meeting and selected the most appropriate site accordingly, as depicted in Fig. 2.

B-3. Site Analysis. Here, the students performed a detailed site analysis determining the main site forces such as solar irradiation, pollutant sources, urban heat island, stormwater management, sea level rise predictions for coastal sites, preservation of native habitats, and so forth, as listed in Table 1. They also performed a SWOT analysis of the selected site, setting the ground for developing their design strategies.

Phase C: Schematic Design

This is the first phase in which students start to "design" as they used to know this term. In this framework, the schematic design phase was divided into the following three steps.

C-1. Site Early Design. The first task that the students performed at this stage was generating four different massing alternatives based on the analysis performed at Stage B-3 (Site analysis), and each building's physical and environmental requirement. Then, they compared the alternatives based on the performance metrics used at the site analysis step (listed in Table 1), and the goals and objectives discussed in the previous phase. Afterward, the students started the site planning process, designing the overall landscape layout. Next, they worked on sustainable site design strategies (e.g., overall vegetation and shading strategies, providing bicycle lines, permeable surfaces), based on the project objectives and site analysis.

C-2. Space-Layout Planning. The teams were divided temporarily at this point, with each student becoming in charge of designing one building (in teams with three students, one building was left out). To complete this step, students performed three main tasks. First, they found the environmental requirements of each space based on related codes and standards (listed in Table 1). The students then categorized and specified a weight for the requirements of all the spaces based on the project information, project goals and objectives, and site analysis. Next, they generated a bubble diagram for each building based on the environmental and architectural requirements of each space, and their compliance with the site potentials, determining the adjacencies and proximities between the spaces, as well as their sunlight accessibilities, views, and acoustic comfort conditions (Fig. 3). Lastly, the students used the bubble diagrams, constructability, mechanical and electrical considerations, as well as aesthetic preferences to generate at least three space layout planning alternatives for their buildings. The students then calculated the

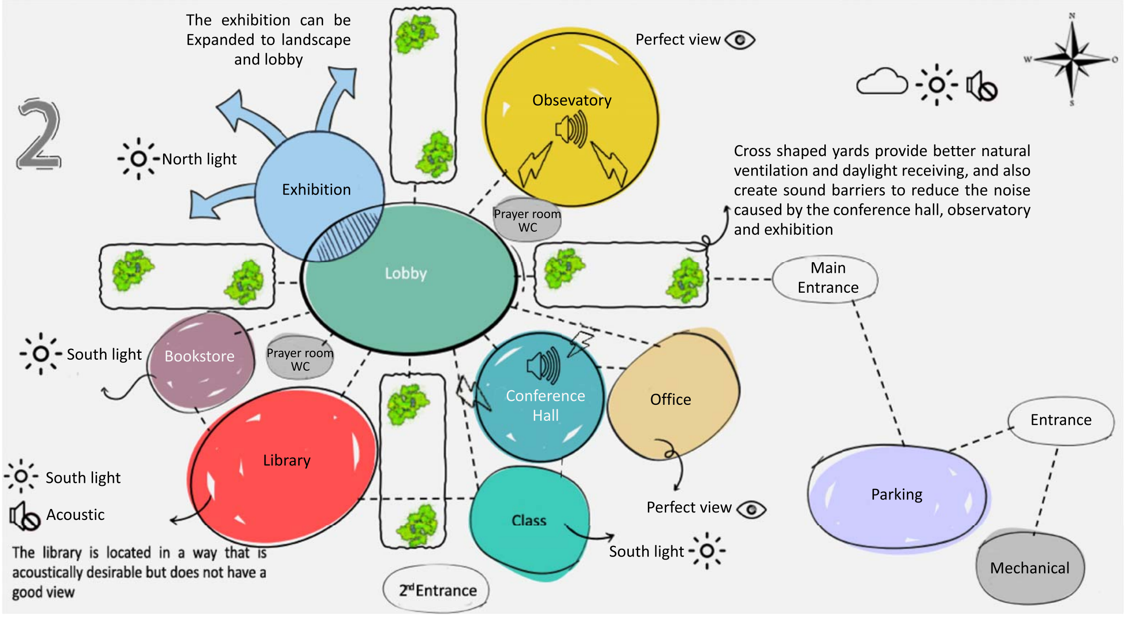
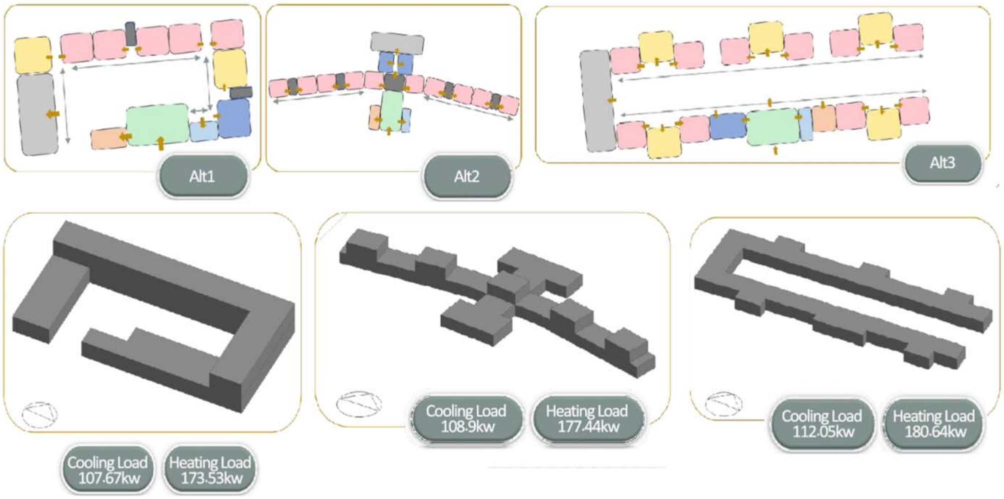


Fig. 3. Bubble diagram for the cultural center; Kish Island team.



