SMART LOCATION-BASED CONSTRUCTION PLANNING OF LARGE-SCALE PROJECTS IN THE INTEGRATED BIM ENVIRONMENT

Veljko JANJIĆ, Bexel Consulting, Serbia, veljko.janjic@bexelconsulting.com; Igor OSMOKROVIĆ, Bexel Consulting, Serbia, igor.osmokrovic@bexelconsulting.com; Jovan MARKOVIĆ, Bexel Consulting, Serbia, jovan.markovic@bexelconsulting.com; Igor PEŠKO, University of Novi Sad, Faculty of Technical Sciences, Serbia, igorbp@uns.ac.rs; Mirjana TERZIĆ, University of Novi Sad, Faculty of Technical Sciences, Serbia, terzic.mirjana@uns.ac.rs

ABSTRACT
Construction industry records unsatisfying results in terms of execution delays and budget overruns, which are result of insufficient planning, miscommunication, and efficiency issues, while it is among the least digitized sectors. Quality proven design, detailed construction schedule with precise data, and well-implemented progress monitoring process are the foundations of successful data-driven construction management. Integrated Building Information Modelling (BIM) is recognized as the technology that will most likely highly impact the industry. BIM increases the effort in the early phases of project design, improving stakeholders’ communication, early identifying and resolving design issues therefore preventing potential losses. Further, at the most cost-intensive project execution phase, BIM is often inadequately implemented or neglected, losing the huge potential of applying the BIM tools and methods for improving construction management processes. This paper analyses development of detailed construction schedule which considers multiple domains that need to be included in the planning process. Traditionally, especially for large-scale projects, it is an effort-intensive process that requires knowledge, focus and vast data inputs. Contrary to the construction industry, productivity in the manufacturing sector is quite enviable. Therefore, authors analyzed the assembly line concepts and Lean principles, applied in manufacturing, fitting them into the BIM environment to improve construction scheduling. The paper presents an advanced BIM model-derived location-based construction planning methodology (BIM-LBP) for development of construction schedules in the integrated 4D and 5D BIM environment making the most of available BIM model data.

KEYWORDS
BIM, 4D, 5D, Construction schedule, Automation, Construction planning.
1. INTRODUCTION

Changing the work habits in the construction sector is a complex and time-consuming process. The missing component in the traditional approach to project management is early detection and prevention of construction phase issues. Instead, project management is more about resolving the consequences of problems that are expected to exist on the project. The causes of most problems are mainly organizational and can be generalized as wasting cost and time on the lower quality of performed work (Andújar-Montoya et al., 2020). The industry can achieve greater efficiency using modern technologies, offsite construction, and automation (Chong et al., 2020). Process transformation, organizational settings and project delivery methods need to be correlated with the adoption of digital technologies in order to gain productivity growth. When processes and technologies develop digitally, all the project participants should change accordingly and move toward collaboration and integration (Daniotti et al., 2020). In order to fully benefit from the digitalization of construction projects, proper management of a data-rich model is needed. While approaching Building Information Modelling, the paper aims to provide a methodology that integrates BIM 4D and 5D processes (Çelik, 2019).

Working in a controlled environment implies implementing technology that transforms how project information is delivered and consumed. A data-driven approach in construction management removes defects causes and minimizes process variability. Optimizing the data usage and interoperability provides more effective project delivery and organizational processes, with higher quality, lower costs and fewer risks, improving legal coordination (Arayici et al., 2018). 3D BIM model integration with schedule and cost analyses can reduce risks and lack of information to avoid re-scheduling and project delivery delays (Chen and Tang, 2019), while artificial intelligence technology integrated with the BIM-based workflow can reduce the technical limitations for improving data processing and analysis automation while reducing errors from manual work (Chen and Tang, 2019).

