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Lessons Learned during the Early Phases of a Modular Project: A Case Study of UNLV's Solar Decathlon 2020 Project

Jin Ouk Choi, Ph.D., AM.ASCE,[1] Seungtaek Lee, Ph.D.,[2*] Eric Weber[3]

[1] *Department of Civil and Environmental Engineering and Construction, University of Nevada, Las Vegas, 4505 S. Maryland Pkwy. Las Vegas, NV 89154, USA,* E-mail address: jinouk.choi@unlv.edu
[2] *Department of Civil and Environmental Engineering and Construction, University of Nevada, Las Vegas, 4505 S. Maryland Pkwy. Las Vegas, NV 89154, USA,* E-mail address: seungtaek.lee@unlv.edu
[3] *College of Architecture, Planning, and Landscape Architecture, University of Arizona, 1040 N. Olive Rd, Tucson, AZ 85719, USA,* E-mail address: ericdweber@arizona.edu

1. **Abstract:** The U.S. Department of Energy conducts the Solar Decathlon competition as a student-based achievement that encourages sustainable design with energy efficiency and solar energy technologies. In the 2020 competition, the University of Nevada, Las Vegas (UNLV) team designed, fabricated, and constructed a net-zero modular house that applies innovative and highly efficient building technologies. This paper focused on the lessons learned during the early phases of this ongoing modular project. The research methodology included obtaining feedback from key project participants using a well-structured questionnaire. The results showed that the major items/challenges in the project's planning phase included selecting the modular size, planning the construction system, planning the materials and procurement, estimating costs and duration, selecting a fabricator, collaboration and communication, safety, and planning module transportation. These findings will help modular practitioners and future Solar Decathlon competition participants better understand how and what factors they should consider most during the early phases through the lessons learned.

Keywords: Green building; Industrialized construction; Off-site construction; Solar Decathlon

1. INTRODUCTION

The Solar Decathlon (SD) is a collegiate competition organized by the U.S. Department of Energy for universities worldwide in which teams demonstrate energy efficiency and solar energy technologies that meet residential energy requirements in an integrated, well-designed home. The main objectives of the SD are to (1) prepare and train students for the renewable energy workforce; (2) educate them on current technologies for energy efficiency, renewable energy, and sustainable buildings; and (3) demonstrate high-performance houses to the public [1]. The SD framework provides students with a proven material-output benchmark to determine where cost improvements can be made while maintaining energy efficiency. For the 2020 competition, according to the original rule published in 2018, the competition required the National Showcase teams to design and construct a modular, transportable house, which can be shipped to the competition site in Washington, DC. Teams were required to transport their house to the competition site, where the house was going to be evaluated in 10 categories, and offered free tours to the public. After the competition, the team would bring the house back to the final project location. Later, these requirements were changed (no in-person competition in Washington, DC) in 2020 due to the COVID-19 outbreak.

The UNLV team chose a modular house method with one truckable-size module for the competition because it was the most suitable method for the objectives of the SD competition and would help the team to score more points.

Modular methods can improve sustainability performance [2,3]. For example, construction waste can be reduced significantly by the modular method [2] because most of the construction work is carried out in a specialized modular factory, and construction materials are used only as needed. Moreover, the remaining materials can be reused in the next project. This also enhances energy efficiency, reduces the destruction of sensitive landscapes, and improves quality control. Also, construction-related site disruption, such as dust and noise creation on construction sites, can be mitigated [4]. Most of the on-site work is done to assemble the factory-made modules, which reduces construction dust emissions by approximately 30%, as compared to a traditional construction site [5,6]. In addition, the modules can be relocated and reused, so there is almost no building demolition waste or contamination. Prefabricated modular design allows flexibility in both public and private uses. The need to be both sustainable and resistant to natural hazards such as hurricanes or flooding can be met by incorporating modular construction [7]. Major attractions of modular construction include the infrastructure's ability to adapt to any neighborhood and the quality of the factory-made components so that the home can be transported and installed relatively quickly in its final volumetric form. The modular construction method implemented in this competition allowed students to study innovative techniques, industry practices, and standards and helped to create a link between concept and reality [8]. Modular construction techniques help to maximize performance and increase quality [9], which is one of the key elements required in the competition. The benefits of modular houses incorporate the need for health, safety, and comfort for residents with a design that allows for customizable spaces and additions to the structure.