		Importance	Alt1	Alt2	Alt3
Load Analysis	Heating Load	3	10	8	7
	Cooling Load	2	10	9	7
Total Score			50	42	35

		Importance	Alt1	Alt2	Alt3
Daylight	Residential	3	3	5	3
	Lobby	2	5	3	5
	Administrative	3	5	5	3
	Coffee shop	2	5	4	4
	Restaurant	2	3	5	3
	Services	1	5	3	5
Total Score			55	57	47

		Importance	Alt1	Alt2	Alt3
Thermal need	Residential	3	5	4	3
	Lobby	2	3	4	3
	Administrative	2	3	3	4
	Coffee shop	3	2	2	2
	Restaurant	3	4	2	3
	Services	1	4	3	3
Total Score			49	41	41

		Importance	Alt1	Alt2	Alt3
Silence	Residential	3	4	4	3
	Lobby	1	3	3	3
	Administrative	2	3	4	4
	Coffee shop	1	5	3	4
	Restaurant	1	4	5	4
	Services	1	3	4	3
Total Score			33	36	31

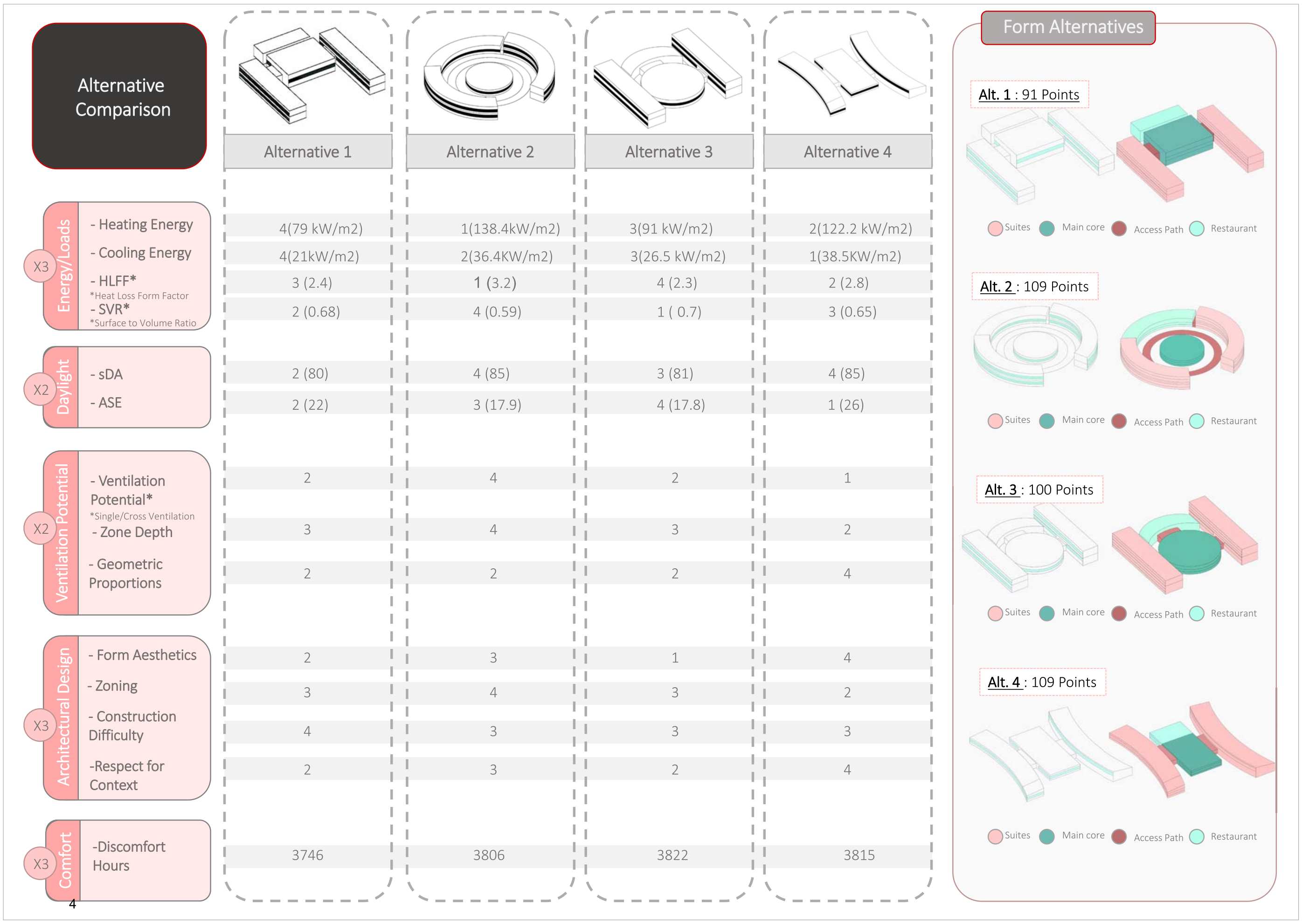
		Importance	Alt1	Alt2	Alt3
Views	Residential	3	4	5	3
	Lobby	2	4	3	4
	Administrative	2	4	3	2
	Coffee shop	3	4	3	4
	Restaurant	3	3	5	3
	Services	1	4	3	4
Total Score			53	54	46

		Importance	Alt1	Alt2	Alt3
Airflow	Residential	2	2	4	2
	Lobby	2	4	3	4
	Administrative	2	3	4	2
	Coffee shop	3	4	2	3
	Restaurant	3	2	4	2
	Services	1	4	3	4
Total Score			40	43	35

		Importance	Alt1	Alt2	Alt3
Exposures to users	Residential	1	3	4	3
	Lobby	3	5	5	5
	Administrative	2	4	4	4
	Coffee shop	2	3	4	4
	Restaurant	2	3	4	3
	Services	2	3	3	4
Total Score			44	49	48

		Importance	Alt1	Alt2	Alt3
Access	Residential	1	3	4	5
	Lobby	3	5	5	5
	Administrative	3	4	4	4
	Coffee shop	2	4	3	3
	Restaurant	2	3	4	3
	Services	3	3	4	5
Total Score			53	57	59

Fig. 4. Floor plan evaluation of the residential building; Urmia team.