Construction management should be an immediate and accurate on-site understanding of the building condition. The most cost-intensive project execution phase suffers from waste manifested as unnecessary waiting time and transportation, unused workspaces and buffers of unassigned tasks. Defects, rework and inadequate maintenance are the results of poorly managed work. Achieving smooth workflow with minimal waste and an optimized cost budget requires proper construction planning and effective production management (Kenley and Seppänen, 2006, Sacks et al., 2010). Location-based management aims to extract all the advantages of 3D modelling to produce 4D and 5D analyses of the project (Kenley and Seppänen, 2006). Planning for productivity implies more methodologies that rely on Lean principles and fit into the BIM environment:

- Integrated Project Delivery (IPD)
- Location-Based Management
- Advanced Work Packaging (AWP)
- Last Planner System (LPS)
The paper presents an advanced BIM-based methodology for developing construction schedules in the integrated 4D and 5D BIM environment based on location-based principles for the project execution phase. In this paper, Section 2 introduces the most important topics related to the construction plan and the principles applied in the developed methodology explained in detail within Section 3 including cost structure and budget development, innovative workflow for generation and fine-tuning of construction schedules, and schedule maintenance and update process following the project changes. Section 4 presents results and extensive analytics made available by implementing the methodology. Finally, Section 5 provides the conclusion.

2. CONSTRUCTION PLAN

2.1 Construction plan data domains

A well-developed project schedule can enhance both productivity and quality and play an important role in successful project delivery. A good schedule combines time and work sequencing with cost and technical data enabling data-driven construction management (Bragadin and Kähkönen, 2016). It has to be analyzed and feasible in terms of available costs and resources. Complementary, one of the key principles for correct schedule development is that task durations should be derived from targeted productivity rates (Kenley and Seppänen, 2006, Kiiras, 1989). In order to do this calculation, precise quantities of work related to tasks are needed. Each of the stated guidelines adds a specific data domain to be considered in a comprehensive construction schedule.

Finally, in order to be controllable and allow for timely corrective actions, the construction schedule needs to be detailed - the more detailed planning the greater possibility for accurate control (Woodgate, 1967). Utilizing traditional tools, the development of a detailed construction schedule, especially for large-scale projects, would assume development of thousands of tasks, for which all mentioned data domains need to be analyzed and inputted. This is an effort-intensive process that requires unavailable resources, knowledge, focus and data inputs, while it is very hard, to maintain updated schedule with project changes.

The paper proposes an integrated BIM-based methodology for generation of BIM model-derived construction schedules that consider multiple BIM data domains that need to be included in the correct planning process. At the task level, these include: work sequencing and relations between tasks, precise quantities, resource productivity rates, resource requirements, duration, location (project zoning), etc. The methodology utilizes computing power, advanced engines, and well-tailored workflows within integrated BIM environment, in order to enable a sound basis for efficient development and smooth updates of detailed multi-domain construction schedules.

2.2 Common planning deficiencies

Factors that affect the cost and time overruns and decrease project planning quality are lack of skilled professionals, unforeseen conditions, slow decision-making, design changes, poor preliminary estimates and insufficient knowledge of construction regulations (Sharma and
Gupta, 2021). Construction processes pass through different stages, from initial planning to project completion, demanding input from many participants (Clough et al., 2015). Lack of project planning is identified as one of the main reasons for unsatisfactory project results (Larsen et al., 2016), since often the quality of the delivered project is sacrificed in attempting to complete the project within budget and deadline (Clough et al., 2015). A significant element in the planning process is scheduling the project's work and then keeping it on track and on time as the project unfolds (Pierce, 2013).

The most common planning deficiencies are unrealistic time and cost schedules, improper planning during the bidding stage, lack of standard procedures, and inefficient use of modern technologies. Some of the most important indicators for the evaluation of a developed construction schedule could be:

- Schedule structure and level of detail - average activity duration;
- Network quality (FS relations are recommended, open ends and open starts avoided);
- Number of critical path activities;
- Number of long activities (should be minimized to have adequate early warnings);
- Average activity value;
- Available information (data domains) related to tasks;
- Balanced resource requirements, etc.

Generally, deviation from the baseline schedule can always be expected in the execution phase, demanding corrective action on time and correctly (Sharma and Gupta, 2021, Kenley and Seppänen, 2006). It is safe to say that planning construction projects, developing of high-quality construction schedule, and its maintenance during execution is quite a demanding task, that requires the implementation of state-of-the-art technology.

2.3 Lean construction management

In Construction Industry for centuries, we have had chronic problems in form of insufficient quality, poor safety, working conditions and, most important low productivity. Many different methods and approaches for minimizing the problems mentioned above have been proposed. Industrialization in the form of prefabrication was one of the directions for solving them. The idea of industrialization comes directly from manufacturing, which, according to Koskela (1997), has been a reference point in construction for many decades and a source of innovations. The same was with the Lean Manufacturing, the term coined in 1991 by James P. Womack, Daniel T. Jones and Daniel Roos from The Massachusetts Institute of Technology in their book The Machine That Changed the World. According to mentioned chronology from Lean Manufacturing the Lean Construction Management was developed.

