The Benefits and Challenges of Automation in the Modular Construction Industry

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Modular construction combined with automation technology such as robotics presents benefits and challenges associated with it. Modular construction takes on the traditional building methods and has streamlined the production of modules making it safer, efficient, and productive. Along with innovation and cutting-edge technology such as automation, it offers an alternative building method to the modular construction industry that enhances productivity, worker safety, and efficiency. This research presents an investigation on factors that may be benefited from the adoption of automation but also addresses the challenges in modular construction. Qualitative interviews with designers and consultants in the modular industry were conducted to gain an understanding on how they are utilizing the technology of robotics and automation to combat the construction industry’s shortcomings. The main benefits and challenges are grouped and ranked in order of importance: Capital-Investment and maturity, Operational and Work-Culture Requirements, Labor shortage, Safety and Productivity, and Affordable housing. This study will help industry leaders and stakeholders arrive at a general sense of the essence of automation and modular construction, while the research community will get a grasp of the embrace of automation.

**Key Words:** Automation, Modular, Safety, Productivity, Construction

**Introduction**

The goal of this research is to analyze the benefits and challenges that are associated with automation in modular construction. Modern modular construction has been on an upward trend due to its advantages over traditional onsite stick building methods (Pierson, 2020). The construction industry is of the most significant economic sectors across the world but has been plagued with inefficiencies and low productivity rates. When compared to the traditional onsite methods, modular construction has proven to have a positive impact on quality, safety, and productivity (Bertram, et al., 2019). Combined with automation and robotic systems, it has the potential to address the shortcomings of traditional construction methods.

Robotics and automated systems have the potential to revolutionize and provide many advantages to the modular industry. Automation shows a prospective capability to generate higher outputs at a lower cost.
unit cost, with better quality products. Furthermore, automation has been gaining more recognition due to some of the performance limitations of conventional construction methodologies. In this research paper, I will be discussing factors that either benefit or hinder the implementation of automation technology in modular construction.

**Literature Review**

**Automation**

Automation has changed the dynamic between human and machine labor. It is all around us, from automobile manufacturing to big Amazon distribution warehouses. Automation is not a new phenomenon and has been around in Japan since the early 1970s and 1980s where it gained momentum with the developments of automation in off-site building manufacturing (Manyika et., 2017). During Lyndon B. Johnson’s presidency, a national commission was established to review the impact of technology on employment and declared that automation did not have to displace jobs but “can be the ally of our prosperity if we will just look ahead” (Manyika et., 2017).

As the modular market is projected to grow at a rate of 6.9% from $82.3 billion in 2020 to $108.8 billion by 2025, there has been a growing demand to adopt the use of automation because of its benefits (Mehra, 2020). It has been said that automation of tasks can enable productivity growth and other benefits at both the level of individual labor process and business. Offsite construction processes have demonstrated that it is capable of reliably accelerating projects, cut schedules by 20-50 percent, and construction cost by 20 percent (Manyika et., 2017). This is because the manufacturing environment is in an enclosed and controlled factory which gives the ability to coordinate, repeat activities, and increase levels of automation. Therefore, by integrating automation and automated systems such as robotics, it will aim to offer a significant boost to productivity.

The authors of *A Future That Works: Automation, Employment, and Productivity* predict to see driving demands of automation in modular construction due to increase of labor, safety and productivity, and housing shortages. In Figure 1, a modular firm, Autovol located in Boise, Idaho is utilizing the revolutionary development of its robotic systems. However, it is important to note that there are certain barriers that hinder the adoption of automation, even in some of the most successful modular firms.
One barrier associated with automation that makes it challenging to adopt is the high capital expenditure required to design, fabricate, and install as it can cost tens of thousands of dollars (Beeton, 2018). A higher cost of maintenance will be required for automative machines compared to that of a manually-operated machine. The cost of automation significantly affects the argument for adoption, as developing and engineering automation technology requires capital. Making the case for adopting automation may be easy as firms can readily see the value of shifting tedious, labor-intensive, and repetitive tasks from humans to automated systems. However, to transition to this, computers need hardware solutions in order to design complex mechanics such as robots with arms and moving parts that require dexterity (Manyika et., 2017). By taking such attributes into account, it increases the cost relative compared to a general-purpose hardware platform. To deploy these types of technologies that integrate automation, it requires significant capital spending and has a high initial cost compared to labor wages. The investments are high risk and finding modular firms that are willing to invest in these kinds of technologies are rare. There is also the high cost associated with owning and using these technologies as some may not be fully developed and as advancements in technology continue, it can be costly to keep up.