Alternative Comparison			Alternative 1	Alternative 2	Alternative 3	Alternative 4
Energy/Loads	X3	- Heating Energy	4(79 kW/m2)	1(138.4kW/m2)	3(91 kW/m2)	2(122.2 kW/m2)
		- Cooling Energy	4(21kW/m2)	2(36.4KW/m2)	3(26.5 kW/m2)	1(38.5KW/m2)
		- HLFF* *Heat Loss Form Factor	3 (2.4)	1 (3.2)	4 (2.3)	2 (2.8)
		- SVR* *Surface to Volume Ratio	2 (0.68)	4 (0.59)	1 (0.7)	3 (0.65)
Daylight	X2	- sDA	2 (80)	4 (85)	3 (81)	4 (85)
		- ASE	2 (22)	3 (17.9)	4 (17.8)	1 (26)
Ventilation Potential	X2	- Ventilation Potential* *Single/Cross Ventilation	2	4	2	1
		- Zone Depth	3	4	3	2
		- Geometric Proportions	2	2	2	4
Architectural Design	X3	- Form Aesthetics	2	3	1	4
		- Zoning	3	4	3	2
		- Construction Difficulty	4	3	3	3
		-Respect for Context	2	3	2	4
Comfort	X3	-Discomfort Hours	3746	3806	3822	3815

Fig. 5. Form early design alternatives, Rasht team.

initial energy performance of each alternative by simply extruding the plan and compared the alternatives based on the selected metrics listed in Table 1. which included daylight, view, acoustics, and ventilation metrics (Fig. 4) in addition to functionality and aesthetics, and chose the alternative with the highest score.

C-3. Form Early Design. In this step, students worked on designing the building form, considering qualitative aesthetics criteria as well as performance metrics such as form factors, thermal loads, daylight and sunlight accessibility, natural ventilation potential, and so forth, as listed in Table 2 and depicted in Fig. 5. This step was divided into the two following tasks. First, based on the bubble diagram, the initial floor plan created at the previous step, the students developed different geometrical form alternatives for each building, known as the form finding process. Next, using the information gathered in the climate analysis stage, students tried various passive strategies such as atrium and skylight, solar chimney, and so forth (Fig. 6) to modify their forms and used performance metrics such as thermal loads, energy consumption, ventilation rate, and so forth (as listed in Table 1) to evaluate the alternatives, keeping in mind the architectural, structural, and mechanical constraints and objectives.

C-4. Evaluation. With the vision gained at the end of the schematic design phase, students performed an overall evaluation of their design process so far and reflected on the decisions that might have appeared to be optimized at the time, but may have had negative subsequences that appeared later, and revised their designs accordingly. At the end of this stage, the students finalized their design concept and evaluated its performance using the related software programs listed in Table 2, and demonstrated how they managed to improve their performance metrics throughout the design process as part of their midterm project submission. The totality of the architectural concept presented at this stage was set as a starting point for the next phase, and no more design iterations were performed on the building massing and concept throughout the rest of the design process, although the building envelope, space layouts, and structural, mechanical, and construction details were brought up to the foreground of the design endeavors during the design development phase.

Phase D: Design Development (A)

The design process that the students followed at this phase can be described within four stages.

D-1. Façade Design. In this step, students designed and evaluated the building's façade with the aim to improve the building's visual comfort, energy demand, and aesthetic qualities in four major steps. First, designing and optimizing windows' characteristics (e.g., location, size, type, visual transmittance, solar heat gain coefficient) considering their potential advantages in increasing daylight accessibility and disadvantages in adversely

Table 2. Recommended software program and tools and their applications in various stages of the IDP

Software tools	Design steps	Domain	Covered parameters and performance metrics
AndrewMarsh	B-1. Climate Analysis, B-2. Site Comparisons, C-3. Form Early Design	Daylighting and glare	Illuminance, Daylight Factor (DF), ASE, DA, UDI
		Climatic analysis	Relative humidity, Air temperature, Radiation, Wind velocity, Wind direction, Sun azimuth and altitude
CityBES	B-2. Site Selection, B-3. Site Analysis, C-1. Site Early, Design	Energy	EUI
		Carbon emission	Total GHG emission
		Water management	Water use
		Renewable energy	PV electricity generation potential
		Benchmarking	—
		Economic efficiency	Cost, SPB
Climate Consultant	B-1. Climate Analysis	Climatic analysis	Relative humidity, Air temperature, Radiation, Wind velocity, Wind direction, Ground temperature, Sun azimuth and altitude
Climate Studio	B. Predesign, C. Schematic Design, D. Design Development (A), E-2. Artificial Lighting, E-3. Fire Safety, E-4. Acoustic Analysis, E-5. CFD Analysis, E-6. Final Evaluation	Climate analysis	Windrose, UTCI, Air temperature, Relative humidity
		Daylighting and glare	DF, SDA, ASE, SDG, DGP
		Artificial lighting	Illuminance, Lighting power loads
		Energy	EUI
		Thermal comfort	Comfort hours
		Carbon emission	Embodied carbon, Operational carbon
		Renewable energy	Energy generation
Covetool	B. Predesign, C-1. Site Early Design, D-1. Façade design, D-3. HVAC	Daylighting and glare	SDA, ASE
		Energy	EUI
		Carbon emission	Carbon emission, Embodied carbon
		Water management	Indoor Water Use, Water Use Intensity, Outdoor water use, Cooling tower water Use, Rainwater use
		Economic efficiency	Costs
		View analysis	LEED v4 quality views
		Climatic analysis	Relative humidity, Air temperature, Radiation, Wind velocity, Wind direction, Ground temperature, Sun azimuth and altitude
		Code compliance	—
		HVAC modeling	—
Design Builder	C-3. Form Early Design, C-4. Evaluation, D. Design Development (A), E-5. CFD Analysis, E-6. Final Evaluation	Energy	Total energy, Primary energy, EUI
		Carbon emission	Embodied carbon, Operational carbon
		Thermal comfort	Comfort hours
		Daylighting	SDA, ASE, DF
		CFD	Air velocity, Air pressure, Air temperature, PMV, PPD
		Natural ventilation	ACH
		HVAC modeling	—
		Envelope detailed analysis	Condensation risk
		load calculation	Cooling and heating loads
		Economic efficiency	Costs
		Renewable energy	Energy generation
Dialux	E-2. Artificial Lighting	Artificial lighting	LPD, Illuminance, UGR
EDGE tool	A-3. Goal Setting	Benchmarking	_
		Water management	Final water use
		Energy	Final energy use
		Economic efficiency	Costs, SPB
Energy Star Portfolio Manager	A-3. Goal Setting	Energy	Site/Source EUI Site/Source energy use Energy cost Total GHG emissions
		Water	Water use intensity (m^3/m^2)
		Waste and materials	—
ENVI-met	B. Predesign, C3. Form Early Design, D-1. Façade Design, D-2. Envelope Design	Microclimate study	Sun and shade hours, Solar energy gain, Air temperature, Relative humidity, Wind speed, Wind comfort, GHG emission, Façade temperatures
Honeybee	D. Design Development (A), E-2. Artificial Lighting	Daylighting and glare	DF, SDA, ASE, DGP, Illuminance
		Energy	EUI