The main purpose of Lean Construction Management is to eliminate, or at least to decrease, the waste from construction processes. Waste reduction increases production capacity, since the total capacity of a production system is the sum of work and waste in the system (Ohno, 1988). The main wastes according to Lean philosophy are the following: waste due to overproduction, stocktaking (taking inventory), transportation, the system/processing itself, defective products, wait periods and movement. According to Alarcon (1997) and Koskela
wastes in the construction industry are different, as follows: work not done, rework, unnecessary work, errors, stoppages, waste of materials, deterioration of materials, loss of labour, unnecessary movement of materials, excessive vigilance, extra supervision, additional space, delays in activities, extra processing, clarifications, abnormal wear and tear of equipment and making do. The most widely used scheduling technique for construction project is the Critical Path Method (CPM) and unfortunately, most of the above-mentioned wastes cannot be decreased by its use. Location-Based Planning can fix many shortcomings of Critical Path Method from a Lean perspective by focusing explicitly on the flow of crews and allowing the schedule to be optimized.

2.4 Location-Based Planning

Location-Based techniques have been used since 1929 in innovative projects such as the Empire State Building, and originally was based on graphical techniques, further developed by the Goodyear Company in the 1940s and expanded by the US Navy in the 1950s. The Empire State Building was officially opened on May 1, 1931, and since then held the distinction of being the world’s tallest building for more than 40 years. It was completed on time and under budget (Willis, 1998), and one of the reasons for that is the fact that main location-based methodologies were used.

Nowadays most used scheduling tool in AEC (Architectural Engineering and Construction) industry are Gantt Charts, a tool where each line corresponds to a task and defines production as a series of activities on a chart with a timescale. Initially, Gantt Chart was a graphical technique limited by its need for an underlying analytical method. Thus was the critical path method (CPM) borne. Gantt Chart as a schedule representation does not focus on the main constraint of a construction site, the occupation of a physical space. This fact is one of the biggest problems in planning and scheduling of AEC projects. Efficiency is being reduced in activity-based methodology in favour of the earliest completion.
According to Kenley and Seppänen (2006), the desire to efficiently manage resources is the critical driver for location-based management. According to location-based management, there is a great value in breaking a project down into smaller locations that provide a container for project data which is easier to monitor and analyze. Also, location-based planning presents the work planning process that protects production efficiency as work moves through locations and manages the continuity of work for involved resources. Compared with activity-based planning, location-based planning has more significant richness and analytical complexity, but combining both logics makes planning more economical. The best way to represent workflow through locations is using the flowline method, which is very similar to the line-of-balance method but with a much cleaner representation, as the activity is presented as a single line. Also, the vertical axis of the flowline represents the location unlike the line-of-balance diagram where vertical axis is related to quantity or cumulative production.
3. METHODOLOGY OF INTEGRATED BIM MODEL DERIVED LOCATION-BASED CONSTRUCTION PLANNING

3.1 Methodology (workflow) overview

The core of the developed construction planning methodology is the BIM model which is the source of project data, the starting point of the planning workflow and the central storage that remains interconnected with all further developed analyses and results (Schäfer et al., 2022). The methodology makes the most of BIM models utilizing the available datasets to generate information-rich multi-domain detailed construction schedules offering automation of various repetitive tasks, allowing more time for analysis and optimization and ensuring a smooth update process following the unavoidable project changes.

Formulating adequate BIM modelling requirements is very important for enabling various potential BIM benefits (Halmetoja, 2019), including the BIM model-derived construction planning. The model requirements do not have to be too extensive but well focused on a sufficient amount of information (Chen and Lu, 2019) to enable envisioned BIM uses and processes, and finally targeted benefits. This is one of the ideas of the Level of Information Need (LOIN) principle introduced in ISO 19650-1 (ISO, 2018a) as well. Further, quality control procedures and data consistency checks are necessary to ensure the compliance of the BIM model with defined requirements (Kumar and Teo, 2021). OpenBIM Industry Foundation Classes standard (ISO, 2018b), and IFC file format provide a classification of BIM objects which can be used for further project management processes (Froese et al., 1999, Ma et al., 2012, Kassem et al., 2015, Kavad et al., 2019). Since it is the open standard, used by a variety of BIM tools the proposed methodology, yet flexible in terms of classification, utilizes IFC-based element classification as the starting point for the development of cost breakdown structure, and further construction schedule and multi-domain plan. The other approach is to set a modelling requirement to define an attribute that is based on desired works classification for all model elements and use it for the development of a cost estimation structure. Defining the cost classification attribute could be done manually or automatically using rule-based BIM model enrichment processes that are offered within different BIM tools.