According to John Lekfus, president of Rad Technology “the steep investment in such high-tech equipment only pays dividends at high volumes” meaning that automation doesn’t really kick in until you’re producing at least 1,000 units (Beeton, 2018). Even in some of the most successful modular firms, it only produces a small quantity, such as Lindback’s in Sweden which is a $55 million, 425,000-square foot modular facility that produces 90 units a week (Beeton, 2018). On top of that, the likelihood to automate a portion of the production process requires a fully matured firm that has been established and is efficient in the modular building industry. One example is the Volumetric Building Cos. Factory where the automated factory process accounts for 6% of its output, 12% of computation engineering, and 82% of IT effort (Beeton, 2018). For high-automation design, “expect about 16 to 24 months” as Automation is not the answer said by President of Volumetric Building Cos. Vaughan Buckley.

**Operational and Work-Culture Requirements**

Transitioning the traditional on-site construction to offsite manufacturing requires overcoming the challenge of technical feasibility and work-culture related factors. While a builder can make quick decisions to work around imperfections in materials, a machine requires greater precision and programming so that it understands how to correct. Robotics and various technology must be invented, integrated, and adapted into solutions that automate specific activities. The rollout of these technologies can only begin when machines have sustained a level of performance that can carry out activities. Although a robot can outperform or match a human on some of the same tasks, there are many other capabilities that require more technological development (Manyika et., 2017). Worker displacement may often be associated with automation despite its social benefits. It could be said that a worker whose job is taken over by a machine undergo a period of emotional stress due to the necessity for relocation in order to find other work which is another source of stress (“Automation-Advantages...”, n.d.).
The work culture interaction between human and machine is a significant challenge that needs careful consideration. There must be effective collaboration between the worker and the robot for a successful adoption. Automated systems and robotics take a considerable amount of time to configure and needs to be constantly monitored by a skilled worker. For modular firms to adopt robotics in their production process, a new breed of workers is needed who have a strong academic background with special training in areas such as electrical, controls, and robotics engineering. To sustain a high rate of automation and robotic utilization, there must be an adequate supply of appropriately skilled workers to operate the machinery whether it is automated or not. There must be training provided and a formal learning of a technical skill such as programming. Older workers must be considered as they may be disinterested or not have the technological aptitude to learn the necessary skills to monitor the robotics (York, n.d.).

**Combating the Labor Shortage**

According to the 2020 Construction Hiring and Business Outlook report by the Associated General Constrictors of America, it was shown that 81% of construction businesses are having trouble finding qualified skilled labor to fill open positions (AGC, 2019). Prior to the COVID-19 pandemic, skilled labor was facing a dire shortage and the country was feeling the repercussions. However, it is important to mention that due to the pandemic, the construction industry lost 975,000 jobs in April 2020 due to a lower demand according to analysts at Statista (Statista, 2020). Along with that, many skilled craftsmen have withdrawn from the industry and many younger people are not considering physical labor as a viable career option in construction. To measure how the labor shortage has impacted the industry, the 2020 Associated General Contractor survey highlighted the most notable effects it has had. This includes 44% of companies seeing higher project costs, 40% of projects are taking longer than anticipated, and a significant decrease in quality and productivity. In reality, the overall industry has experienced an overall growth according to the National Accreditation of Home Builders (Dietz, 2020). But to fill this labor gap, it is going to require efforts in encouraging America’s youth to consider working within these trades as well as developing cutting-edge technology such as automation to combat this issue.