Table 2. (*Continued*.)

Software tools	Design steps	Domain	Covered parameters and performance metrics
		Thermal comfort Artificial lighting Load calculation Envelope detailed analysis HVAC modeling	PMV Illuminance Cooling and heating loads Condensation risk, Thermal bridge —
Ladybug	B-1. Climate Analysis, B-3. Site Analysis, C-1. Site Early Design, C-3. Passive Strategies, C-4. Evaluation, D-1. Façade Design, D-4. Renewable Energy Feasibility Study	Climatic analysis	Thermal climate index, Relative humidity, Air temperature, Radiation, CDD, HDD, Wind velocity, Wind direction, Ground temperature, Sun azimuth and altitude
		Daylighting	Sunlight hours, Solar heat gain, Sun position, Solar right (max and min building height)
		View analysis	Horizontal vision, Sky view factor
		Renewable energy	Renewable energy potentials, Optimal tilt angle
		Thermal comfort	UTCI, PMV, PPD
Pachyderm Acoustic	E-4. Acoustic Analysis	Acoustics	Reverberation time, Sound Pressure Level (SPL), Speech Transmission Index (STI)
Pathfinder	E-3. Fire Safety	Fire safety	Evacuation time, evacuation path, occupants flow rate (person/s), Occupation density (person/m^2), Social distance behavior, Smoke and fire visualization
Rainwater Harvesting Tool	E-1. Water Management	Water management	Rainfall, Rainwater collected
Retscreen	A-1. Project Setup, A-3. Goal Setting	Benchmarking Energy Economic efficiency Carbon emission Renewable energy	— EUI Initial cost, Annual cost GHG emission Energy generation, Energy production cost
Simscale	B-2. Site Selection, B-3. Site Analysis, E-5. CFD Analysis	CFD	Air velocity, Air pressure, Air temperature
Urban Modeling Interface (UMI)	C-1. Site Early Design	Carbon emission Energy Daylighting Health	Site GHG emission Site EUI Site sDA Walkability

increasing the building cooling loads, while insuring economic viability of the high-performance windows. Then, students assessed façade-related passive strategies such as static and dynamic shadings, green walls, and double skin façades based on corresponding energy performance metrics, such as thermal loads, thermal comfort, natural ventilation, and visual performance metrics including Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) ensuring economic efficiency and justifiability of each strategy. Lastly, they performed daylight and energy performance analysis considering all the new design parameters and evaluated the results (Fig. 7).

D-2. Envelope Design. Building envelopes play an important role in creating thermal comfort for building occupants, decreasing building thermal loads and HVAC systems energy use, as well as controlling outside noise. At this stage, the students performed the following four steps for reaching the best composition for their building envelopes. The first step was material selection. Here, the students performed a sensitivity analysis on the buildings' heat loss and gain to reveal the most influential building components (i.e., roof, external walls, glazing, and floor) on energy efficiency and thermal comfort of the building. Then, they selected three alternatives for each of the envelope components including smart materials such as Phase Change Materials (PCMs), electrochromic, thermochromic, and photochromic glazing. Students evaluated the selected materials based on their structural strength, compliance with fire safety codes, economic efficiency, thermal and acoustic comfort, building energy use, and embodied carbon and life cycle analysis. Next, they used passive strategies such as thermal mass and insulating materials considering their compatibility with climatic context and regional codes to reduce the building's thermal loads and energy use, while improving its thermal comfort. Lastly, they ran performance analysis and evaluated the proposed alternatives using performance metrics such as primary and final energy use, and so forth, as listed in Table 1. Fig. 8 depicts an example of results achieved in this step.

D-3. HVAC Systems' Selection. In many climatic contexts, providing thermal comfort throughout the whole year is almost impossible without using HVAC systems. The students chose a suitable HVAC system for their projects based on their scales, specified requirements and goals, and environmental conditions. The students followed three main steps to choose the best HVAC system for their buildings. First, they performed case studies on commonplace HVAC systems of buildings with similar scales and climatic contexts, and environmental conditions. Afterward, they compared the alternatives by assigning weights to different socioeconomic, environmental, and user-related factors, and eliminated the systems with the lowest scores (Fig. 9). Next, they performed energy and thermal comfort performance simulation to select the best HVAC solution for their project.

