MODULAR AND OFFSITE CONSTRUCTION SUMMIT
JULY 27-29, 2022 EDMONTON, CANADA

AWP for residential buildings to modular construction: A proposed framework

Slim REBAI[1], Olfa HAMDI[2], Samer BU HAMDAN[3], Zoubeir LAFHAJ[4], Pascal YIM[5]

[1] *Doctoral Candidate, Univ. Lille, CNRS, LAMcube, Centrale Lille, France*
[2] *CEO, Concord Project Technologies, USA*
[3] *Research Associate, Univ. Lille, CNRS, LAMcube, Centrale Lille, France*
[4] *Full Professor, Univ. Lille, CNRS, LAMcube, Centrale Lille, France*
[5] *Full Professor, Centre de Recherche en Informatique Signal et Automatique de Lille, Centrale Lille, France*
**Corresponding author's e-mail: slim.rebai@gmail.com*

ABSTRACT
The demand on affording homes for the growing population in the world is noticeably increasing. This demand creates a high pressure to find solutions that can help in constructing quick and affordable shelters. In efforts to improve productivity, performance, and constructability of residential buildings, the direction toward modularity in construction is increasing. In order to gain the best benefits of modular systems in construction, these systems should be associated with project management practices. Among these practices, Advanced Work Packaging (AWP) is a construction driven planning tool that proved its value in improve the delivery and execution effectiveness in the oil and gas fields and currently is witnessing greater consideration in the construction industry. The current study aims to link the two concepts through proposing a framework to integrate AWP in residential modular construction. This article is also presenting an example about the possible way for this integration. The article also discusses the opportunity to improve productivity and installation costs due to the implementation of the proposed framework.

KEYWORDS
Residential Buildings, AWP, Modular Construction, Modularization

INTRODUCTION
Amid the rapid pace at which the global population is soaring, which is projected to hit a rate of 45 million per year by the end of the century (United Nations, 2019) , the demand for housing of different sizes is swelling (United Nations, 2017); meaning that millions of new homes must be built to accommodate the world's growing population. The World Economic Forum suggests that the world needs over two billion new homes by the end of the 21st century (World Economic Forum, 2018). Such ambitious goals necessitate innovations in the construction industry to live to the great challenges, cutting housing lead times, increasing quality, and reducing waste. In this context, modular construction has shown a promising ability to accelerate housing delivery.
In recent years, the increasing development of the modularization technique has raised its profile and generated momentum and interest from regulators, academics, and industry professionals. Modular construction is known for its speed, quality, and high cost (Young et al., 2020). The high installation cost remains a significant obstacle. Modular construction companies have to overcome

to facilitate the widespread adaptation of modular construction, particularly in residential buildings (Young et al., 2020). In this context, modularizing the scope can be a significant driver of the high installation costs. It should be defined at multiple stages and themes from the initial phases of the project. As such, efforts to hone the potential of modular construction practices are hindered by the lack of a standardized approach to modularizing the design. The Advanced Work Packaging (AWP), a method initially developed to support modularization efforts in heavy construction, can lend some clues on standardizing residential buildings' modularization. Therefore, the present work aims to learn from AWP applications in heavy construction to develop a framework for its implementation in residential construction.

The rest of the paper is organized as follows. The following section provides a brief background around modular construction and AWP. Using the concept established in the environment, the framework section discusses the proposed framework and how it can be implemented, which is followed by an illustration of its implementation in an example project showing the mechanism of applying AWP for modular construction in early and detailed stages for projects of modular residential buildings, until the structural setting. The observations and recommendations are discussed after the case study.

BACKGROUND

Modular construction: advantages and limitations

Modularization is a project execution strategy for transferring a significant part of onsite construction operations to a well-monitored factory environment in the fabrication plants (Goulding et al. 2013). The process necessitates designing units or modules to be assembled and transported. Consequently, compared to conventional construction, it imposes changes in the design and planning process concerning all construction operations from fabrication to installation (Carvalho et al. 2019).

Since its introduction, the benefits of modularization have been widely recognized. These include minimizing on-site construction (Isaac et al., 2016) and reducing the cost and time of on-site activities (Ocheoha et al. 2018), which allows tasks to be performed efficiently. Thus, modularization can increase productivity, improve overall quality and safety, reduce waste, and improve environmental performance (Choi et al., 2019). Furthermore, a modular construction approach for sequencing the installation activities of the different components in the housing unit is proven to reduce the duration of the construction process (Isaac et al., 2016).