The fear that machines will take over jobs from humans is vastly overblown as it is predicted to do better than bad as the World Economic Form predicts that automation will result in a net increase of 58 million jobs by 2025 (Cann, 2018). The current labor shortage is just one of many reasons why automation, if adopted and approached properly, could have a positive impact on the modular industry (Cann, 2018). Modular construction can alleviate the problems associated with the shortage by allowing the work to happen in a factory. The expenditure of transporting modules is less than transporting workers, as modules are made to move. Although a facility may be more than several hundred miles from a project site, the cost of transporting is less than relocating a team of workers for several weeks or months (Rozycki, 2020). Like any other employer, modular firms hire workers with the right skills, and schedule a steady stream of projects to promote job positions. With automation technology integrated into it, it creates careers in a new kind of work environment that combines engineers, machine operators, and the construction trades. Furthermore, with robots reducing the labor-intensive demands, people from different work backgrounds have the opportunity to work in the modular construction industry.

**Safety & Productivity**

Construction worker safety is an area of top concern that contractors, subcontractors, and owners take into consideration. Construction is one of the most dangerous industries as 20% of worker fatalities in
2019 were in construction, according to the Occupational Safety and Health Administration stats (“Commonly Used Statistics”, n.d). As of 2020, OSHA reported that one in five worker deaths were in construction because of falls, electrocution, and struck by objects.

With safety being a top priority on almost every project site, many contractors and business owners have quickly realized the benefit of reducing injuries by turning to off-site construction and are leaning towards modular construction for future projects (Meyers, 2016). A McGraw Hill Smart Market Report on Prefabrication and Modularization indicated that 44% of general contractors who utilize modularization believe that it has a positive impact on safety, based on an internet survey of hundreds (Bernstein et., 2013). In general, they addressed the three main safety benefits of the modular building process which were: the ability to do complex assembly at ground level, fewer workers on-site, and fewer number of tasks completed at great heights (Bernstein et., 2013). Another safety benefit to modular construction is that it reduces the number of workers that are exposed to potentially hazardous situations caused by rain and other natural occurrences.

By adopting automation in modular construction, it dramatically reduces the chances of injuries and is largely viewed as an unprecedented benefit to worker safety. It allows for better coordination, with fewer worker competing for the same workspace and by having work in a fixed weather environment, it can boost the well-being of the labor force. Workers can greatly benefit from the use of automation in order to perform repetitive, unsafe, and potentially hazardous tasks as well as complete them precisely which can even further decrease potential hazards. The use of robotics can also extend the production process beyond the limits of human capability by handling heavy loads or through manipulation of tools such as a pneumatic nail gun.

As seen in Figure 2, labor productivity in the construction industry has been decreasing for decades. Modular construction has piqued the interest of many companies are attempting to utilize its techniques due to its advantages in various areas such as production speed and reduced labor, relative to traditional construction methods (Bock, 2015). The modular industry is adopting new materials and technology such as automation, that enhances design capabilities and variability as well as improves precision and productivity.
The automation of specific tasks in a modular production facility can enable productivity growth at the workers’ level. Automation enables improved performance in quality and speed as well as reduction of errors past what is within human capability the production process (Manyika et., 2017). In addition, increasing the use of robotic systems and automation technology can not only reduce human error, but increase consistency as well. By moving traditional labor activity to an offsite facility, some of the most skill-intensive tasks such as mechanical, electrical, and plumbing can be handled at a lower cost. More importantly, increasing a standardized, automated, and controlled operating environment can double productivity (Bertram, et al., 2019). This would also ensure any prefabricated parts and units that are being transported to the site that would require little to no additional rework during the assembly (Barbosa et., 2017). Productivity growth enabled by automation can also ensure continued prosperity in an industry where there is a shortage of labor. Automation will aim to offer an exponential boost to productivity given that modular construction already twice as productive relative to traditional construction methods, there is an outlook on the bright and beneficial future of automation beneficial (Bertram, et al., 2019).