INDICATORS	METRICS	SPACES	IMPORTANCE (1-5)	SIMULATION RESULTS			POINTS (1-5)		
				ALT 1	ALT 2	ALT 3	ALT 1	ALT 2	ALT 3
Loads	Heating load	Whole building	5	157.72	144.96	264.42	3	4	1
	Cooling load	Whole building	5	199.45	190.2	278.97	3	4	1
Load points							30	40	10
INDICATORS	METRICS	SPACES	IMPORTANCE (1-5)	SIMULATION RESULTS			POINTS (1-5)		
				ALT 1	ALT 2	ALT 3	ALT 1	ALT 2	ALT 3
Daylight	Average daylight factor 5>x>2:5, x>5:4, x<2:1-3	Ground floor	1	0.92	0.76	0.65	0	0	0
		First floor	2	1.68	1.68	0.82	0	0	0
		Whole building	2	1.3	1.22	0.73	0	0	0
	Uniformity min/average x>0.3:5, x<0.3:1-4	Ground floor	1	0.16	0.1	0.05	0	0	0
		First floor	2	0.23	0.2	0.09	0	0	0
		Whole building	2	0	0	0	0	0	0
Daylight points							0	0	0
INDICATORS	METRICS	SPACES	IMPORTANCE (1-5)	SIMULATION RESULTS			POINTS (1-5)		
				ALT 1	ALT 2	ALT 3	ALT 1	ALT 2	ALT 3
Ventilation	ACH	Ground floor	4	1.74	1.76	1.6	3	3	3
		First floor	3	1.75	1.11	1.3	3	2	2
		Whole building	3	1.71	1.48	1.5	3	2	2
Ventilation points							30	24	24
INDICATORS	METRICS	SPACES	IMPORTANCE (1-5)	SIMULATION RESULTS			POINTS (1-5)		
				ALT 1	ALT 2	ALT 3	ALT 1	ALT 2	ALT 3
Comfort	% Comfort (free running)	Ground floor	3	60%	45%	45%	2	1	1
		First floor	4	57%	77%	63%	1	4	2
		Whole building	3	59%	59%	53%	1	1	1
Comfort points							13	22	14
Final points							73	86	48

Fig. 6. Form early design of the sports facility; Tabriz team.

Lastly, they tested some strategies including utilization of local or central air preheating systems, heat recovery, and mixed mode ventilation to optimize performance of their selected HVAC systems.

D-4. Integration of Renewable Energies. The students followed two main steps to integrate their designs with appropriate renewable energy technologies. First, they performed a feasibility study on the renewable energy sources common within the geographical location of the project and performed the following analysis accordingly: radiation analysis for solar energy systems, air flow and wind analysis for wind energy systems, soil properties and temperature for geothermal systems, and waste analysis for biomass energy systems. If applicable, students also assessed using local renewable power plants, based on the information collected at site selection (Stage B-2). Next, students conduct performance analysis for the selected systems. Here, they considered government subsidy schemes of renewable energy policies for electricity generation, and any other relevant performance and economic metrics identified in Table 1, and calculated and analyzed the amount of energy generation and corresponding payback periods (both for onsite and offgrid energy generation). The students also determined the location of their photovoltaic systems by performing a radiation and shadow analysis, and selected the best locations on site for placement of the panels, and compared the alternatives as depicted in Fig 10.

Phase E: Design Development (B)

In this phase, the students performed final evaluations and assessments for their designs, which lead to the generation of architectural drawings and design details. The students completed this phase in five main steps.

E-1. Water Management. To come up with a water management plan, students performed indoor and outdoor water consumption assessments for their proposed designs. For reducing indoor water consumption, they assessed use of water saving products for taps, shower heads, washing machines, and so forth, and evaluated use of grey water treatment systems. For reducing outdoor water use and controlling stormwater runoffs, they evaluated use of different landscaping and vegetation plans, as well

	Metrics					Scores					
	sDA	ASE	SDG	Total Energy (KWh/sqm)	Discomfort Hours	sDA	ASE	SDG	Total Energy (KWh/sqm)	Discomfort Hours	Total Score
Alt1	79	14.47	24.6	197	1604	1	2	3	2	2	10
Alt2	81	15	24.8	199	1575	2	2	3	2	3	12
Alt3	82.72	43.2	56.5	207	1620	3	1	0	1	1	6

Fig. 7. Facade design – Performance analysis and evaluation of the commercial building; Urmia team.

as implementation of a rainwater harvesting system and use of raingardens on site.

E-2. Artificial Lighting. To come up with a proper artificial lighting design for the buildings' interiors as well as the landscapes, students followed two steps. The first step was providing target illuminance for a set of representative spaces based on their specific functional requirements, while giving attention to other parameters of selected lighting systems as listed in Table 1, namely Color Rendering Index (CRI) and Correlated Color Temperature (CCT). They also considered proper numbers, lighting distribution, and arrangement of lighting sources, as well as their efficiency and efficacy, as depicted in Fig. 11. The next step was designing the lighting control systems to control fixed groups of lights. If dynamic or daylight-responsive shadings were integrated into the buildings, further attention was given to synchronize the two systems.

E-3. Fire Safety. In this step, students studied local and international fire safety codes and guidelines, assessing population density of the buildings, providing adequate means of escape, and performing smoke extraction assessments. They also reviewed other fire safety related measures that are addressed in previous steps including building location within the site and using flame-retardant materials for interiors.

E-4. Acoustic Analysis. While the buildings' acoustic performance was initially considered during the site selection, site analysis, site early design, and space-layout planning (Steps B-2 to C-2), in this step, students analyzed acoustic performance of external walls, windows, and roofs, as well as internal partitions and floors, and made potential enhancements to meet the acoustic standard requirements of each space.

E-5. CFD Analysis. In this step, to accurately predict thermal comfort and indoor air quality of the buildings, students performed an internal CFD analysis for naturally and mechanically ventilated spaces in their buildings. Due to its high computational cost, this analysis was done for critical spaces in each building. The results were used to modify the air inlets and outlets.

E-6. Final Evaluation. At the end, the students reviewed all the information and decisions made in previous steps, ensuring that they have achieved the specified benchmarks and rating system certification levels for their projects. In their final submissions, the students reported 43% reduction in the total energy consumption, 30% reductions in total carbon emissions, and 27% increase in the annual thermal comfort autonomy of the final designs compared to the base case models (Fig. 12).

The students also achieved 25%–40% reduction on their indoor water use, compared to the baselines (e.g, LEED and EDGE) by using mechanical systems with minimum water requirements, low-flow fixtures and fittings. In addition, by selecting drought-tolerant and self-sustaining plant species, all teams were able to minimize the need for irrigation throughout the year. Moreover, the Rasht and Urmia teams working on climate contexts with high annual rainfalls, managed to design rainwater harvesting systems for their projects and reused the collected water for their landscape irrigation needs.