In addition, modular construction benefits general construction performance. Prefabrication significantly enhances project management, improves work stability, limits financial outlays, and shortens the construction schedule [2,3,10–15]. According to recent research, the modular method can save up to 20% in costs [16]. Labor and maintenance expenses also can be minimized by installing complicated structures in a regulated environment and reducing on-site construction time. In addition, the project schedule can be shortened by up to 50% because of increased productivity, parallel construction, and minimal weather impacts [16]. Also, offsite construction simplifies the permit/review phase [17]. The modular method also helps tackle health and safety issues on-site since a factory environment is much safer [18–21]. Moreover, the method shows better performance with respect to labor productivity [16,22] and construction quality [16,18,21].

Despite these advantages, modular construction has some challenges in practice. Most significantly, modular construction has higher initial project costs because of the additional project costs for planning, design, and procurement due to long-lead materials [21,23–25]. Also, the modular method requires communication and coordination that are more extensive and frequent [23,25–27]. Furthermore, module transportation is challenging. Factory-made modules are usually heavier and larger than conventional construction parts and materials are [28].

The study aimed to analyze the major items, issues, considerations, and challenges that were addressed during the planning phase of the ongoing Mojave Bloom modular house project by UNLV for the SD 2020 competition. This paper reported solutions for future modular construction work by illustrating all of the challenges and the necessary measures adopted by Team Las Vegas during the project-planning phase. Thus, this paper could provide valuable information to help future practitioners can make better decisions in future modular projects.

Figure 1. UNLV's Solar Decathlon 2020 project in progress

About the UNLV's Solar Decathlon 2020 Project

UNLV's SD 2020 project, Mojave Bloom, was inspired by traditional Islamic Sahn and was designed to be a therapeutic environment for the United States military veterans experiencing the negative effects of traumatic stress. Mojave Bloom had a total area of 628 square feet with one bedroom and one bathroom. The total number of team members was 41, including undergraduate and graduate students from different disciplines, an engineer, and professors. The first leadership team meeting was held in September 2018. The planning and design periods for the Mojave Bloom project was about 18 months, and Team Las Vegas finished all project activities such as the framework, subfloors, interior wall framing, drilling of pipes, HVAC rough-in, plumbing rough-in, electrical rough-in, and installation of electrical boxes on-site as of December 2020. Because of the COVID-19 situation, the in-person competition at Washington D.C. was canceled so that the house was transferred directly to the final site location, Las Vegas Community Healing Garden, Las Vegas, NV. Figure 1 shows the pictures of the project during the fabrication/construction.

2. RESEARCH METHODOLOGY

The study's research methodology included obtaining feedback from key personnel and data by the observation of the authors during the meetings. Information regarding the constraints in the project's planning phase was gathered from the team's architecture lead and construction manager. Google Forms was used to obtain the questionnaire feedback. Most of the questions used in the questionnaire were drawn from analyzing the literature and write-ups by previous teams on their competition experience as well as from direct observation. There were 15 total questions, with most being short open-ended questions. Two questions were scored with five-point Likert scales. A weekly meeting with the core team, which included the faculty and student team leads, and site visits also helped in gathering more information for this research.