**Affordable Housing Crisis**

America is facing a rapid growing need for affordable and high-quality housing but can be easily observed in California where it is becoming a prominent issue (Housing Needs Dashboard, 2020). In a recent study by the California Housing Partnership, key findings highlighted that in order to meet the current demand for affordable housing in California, 1.3 million more affordable homes are needed. Despite the 2017 housing package, state funding remains well below the 2012 levels, which undermining the progress in addressing homelessness as seen in figure 3 (“Housing Needs Dashboard, 2020). To understand why there is a statewide housing crisis, it is important to mention several factors affordable and market rate developers have been seeing. This includes higher development cost involving land, capital cost, materials, and labor hindering the feasibility of new projects due to affordability constraints. Materials and labor alone are referred to as “hard construction costs,” comprising more than 60% of the total development cost (Raetz et al., 2020).

![Figure 3 - California state funding over the last several years](image)

Source: California Dept. of Housing and Community (HCD) Redevelopment Housing Activities Report 2009-2011.
The cost of development is a fundamental obstacle to building more affordable housing in California, especially to some that are accessible to low and moderate-income households (Garcia, 2020). Given that material and labor play a significant role in determining the financial feasibility of new affordable housing, by transitioning traditional building methods to offsite has the potential to produce dramatic improvements in terms of cost savings.

Affordable housing is heavily dependent on construction cost as the higher the cost of construction, the less affordable the housing, threatening the viability of new housing development overall (Raetz et al., 2020). Furthermore, these affordable projects may be subjected to prevailing wage requirements, increasing the cost of construction. However, modular construction and automation together have the potential to address these issues. Approaching these issues through modularization and robots, it would mean that each unit delivered and produced would require significantly less labor, resulting in lower hard construction cost (Raetz et al., 2020). Automation and robotic systems have the capability to build efficiently and consistently, reducing overall construction cost. By saving on construction and labor costs, affordable housing becomes more palatable for developers.

**Research Methodology**

For this research paper, a mixed research method was used that combines a literature review and a qualitative method to gather data. These research methods have been proven to be powerful tools to investigate the process and function of automation. To gain more insight on the benefits and challenge of automation in modular construction, a list of predetermined questions was developed to focus on the benefits and challenges of automation and modular construction.

To understand more about automation in the modular industry, I reached out to those who are knowledgeable of automation in their respective area of construction. Architects Orange is a firm located in Southern California that has been renowned for their design work in modular, mixed use, retail, hospitality, etc. Through innovative design and methodical project management, they have developed a deep understanding of modular building approaches. I also got the opportunity to speak with a representative from Prefab Logic, who is working in conjunction with Autovol, a first of its kind automated volumetric modular factory that is leading the development of a revolutionary technology adoption that will set a new benchmark for modular construction (“Announcing Autovol”, 2019).

From Architects Orange, I had the opportunity to have a virtual discussion with Edward Wu and Ioanna Magiati who are architects that are currently working on several modular projects. I also had the chance to speak with Tim Mathson who is the director of design at Prefab Logic which is a consulting firm that specializes in volumetric modular construction. During our discussion, we reviewed the current state of modular construction and how automation will have an impact on the modular industry now and in the future.

The free-flowing interviews discussed a range of questions that addressed several points on automation. Most of the questions were predetermined, but the interview was an open discourse that allowed the respondents to add whatever they felt important to address. These are main topics in this study that were discussed amongst other things:

- The benefits and challenges of automation
- Whether automation will create or take away jobs
- How will automation combat the affordable housing crisis
- Design tolerances when considering automated systems such as robots
- Safety in automation compared to traditional building methods

Results

The following sections will address how Architect Orange, Prefab Logic, and Autovol have partnered together to design and produce volumetric modular units. These are by no means modular industry standards as these are just examples given by a highly reputable architectural firm and a first of its kind automated volumetric modular company.