With regard to the comfort and wellbeing goals, the students used design strategies that enhanced senses of comfort inside

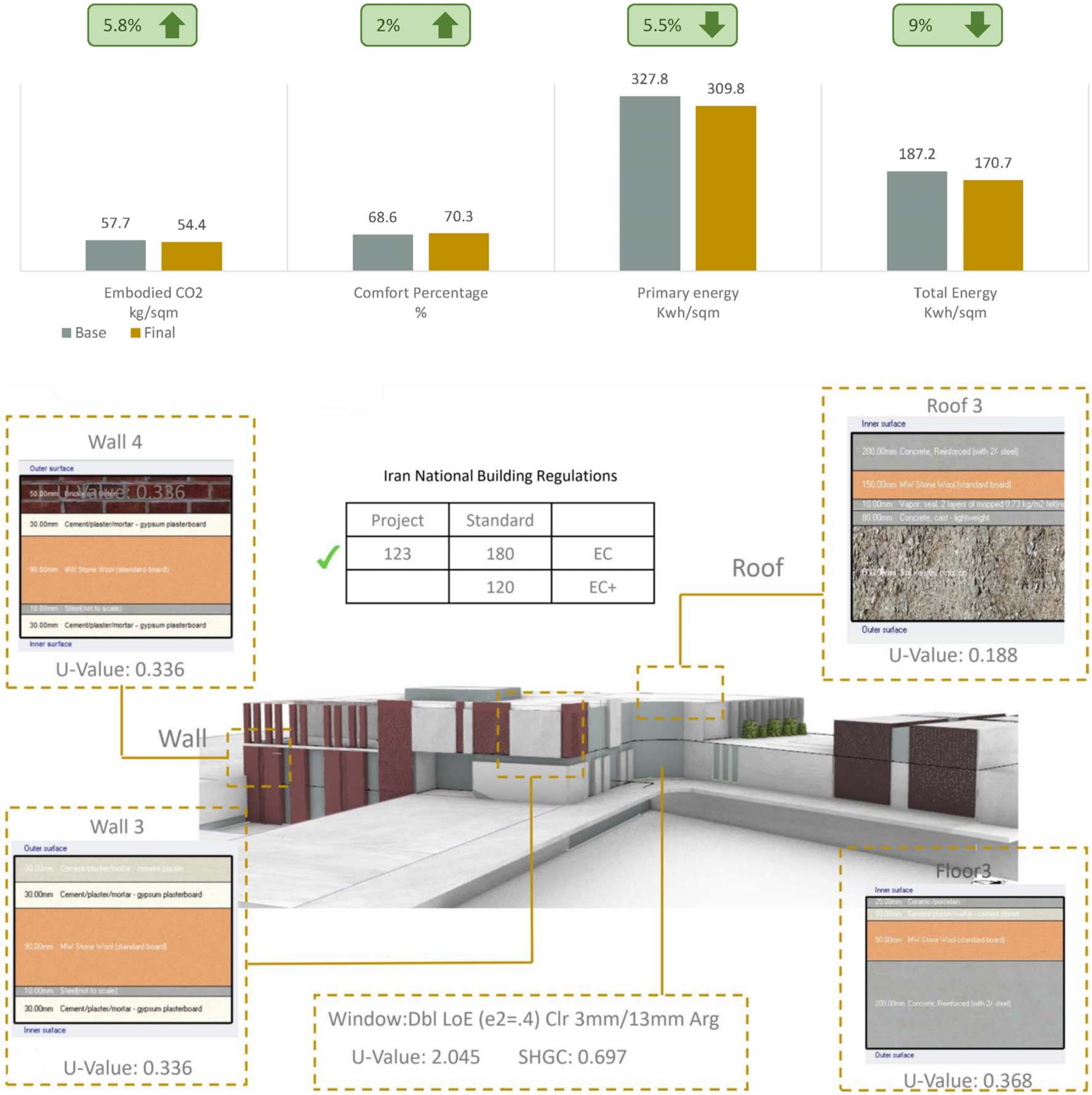


Fig. 8. Final Envelope design solution of the convention center; Urmia team.

and outside the buildings. For instance, they considered unit-level controls for ventilation and heating, and envisioned ceiling fans for common spaces in addition to air-conditioning systems to address peak heat waves. In addition, more than 90% of occupied spaces on average were designed to have a direct view to the outdoors and more than 50% of occupants, on average, had access to operable windows, and full control of daylighting and electrical devices. Regarding acoustical comfort, all teams managed to group the loud and quiet spaces together and considered appropriate sound insulation for all the spaces based on local building codes. Lastly, the students were able to provide well balanced natural daylighting in most spaces. They performed extensive modeling in spaces such as atriums and double façades to minimize solar heat gain and glare to ensure uniform light distribution throughout the space, while maintaining 55% daylight autonomy for all the buildings.

Discussions

Experiencing an IDP, BIM-based HP design studio, with the level of attention given to various performance metrics throughout the design process, was a unique experience due to the short time span of the academic semesters and complexity of the design process. Our attempt to break down this complexity to practicable design steps for MS students in the Building Science program had many accomplishments and lessons learned, which are worth discussing for future experiences.

Not having restrictions on the choice of software programs. Each team was allowed to use any software programs of their choice in the design process for 3D modelling, performance analysis, simulation, and presentation. This freedom of choice affected the number of design alternatives they could manage to analyze at each design stage. For instance, some groups