Nevertheless, construction modularization’s limitations persist. (Mao et al., 2015) argued that initial planning and engineering costs are higher than conventional construction, which is accompanied by fragmentation and high transportation costs, leading to hesitation in embracing modular construction. (Ramaji et al., 2017) reported limitations related to construction methods and engineering issues for modular buildings, which become more complicated, especially as the number of floors increases.

The opportunities and barriers to implementing modularization have prompted researchers to investigate its practical implementation (CII Member Companies, 2014; O’Connor et al., 2015). As a strategy, a natural working environment and adaptations are needed to create an environment to leverage modularization in the most efficient way possible in the construction industry. However, conventional approaches to modular construction development have proven insufficient, especially when it comes to the modular construction of residential buildings. That is because the

integration between projects and products needs to be more thorough. The scope of modularization design needs to be extended to multiple stages and themes from the initial phases.
Systems engineering methodologies and knowledge support management offer important lessons for developing guidelines for modular construction (Miller et al., 1998); of those methods is the AWP. The following section presents the AWP method.

AWP's concepts

According to the Construction Industry Institute, AWP is a method of designing, planning and executing of a complex construction project. This technique translates into an optimal alignment of the actors on proactive planning, which constitutes a fundamental decision-making tool (CII, 2021). AWP was developed to improve the project's performance. It is a construction-driven project delivery process built on the idea that "construction is the customer". These projects involve many stakeholders who interact simultaneously, each according to its own rules of the game and its interest (CII, 2021). The main principle of AWP is sequencing the entire process into small work packages (CII, 2021). These work packages need to be planned without constraints with the mindset of starting with the end in mind to complete the work in the proper sequence correctly, from the first time.
AWP is an integrated process that consists of five stages:

- **Stage 0**: focuses on the pre-implementation of the AWP in the system (enterprise, project, or resource).
- **Stage 1**: (Preliminary Planning/Design) in which the project is defined. Preliminary Planning/Design
- **Stage 2**: (Detailed Engineering), where construction engineering data is developed in-depth to be free of constraints during the detailed engineering phase, and a detailed construction schedule will be set
- **Stage 3**: The planning will be carried out during the construction phase until the finalization of the project and the commissioning in the fourth stage. Construction Execution, testing & Completions
- **Stage 4**: Energization & Commissioning: Turnover to startups.

Through its limited implementation in North America, AWP has shown promising results, remarkably increasing productivity, improving project personnel management, increasing project results predictability, limiting accidents on site, and respecting deadlines (CII, 2021).
Nevertheless, AWP is struggling to break through into modular residential construction due to a lack of a mechanism to incorporate it into modular construction practices in residential construction. Therefore, the present work proposes a framework to implement the AWP in residential modular construction.

A FRAMEWORK TO IMPLEMENT AWP IN RESIDENTIAL MODULAR CONSTRUCTION

To evaluate the matching between the benefits of the AWP method and its adequacy to overcome the limitation of the modular construction approach for residential buildings, a framework to implement the AWP method for residential modular construction is proposed. The starting point of our projects is to make a modular residential building with the highest percentage of modularization. Given the scope of the present work, i.e., implementing AWP, Stage 0 focuses on the pre-implementation of the AWP necessary in our context.

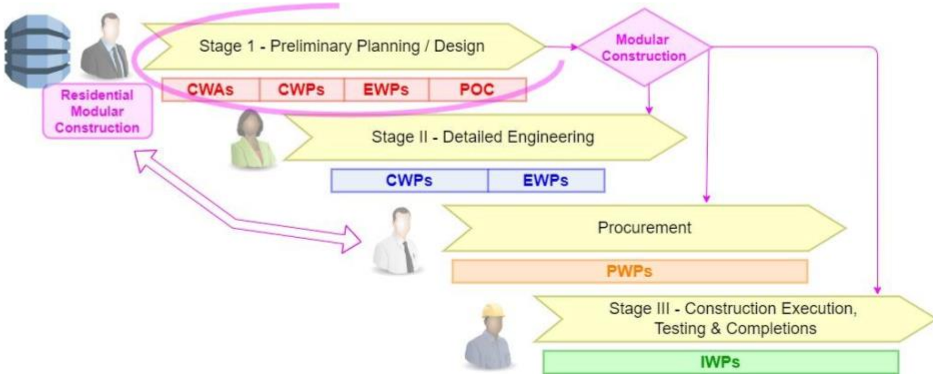

Figure 1. AWP Framework for Residential Modular Construction (Build On CII, 2021)

The framework's AWP stages
Planning in AWP is supported in the earliest stages of the project, so planned activities are carried through to field execution until start-up and turnover processes. As the decision is to implement AWP in the project/system, coordination between the packages is carried out in only three stages, modular construction integration in this proposed concept is drawn in pink colour (Figure 1).