3. QUESTIONNAIRE FEEDBACK

The responses received were summarized in this section. The major advantages of modular construction in the project were stated as including cost-effectiveness, ease of transport, compact, stackable, energy efficiency, design flexibility, and time savings in construction. According to the key personnel, the major difficulties associated with the project's planning phase involved communication and collaboration with different disciplines. Because the modular project required more planning, the ease of finding a fabricator and other vendors was rated 3.5 out of 5, according to the feedback from the project participants' leadership. The major considerations in selecting a fabricator included its experience, the location of the fab shop, the availability of the fabricator, its flexibility, and funding. Regarding the experience of the current contracting fabrication firm with modular construction, both leaders gave a rating of 5 out of 5.

Procurement planning for the project was conducted during the early planning stage. Because this was a competition project, finding funding and sponsors was a crucial task for the team. Attending trade shows and conferences and speaking at events were the main ways used to acquire sponsors, materials, tools, equipment, expertise, and funds for the project. Regarding the project's costs, the key personnel claimed that modular construction saved money in construction. Regarding how the team tackled delays due to the availability of resources, the construction manager confirmed that at this point in the construction, material availability has been good and that there are no major delays. The construction activities were planned and adjusted at the site according to the resource availability to avoid any delays. The early identification of long-lead items also helped to avoid delays.

One major change to the project since the initial planning stage was that the mechanical room dimensions were changed to fit the mechanical systems better and for a visually pleasing effect. Another change was made to the finishing materials for availability and cost. One future suggestion was to make the structure out of steel (studs, joists, etc.) instead of wood for a lighter structure. Note: using metal studs was considered at the beginning of the design phase, but wasn't implemented due to the fact that metal studs result in significantly higher thermal bridging than wood. In order to get the same level of insulation, the project would need approximately 20% more insulation, which would significantly increase costs, as well as result in a thicker wall assembly.

4. EIGHT MAJOR CONSIDERATIONS DURING THE PLANNING PHASE

In this section of the paper, the major considerations during the project's planning phase from the questionnaire feedback, in-depth interviews, and direct observations were confirmed and summarized. The major constraints and the solutions adopted by the team were also provided.

(1) Module size selection. Because modular projects must be planned early, the module size selection and planning were challenging parts of the project. The difficulties faced during the 2017 competition were also a major reason for the module size planning being challenging [29]. The module size for the competition was selected based on limitations in the transportation route and the national showcase size restrictions for the building challenge at Washington, D.C.

(2) Planning the construction system. Planning the construction system was another major task. The contractor for the project, a local construction manufacturing firm, conducted a study on using shipping containers as modules but found limitations involving structural integrity and architectural space. The solution it came up with was to design a system with moment resistance at corners and between hollow steel parts (HSS members). Another interesting fact was that the system did not depend on an infill panel for structural rigidity. This design system helped the team to choose wooden panel framing with a single-layer top and bottom plate. In addition, plywood was used in conventional sheathing, and closed-cell spray foam insulation was planned for use in filling cavities.

(3) Material planning for the project. Material planning for the project was another challenge because synthetic materials and coatings were badly affected by desert climates, so it was essential to choose natural and durable construction materials. Instead of using paint, the designers opted for a galvanized metal surface for the exterior. Concerning the desert climate, native desert plants were used in the landscaping for the project. All of the materials and equipment required for the construction were enumerated based on divisions, such as earthwork, concrete, metals, wood plastic and composites, thermal and moisture protection, finishes, specialties, fire suppression, plumbing, HVAC, electrical, integrated automation, electronic safety and security, and exterior improvements. The list also included the size, quantity, source, lead time, installer, and status details. This helped with identifying the long-lead items at an early stage, which prevented delays.

(4) Adaptability of the house. The adaptability of the house was another concern while planning the project. The Mojave Bloom project was fully solar-powered and capable of operating off-grid. Even on rainy days, the solar thermal array would heat water, and high-efficiency radiant pipes would heat the house in winter. Also, the degree of modularity in the architecture enabled customizable spaces and modifications to the structure. As residents' housing needed to change with age, additional modules were introduced to fit those needs. This feature of the project improved its marketability.