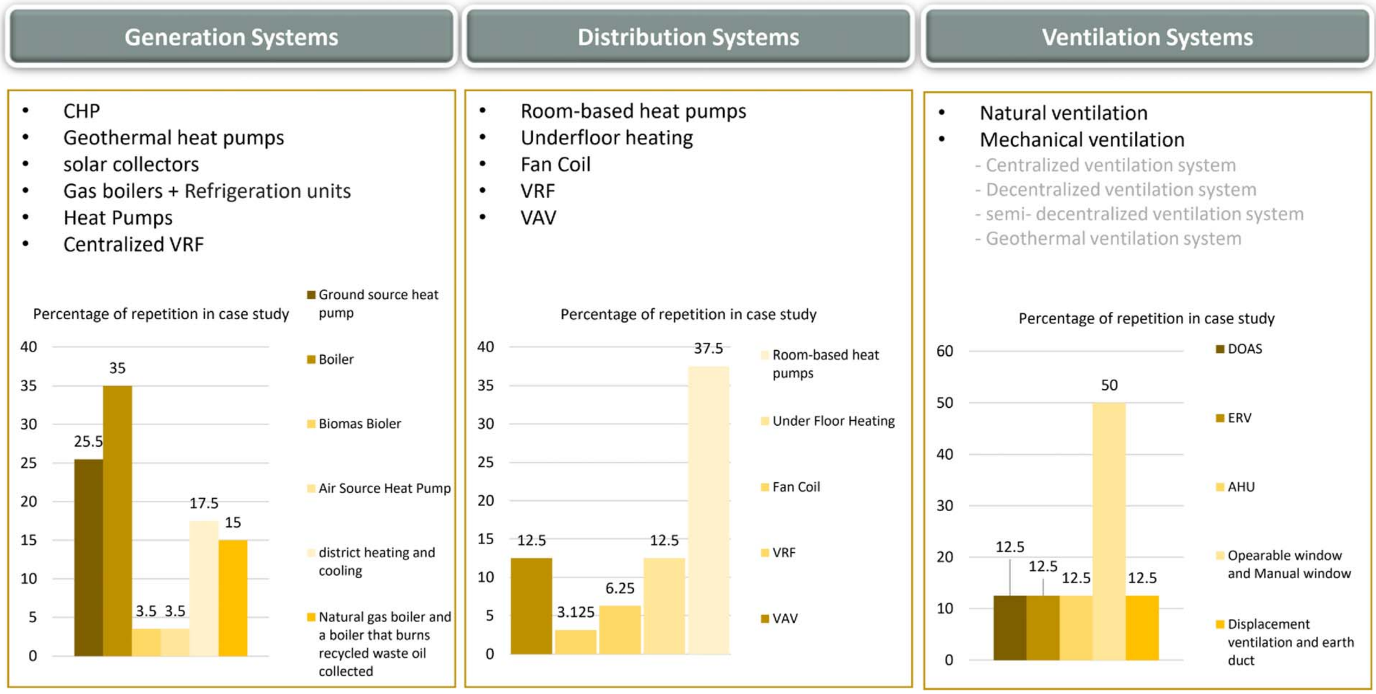
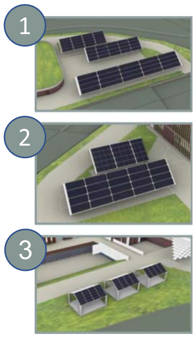


Fig. 9. Compilation of the case studies on HVAC system selection of the commercial building; Urmia team.



PV DESIGN STRATEGIES	PV AREA M2	PANEL NUMBERS	TOTAL RADIATION KWH	PV GENERATION PER YEAR KWH	INITIAL + MAINTANANCE COST (25 YEARS) M.TOMAN	GENERATION ELECTRICITY PRICE (25 YEARS) M.TOMAN	LCOE	SPB	
Parking 1	463.0	240	927331.7	147677.6	1289.9	3359.7	0.38	8.44	✓
PARKING 2	205.0	106	373541.6	59486.5	571.1	1353.3	0.42	9.28	✓
West pergolas	38.9	20	76196.4	12134.3	108.4	276.1	0.39	8.63	

Fig. 10. Procedure of determining the location and quantity of PV panels; Urmia team.

used the DIVA plug-in for assessing visual comfort in different form and façade design alternatives which led to more time spent for each assessment than those who used ClimateStudio. Therefore, the latter groups could assess a higher number of design alternatives and met the deadlines easier. The same situation occurred when some groups used the DesignBuilder program for simulating thermal loads of the buildings, while others preferred using the Archsim plug-in which considerably has less process time. In the future experiences, the tools can be limited at each design stage to make the performance evaluation processes of all groups more comparable.

Limitations of software programs. Several tools required for performance analysis in the studio had limitations regarding their access for students, project scales, and detailing requirements, or their output resolutions. For instance, modeling the impact of an adjacent located near a lake can be done by the ENVI-met program, but the program was not freely available to the students at the time. Thus, the group had to neglect the microclimate of their selected site and continued the design process by using the weather file only. Also, accurately simulating the detailed water source heat pump systems (WHSP) was not possible for the same group due to the lack of detailed information that Energyplus needed for performing the analysis. The students, therefore, needed to simplify their analysis using the program defaults. For future studios, the process will go much smoother if the requirements and limitations of all the main software programs are checked before starting the semester, and provisions to deal with the issue are considered.

Time limitation/ Lack of involvement of multiple disciplines. All the individual and group tasks of the design process needed to be completed within the roughly 4-months duration of the studio, and many steps had to be addressed very quickly with not enough time for students to redo some of the processes to fix their mistakes or learn to work with unfamiliar software tools. For the future, involving more than one department in the process would lead to division of tasks from the beginning

Num.	Prod.	Product	P	Φ	Luminous efficacy
12	FLOS	COMPASS SPOT	70 W	4967lm	71 lm/w
4	RIO	36W4000KCRI9066D	41 W	2320lm	56.6 lm/w
4	SLV	LENITO TRACK	22.9 W	2522 lm	110.3 lm/w

Store	Calculated	Target	Check
Shelves	575lx	>500lx	✓
Desk	350lx	>500lx	✓
Floor	600lx	>500lx	✓

Fig. 11. Artificial lighting analysis for a storeroom in the commercial building; Urmia team.