The most important feature of the proposed methodology is the full integration of BIM model geometry and information (3D), with time (4D), and costs and resources (5D) data domains within a single environment. In that way, rich and consistent BIM model data is utilized to improve project budgeting and planning workflows, enable native implementation of location-based scheduling principles, and develop a detailed multi-domain construction plan and subsequent analyses. The described workflow is fully enabled within the BEXEL Manager BIM platform, which is used to demonstrate the entire workflow in this paper.

The methodology of smart BIM model-derived location-based planning (BIM-LBP) includes the following steps (Figure 2.):

1. Generate 5D cost structure utilizing BIM model data and fine-tune it according to model specifics and/or rules of measurement;
2. Generate the project budget, and integrate cost items that do not have representation within the BIM model;

3. Define construction sequencing (methodology) and project-specific spatial breakdown (zones), as well as construction schedule outline levels;

4. Generate, analyze and fine-tune the construction schedule

The following sections elaborate on the stated steps, emphasizing the advantages and improvements the methodology offers due to having a direct link to the BIM model of the project in question. Also, considerations in terms of the applicability of the methodology to various project types will be discussed.

![Image](image.png)

**Figure 2. BIM model-derived Location-Based Planning (BIM-LBP) methodology overview**

### 3.2 Cost breakdown structure

Developing cost estimation based on IFC standard has been actively analyzed by multiple authors since the early developments of the standard up until today (Froese et al., 1999, Staub-French and Fischer, 2000, Ma et al., 2012, Alzraiee, 2020, Akanbi, 2021). Related to cost structure, the importance of product (element) features for development of cost estimation, the necessity of analyzing multiple work activities related to a single element, the analysis of resources needed for their execution, as well as the issue of updating the estimation with changes have been pointed out. The presented BIM-LBP methodology considers all these cost classification-related topics within an automated workflow utilizing knowledge templates.
Based on the BIM model structure (sources for different design trades), existing IFC classification (IFC Entity), element types (IFC Name) and, where applicable, additional relevant attributes (such as element thickness or diameter, affiliation to system etc.) the initial quantity takeoff (QTO) breakdown structure is generated having direct link of each item with corresponding elements. Quantity takeoff is automatically transformed into the cost database. QTO structure’s parent items are transferred into the cost classification items, while the leaf items are transformed into the cost items. For both classification and cost items smart BIM queries are automatically created, as attribute-based rules that define and maintain the link with appropriate BIM model elements. This is very important since remains applicable to any future BIM model update and change, and enables timely update of budget analysis with any elements being added, changed or removed. Apart from the BIM query, the cost items are defined with unit of measurement, quantity formula related to the element attributes that are used for quantity calculation and applicable mathematics, unit price or work execution resource-based “recipe” providing material, labor and equipment resources productivity rates for either a single unit, or the defined daily output.

At this point, in the automatically generated IFC-based cost classification each model element is linked to a single cost item (work activity). Since the classification can already contain hundreds or thousands of items, the automation of the cost classification adjustment process is made possible by importing the Rules of Measurement, spreadsheet-based template that enables rule-based multiplication of cost classification items, and adjustments of in terms of Quantity formulas. Example: The cost items generated according to following criteria: [IFC Entity] = IfcWall, with attribute [Structural] = TRUE; are automatically multiplied to create four groups of cost items that are all linked to the same groups of elements (same BIM queries), but shall have different units and quantity formulas, as well as unit prices, or necessary resources:

<table>
<thead>
<tr>
<th>IFC Entity = IfcWall</th>
<th>Reinforcement</th>
<th>kg</th>
<th>[Volume]*[Reinforcement]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural = TRUE</td>
<td>Formworks</td>
<td>m2</td>
<td>[Area]*2</td>
</tr>
<tr>
<td></td>
<td>Concrete Pouring</td>
<td>m3</td>
<td>[Volume]</td>
</tr>
<tr>
<td></td>
<td>Concrete Finishing</td>
<td>m2</td>
<td>[Area]*2</td>
</tr>
</tbody>
</table>

Explained workflow enables quick generation and fine-tuning of cost classification structure based on any IFC-based BIM model. Generated cost items are then enriched with either unit prices, or with resource database and resource productivity rates which can be done by exporting cost classification into a spreadsheet form, adding data, and importing it back to the integrated BIM environment. It is important that once created, cost database can be applied to any new BIM model as long as it is IFC-based and follows the same data requirements.