- Stage I - Preliminary Planning/Design

The project concept is recognized during this stage, and an investment decision must be made based on the relevant details prepared. During this stage, there are critical elements to develop and to be verified, as follows.

1) It is needed to define the project definition strategy in this step, the scope of work of the project, it is a residential building, and the aim is to increase the modularity percentage, that's why, and as shown in figure 1, the involvement of the procurement is required to define with the different stakeholders the contracting and the procurement plan. As it is modular construction, the level of design should be well specified. It is essential to identify the critical stakeholders for our project.
2) It is crucial in this step to define the plan for the work packaging, with a concentration on modular construction for residential buildings, like to define the general arrangement of the modular plan/project, different precise plans for the work packages, enhance the commitment of the engineering in the details of other disciplines to be managed and to be designed and constructed in a modular way, for example in the different level of the building, the additional eventual modularity in each discipline: foundation, structures, etc. (we are exempting here excavation work and preparation of the surface). Depending on this work, the contracting plan should be refined, and the procedure for procurement and logistics has to be proposed. So, the construction, engineering, and procurement plans are prepared in this step.
3) Once step1 and step2 are completed, the offshore and site preparation activities start to be tangible, defining the project construction sequencing. The sequencing should be refined during construction planning. The construction sequence has to be reviewed during the engineering planning. A clear boundary development starts to be in place when looking at the series of installations to offer the path of construction.

4) After these steps, a level 2 schedule for engineering would be prepared; this schedule must be by discipline by modular systems. That's why the procurement schedule would be by commodity, and the construction would be by discipline.
5) As the final step of this stage, the consideration of modular construction has been taken in charge, especially in a residential building with different disciplines, so the general arrangement drawings are prepared, the construction plan the same thing, the contracting and procurement for execution plans are available, the crafts workers are defining, the modular subdivisions are clarified, and the work breakdown schedule is in place. The layout of the system/areas enables the expressive client and contractor milestone definition. And so, the construction materials, onsite or offsite, are well defined.

- Stage II - Detailed Engineering

After the financial/investment decision is made, build on the plans from Stage I by aligning detailed engineering deliverables with construction requirements. This stage involves detailed engineering, and the detailed project work can begin. This stage continues the job done in phase I by adding considerable value and details to the work packaging needs to be defined in stage I.
Once the preliminary planning design is completed, in this stage, references to modular construction in a residential building should be handled to make detailed engineering in the same sequence provided by the POC, final CWPs will be fixed, and CWP will define the level 3 schedule for construction. So, engineering deliverables would be provided like the level 3 schedule for engineering (by discipline). The procurement level 3 planning will also be prepared and consequently, a detailed construction schedule will be in place after reviewing and assessing the changes since stage 1.

- Stage III – Construction

During this stage, construction organizations perform detailed planning to create the IWPs, make the document control, process the issuance to the field, perform control in the area, and finally, close out the IWPs. Collectively these five steps represent a robust process for managing installation work packages. The process flowchart for this stage is the most detailed despite having many sub-tasks. And the IWP management process described in stage III uses constraints management. In this stage, considering the previous work done and the concept and the context of this stage, the IWP would be created by defining their contents, limits, and boundaries, identifying the different risks in small work packages to make, recognizing auxiliary equipment, labour, logistics or materials. The workforce planner will develop and manage the IWP log and schedule for site installation. He will monitor the constraints depending on the IWP planning. As it is a construction stage, monitoring the IWP execution plan consists of a primary workload in the site. To make the AWP method and the Modularity technique objectives, it is needed to review the completion of the IWP within their scheduled time frame, verify the quality of the provided elements, and realize work to confirm the completion of each IWP.

Procurement
Once the three discussed stages are complete, the team develops the Procurement Work Packages (PWP). This service addresses procurement and takes care of transportation points, delivery methods and tools, offsite and onsite controls, and supervising-lifting materials and methods

depending on the modularity strategy. To evaluate the relevance of the proposed framework, an example of the application of the AWP method for modular construction in residential buildings is presented in the following section.

APPLICATION EXAMPLE: USING AWP FRAMEWORK FOR RESIDENTIAL MODULAR CONSTRUCTION

The building used in the example comprises two typical floors, a ground floor and a substructure, as in Figure 2. To facilitate the presentation of the framework, the implantation will be limited to the construction of the structural components only.