Design and Production

The design phase is crucial when it comes to the coaction of modular building methods and automation. When designing to build volumetric modules, the design team must be “disciplined” as Edward Wu stated because several aspects must be taken into consideration for a smooth and efficient completion. Transportation and assembly of the modules are factors that need to be taken into consideration. Determining load conditions and specific design tolerances that the modules experience should be determined in a way that handles the load effectively and how the buildings skin is protected during transportation. One of Prefab Logic’s task dependency when it comes to the volumetric modules is design efficiency. This was heavily emphasized as studs, sheathing, pipe fittings, etc. and are all meticulously planned and designed based on greatest efficiency. Cost analyses are also conducted to identify and prioritize where money and material can be both saved, tying back to the reduction of construction cost. Everything must be perfect to ensure that the building elements are constructible when the automated robots begin to assemble the wall or floor. One key thing in is that automation is 100 percent coordinated from the design side through to the production end. Mathson explains that the precision in digital pre-construction side is crucial due to the driving factors of cost implications catalyzed by delays. Prefab logic prides themselves in the accuracy of their work when it comes to designing these volumetric modules, as a small mistake can completely derail the production line.

Another benefit to the modular and automation production is that it reduces material waste and minimizes its carbon footprint, as well as utilizing less energy, making is environmentally sustainable. Mathson discusses how these manufacturing facilities utilize recycling programs to reduce scraps and traditional waste onsite. This all relates back to the design process. For example, when floor sheathing is laid out and is to be cut in half, the other half can be applied to the next unit. The goal is to maximize the material usage as much as possible.

Overall, the design and production of these volumetric modules stem from the ability of it being efficiently standardize and replicated. The integration of robotics has also further enhanced quality control and worker safety, alleviating construction delays and shorten construction timelines.

Affordable Housing Crisis

Autovol, Prefab Logic Solutions, and Architect’s Orange have created a partnership dedicated to designing and developing over a dozen of affordable multi-family projects throughout California. For example, in the bay area, stick-built home prices and rent have increased exponentially over the last several years and will continue to do so. In addition, technology companies in those areas are driving
prices up well above the median income of the residents who reside there. The solution for this affordable housing crisis? Mathson believes this is where modular comes in to play.

Modular construction is beneficial in terms of speed, efficiency, productivity, speed to market, and reduced risk which all equate to a considerable amount of time and cost savings. The speed and efficiency in modular construction stems from its ability to replicate and standardize units and with the utilization of robotics, it even further enhances the production rate. Located in Nampa, Idaho, Autovol’s factory is set to create new “breakthroughs in construction speed, capacity, and efficiency,” Mathson predicts. By integrating automation onto their production process, it will go far beyond what has been done in any modular factory. The working partnership among the three firms have allowed them to collaborate closely in order to create a formula that integrates modular and automation, maximizing the potential for viable affordable housing.

For this reason, highly dense community developments on the affordable housing market are best-suited for this delivery method. Although modular and automation may not be the silver bullet to the affordable housing crisis, it proves that emerging technology and modular construction have the potential alleviate the challenges of affordable housing by reducing construction cost.

Conclusion

After conducting extensive interviews and researching the benefits and challenges associated with automation in modular construction, this research has revealed that its implementation is feasible. The automation of building tasks can enable the modular industry to improve performance by reducing errors, improving quality and speed, and going beyond human capabilities. It is the technological, economical, and social factors that will play a big role in determining the pace of adoption in the modular industry. Although construction automation is still in development, it can be expected that with continued effort in research and development, the integration of automation may soon see a phase of growth and adoption on a substantial scale. In order for builders and developers to obtain performance benefits of automation, they must embrace the opportunities of productivity growth potential and advocate for innovative polices that help workers and institutions adapt to the change of work environment. Rethinking education and training programs will be crucial in the adoption of automation due to the new demand of engaging comprehensively with automated systems. Furthermore, to achieve a positive outcome, policymakers and business developers need to embrace the benefits of automation, and at the same time address the technological transition to the workforce.

References