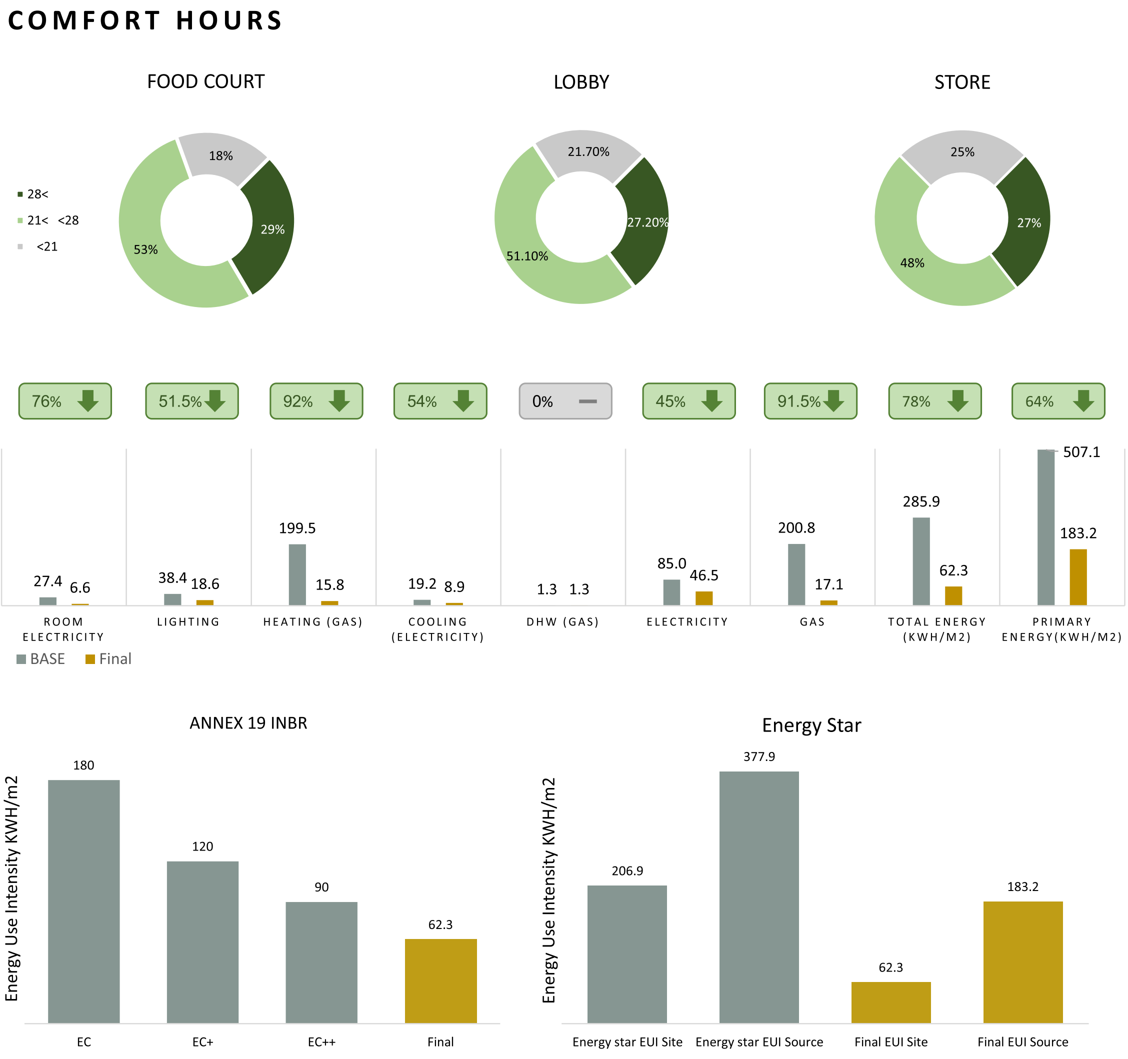


Fig. 12. Final building energy performance evaluations; Urmia team.

and it would therefore facilitate having a compact schedule without imposing as much pressure on the students. This decision, at the same time, better resembles the integrated design process in the industry and can potentially lead to more accurate results. Our recommendation for this process is to add one discipline at a time to be able to manage the transformation smoothly. The most beneficial disciplines to be added to the process in terms of learning outcome for the students throughout the semester are mechanical engineering, construction management, civil engineering, landscape design, structural engineering, and interior design. However, adding more disciplines, at some point, would decrease the efficiency of the process. Future research is needed to find the optimum number of disciplines to collaborate within a semester-long design studio.

Low level of motivation. The very compact nature of the studio required a high level of motivation from the students' part, so that they could follow all the steps on time. This was not the case for all the teams. The low level of motivation in some of the teams can be linked to several reasons. First, the virtual nature of the studio prevented students from having face to face interactions, and they had to settle with online communication tools with lower qualities. Also, less connections were formed across the teams and therefore students were not comfortable asking for help from their peers. For future and physical design studios, we recommend conducting several eco-charrettes within the process, to have a good amount of work done with high-level of energy within a day and have some more relaxing days in between.

Reported level of Energy Use Intensities (EUIs). The students defined their EUI baselines based on both national median EUI for building type and local energy codes for each climate (Iranian National Code 19). However, since economic considerations and the return on investments were important considerations in this studio, and given that the study is conducted in a developing country (Iran) with a lot of subsidies on Energy prices, more reduction on energy consumptions would not seem practical and achieving zero carbon was not feasible due to the high investment cost for onsite solar energy generation in our region.

Conclusion and Future Work

Incorporating environmental awareness and energy efficiency measures into design studios is a major concern for scholars of architectural education nowadays. Based on the emerged promising approaches of IDP and BIM technologies in design and construction of HP buildings, we developed a pedagogical framework for teaching an HP design studio for third semester students in the Building Science program in the Architecture and Urban Planning department, at SBU. The course pedagogy focused on whole system design approach through setting multiple high-performance goals for the projects, producing multiple design alternatives on most design steps, and evaluating functional, environmental, and cost implications of each alternative, and iterations on design steps.

Among the most important opportunities provided in this framework is the flexibility provided for the students in four areas of: (1) teaming and assigning tasks and responsibilities; (2) the sustainability assessment systems including the parameters and performance metrics to evaluate the results; (3) implemented software tools; and (4) the design processes allowing students to have more iterations on steps that seem more influential on their performance goals. However, the two most important limitations of the implemented approach can be specified as too much workload for the students and lack of involvement of students from other disciplines. Both issues have the potential to be alleviated by inviting students from other disciplines to join the studio and adjusting the roadmap accordingly.

The pedagogical methodology presented in this study is applicable to other contexts and can be adjusted to different educational settings, based on the students' level of knowledge, familiarity with HP concepts and simulation software tools, and so forth. The future work for this project includes comparing the results of the experience with similar HP design studios on multiple levels, including the learning outcomes of the students, creativity and novelty of the produced designs, and overall projects' success in addressing HP goals of the projects. A plan can be further developed for overcoming the potential shortcomings of the experience and evolving the presented framework accordingly.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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