Given the AWP principles and stages, the project is broken down into construction work areas (CWA) based on the site plans in logical work areas. As this method is a construction-driven process and draws the construction building into CWAs, the first objective is to prepare the decomposition for the POC implementation. The concept of residential construction is building from the bottom to the up (Figure 2). As shown in figure 2, the first principle is to decompose the building vertically, considering the following: 1) all the outdoor layout outside the building is the first CWA. 2) the ground, including the foundation of the building, is considered another CWA. 3) every slab is considered a separate CWA. CWA and POC will be defined from the bottom to the up, and they will be executed as an integrated process including all different disciplines.

Stairs, and technical ducts, are not shown in Figure 2. From a builder's perspective, those elements would be built from bottom to up, but they are not shown in this vertical decomposition.

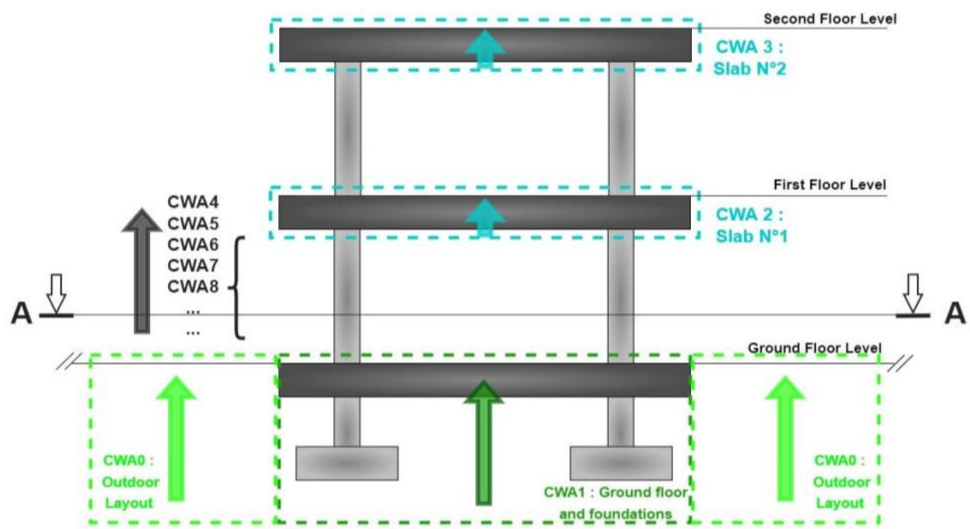

Figure 2. Decomposition in a vertical concept of a structural residential building

Considering this limitation, we must decompose our CWAs horizontally on each floor. In our case, we offer the decomposition of the ground floor only, while the same concept is applied to the rest. Figure 3 shows the horizontal CWAs. In Figure 3, we see the CWA of the outdoor layout, where the POC depends on the technical ducts because all the supply resources will not be installed until the specialized ducts are in the building. Furthermore, the decomposition is made according to the following logic.

1) CWAs follow the floor's functional division, i.e., apartments, offices, and common and technical areas.
2) CWA of common area, which contains all the outputs of the other CWA on the floor.

3) CWAs of stairs, Elevators, and technical ducts; these CWA's are particular zone because they should be decomposed simultaneously vertically and horizontally at the same time.
4) As we adopt this framework, the foundations, the slabs, the columns, the formwork, the rebar, the stairs, the elevator, and technical ducts could all be modularized.
5) After decomposing the residential building in horizontal and vertical ways, each CWA is divided by discipline into construction work packages (CWP). It is to be noted that each CWP requires its engineering work package (EWP) defined.
6) The next step is to divide each CWP into an installation work Package (IWP), which deliverables allow a construction crew to perform work in a safe, predictable, measurable, and efficient manner. The IWP includes the work related to a work team supervised by a foreman for a maximum duration varying between one and two weeks maximum.
7) This process is guided mainly by the POC, which defines the work sequencing in each construction work area in planning, engineering, procurement, etc. The POC is driven by construction while involving all stakeholders related to the project, such as engineering, procurement, contractors, business managers, and even the operations department.