(5) Cost and duration of the project. The cost and duration of the project were two crucial factors in the planning phase. The project estimate underwent several revisions due to changes to the design and materials. The team's key personnel stated in the questionnaire feedback that the modular construction method helped to reduce the project's costs. The project schedule was also changed several times. The initial schedule was based on dividing the project into modules: Module 1—bathroom pod, Module 2—kitchen unit, Module 3—the headwall unit, Module 4—the ceiling unit, Module 5—wall unit 1, and Module 6—wall unit 2. This was revised, and the new schedule included the project's fabrication as a whole, including the major tasks such as site preparation and tasks involving the temporary foundation, framing, wall work, HVAC system, plumbing, electrical, specialty rough-in, roofing, exterior finishes, hanging of drywall, radiant heat system, floor finishes, interior trim, plumbing trim, exterior landscaping, electrical final trim, mechanical room fittings, and outside deck as well as special construction, cleaning, and post-fabrication tasks. Initially, the construction was to begin by November 2019, but actual site work was started in January 2020, and these changes were also made to the schedule. As the project progressed, the initial plan was that the changes made to construction activities at the site would be incorporated into the project schedule. The schedule required further revisions due to the competition's postponement caused by the current pandemic situation.

(6) Collaboration and communication planning. As discussed in the questionnaire, obtaining feedback on the collaboration and communication planning was a challenging part of the project. The team included the engineering team, architectural team, interior design team, landscape architects, and graphic designers and collaboration with the school of hospitality. The lack of organization and communication was the most significant challenge for the previous 2017 team [29]; to eliminate that issue, the 2020 team used the cloud-based project-management platform Procore for communication and collaboration in this project. Training on using the Procore software was conducted before the start of construction. All of the involved students and faculty members had an account on Procore, and they could use either the Web-based version or the mobile app. This made communication easy because requests for information could be assigned to required personnel directly. Procore also helped the team to view drawings and specifications and update them easily. The students were also asked to input their site visit times in the daily log feature of the software to record their working hours at the site.

(7) Safety. Even though the modular construction method is safer compared to traditional stick-built construction, the involvement of students and their unfamiliarity in the practical field was challenging. Therefore, to increase safety, the students and faculty were required to undergo 10-hour and 30-hour OSHA training prior to construction. The students involved in the direct construction were also required to complete safety training conducted by the project contractor, a local construction manufacturing firm from Henderson, NV. This also allowed the team to recognize construction materials and activities that can create significant health risks for the workforce.

(8) Transportation planning. The solar home built by the 2017 Team Vegas had a total area of 970 square feet and was assembled on two chassis modules. The team had difficulties transporting the previous house module from Las Vegas to Denver due to its weight and size [29]. Therefore, the plan for transporting the housing module from Las Vegas to Washington DC was crucial. After learning from the previous experience and anticipating the probable difficulties along the way, more than one feasible route was sought. From the preliminary analysis, the three shortest routes were located. The 2020 team limited the module size to 14’ width, 14’ height, and 60’ length, incorporating the minimum limits of the three identified routes to the competition site. It was initially planned that multiple forklifts would be used for module lifting, and a lowboy trailer would be used to transport the modular house.

5. CONCLUSION

This paper discussed several of the constraints and necessary measures taken in the planning phase of the Mojave Bloom project. The main considerations and solutions to those issues were discussed, using in-depth interviews with the key project personnel. The survey responses provided by the architecture lead and construction manager offered excellent insight into the issues and hurdles they experienced throughout the planning phase and how some of those considerations should be controlled along the way.

Regarding the following results, additional research and data compilation would help reduce the unknowns for future modular projects. This research focused on the early phases of the project, as the project was still in progress when this paper was prepared in early Spring 2021. However, some significant changes were already made (i.e., transporting to Washington D.C. to Las Vegas downtown) during the design construction phase, and those changes are ongoing. Thus, additional data should be collected from both the detailed design and construction phases.

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