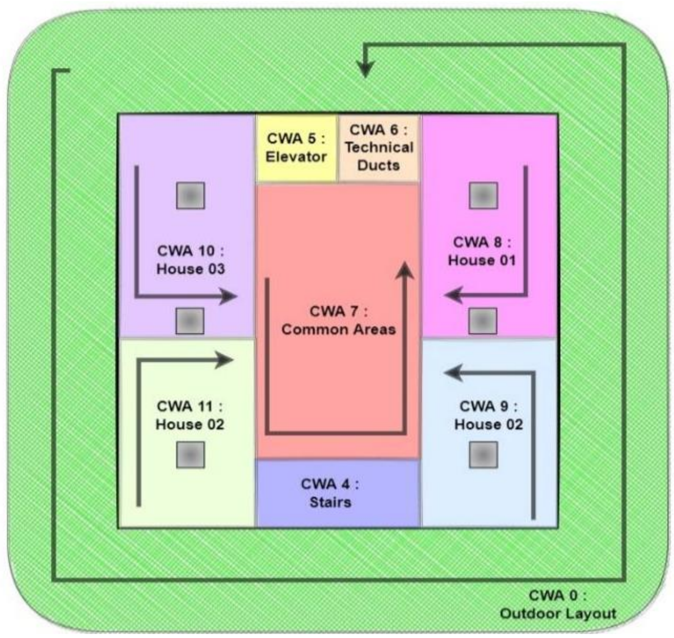

Figure 3. Decomposition is a horizontal concept of a structural residential building

DISCUSSION AND CONCLUSION

Applying the concept of AWP in residential modular construction can help to modularize each element of a building. The decision to choose the proper method for the construction of each module is also possible (concrete, steel structures, or mix). The complexity of this type of construction is that it contains so many disciplines in a small area. Using the proposed framework, the sequencing was possible without overlapping work areas and disciplines as Construction Industry Institute reported that this method increased field labour productivity on average by 25% and reduced the by 10% project installation costs (CII, 2021).

On the other hand, this concept wouldn't give results if not considering the decomposition of CWAs simultaneously horizontally and vertically. Using only drawings to make this type of decomposition would limit a building with a high number of floors and complexity. The tolerances and quality control of the construction of the modules offsite is an axis of research to be developed in later research.

REFERENCES

Carvalho, B. S. de, & Scheer, S. (2019). Lean as an Integrator of Modular Construction. *Modular and Offsite Construction (MOC) Summit Proceedings*, 149–156. https://doi.org/10.29173/MOCS88

Choi, J. O., O'Connor, J. T., Kwak, Y. H., & Ghimire, R. (2019). Calibrating CII RT283's Modularization Critical Success Factor Accomplishments. *Modular and Offsite Construction (MOC) Summit Proceedings*, 235–242. https://doi.org/10.29173/MOCS99

CII Member Companies. (2014). *IR283-2 - Industrial Modularization: Five Solution Elements, Version 1.1*. http://construction-institute.org/catalog.htm

Construction Industry Institute, & Community for Business Advancement. (2021). *AWP EDUCATION PRIMER*. https://www.construction-institute.org

Goulding, J., & Arif, M. (2013). *Offsite Production and Manufacturing - Research Road Map*. CIB Publication 372.

Isaac, S., Bock, T., & Stoliar, Y. (2016). A methodology for the optimal modularization of building design. *Automation in Construction*, *65*, 116–124.

Mao, C., Shen, Q., Pan, W., & Ye, K. (2015). Major Barriers to Off-Site Construction: The Developer's Perspective in China. *Journal of Management in Engineering*, *31*(3), 04014043.

Miller, T., seminar, P. E.-P. of the 13th I. research, & 1998, undefined. (1998). Defining modules, modularity and modularization.

Ocheoha, I., & O Moselhi - Modular. (2018). A BIM-based supply chain integration for prefabrication and modularization.

O'Connor, J. T., O'Brien, W. J., & Choi, J. O. (2015). Standardization Strategy for Modular Industrial Plants. *Journal of Construction Engineering and Management*, *141*(9), 04015026.

Ramaji, I., Memari, A., civil, J. M.-J. of computing in, & 2017, undefined. (2017). Product-oriented information delivery framework for multistory modular building projects. *Ascelibrary.Org*, *31*(4), 04017001. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000649

United Nations Department of Economic and Social Affairs. (2017). *World Population Prospects: The 2017 Revision | Multimedia Library*.

United Nations Department of Economic and Social Affairs. (2019). *Population division. World Population Prospects 2019*.

World Economic Forum. (2018). *The world needs to build 2 billion new homes over the next 80 years*. https://www.weforum.org/agenda/2018/03/the-world-needs-to-build-more-than-two-billion-new-homes-over-the-next-80-years

Young, B., Seidu, R., & M Thayaparan. (2020). Modular construction innovation in the UK: the case of residential buildings. *Proceedings of the International Conference on Industrial Engineering and Operations Management Dubai, UAE, March 10-12*