3.3 Bill of Quantities Generation

Each cost item of the generated cost database contains BIM query and can be automatically assigned to applicable BIM elements, which is the next step of the proposed workflow. In
the process of auto assigning the cost database to BIM model, the system checks the query collecting the corresponding elements, checks if the elements contain needed information for quantity calculation based on the cost item formula, calculates exact quantities, applies the unit price, and creates the cost estimation. The result of successful auto-assign process is generated Bill of Quantities (BoQ) that follows the structure of cost classification, while its every item has a link with corresponding BIM elements that can be easily visualized. It has been noticed that different BoQ structure is needed to support different project management needs, which is why the possibility of ungrouping and grouping it according to newly defined classification rules is implemented, as well as regrouping it to initial classification from the cost database. Various useful classification criteria include those such as location (by buildings, zones, floors), subcontractor, or any other specific model attribute.

Modelling of each and every building element is not feasible, or at least not optimal in terms of efficiency (Vitasek, 2019). As previously shown with examples of reinforcement or formworks, many types of work can be described and taken into consideration with a decent approximation based on formulas that use available BIM data. Still, within the project budget, there will be those cost items, that anyhow cannot be represented and calculated based on existing BIM elements, called non-BIM cost items, or non-selection work items (Park et al., 2019). Within the BIM-LBP methodology, such cost items are additionally added to the cost classification structure, “traditionally” quantified and included in the BoQ to achieve that 100% of works and budget estimation are included in the integrated BIM environment ready for the following steps of project planning, monitoring, and reporting during construction execution.

3.4 Project spatial segmentation

Location-based planning logic analyzes the movement of tasks through locations (zones) that represent the main unit for scheduling work. (Kenley and Seppänen, 2006). A project can be (physically) segmented into zones vertically (to floors) and horizontally (buildings, wings, zones, etc.) as shown in Figure 3., and the hierarchy of the zoning needs to be defined (Birrell, 1980).

A project spatial breakdown and defined order of work execution through zones are very important for the structure and the quality of the developed construction schedule. Aiming for the continuous flow of work activities, balanced resources, and improved control over the project implementation, when defining zones and engaging resources, construction managers shall tend, where execution process allows it, to achieve that the tasks’ duration for mutually interconnected activities are the same, compliant to takt time planning, as another Lean construction planning approach (Frandson et al., (2013)). This enables the crew that performs a predecessor activity to finish its work and move to the next zone, just in time for the next activity to start working in the first zone.

BIM environment natively includes various attributes that spatially segment the designed building and that could be used to define project zones (buildings or floors). Additional
zoning attributes could be required and defined in the authoring tool based on, elements could be manually selected to define zones, or automated data enrichment could be done through the identification of all BIM elements contained within space elements defining zones (IfcSpace) which can be also done using BEXEL Manager platform.

Figure 3. Project segmentation horizontal (left) and vertical (right)

Based on model attributes automated custom breakdown structures are generated, and transferred to smart selection sets that are used for defining zones. Planned order of execution is defined for each of the zone hierarchy levels using standard FS, SS, FF, and SF relations with any required time lags. Apart from time lags, the construction logic may require spatial lags or spatial buffers between the different work locations (Russel and Wong, 1993). This refers to particular work activities and can be handled in defining execution methodology.

3.5 Work sequencing (execution methodology)

Besides spatial breakdown, the definition of work sequence (execution methodology) that defines the order of activities execution within defined spatial zones is another aspect of location-based scheduling. It mostly depends on project type, the technology of execution or construction process logic, and in the traditional scheduling approach, it is defined by the planner within every spatial project zone commonly developed from scratch for each project.

The first step in improvement and automation of the scheduling process is to allow work sequence definition on the project level and not on the level of a particular zone. Similar to the spatial distribution, in BIM environment, the most beneficial way is to utilize available information for this process. Works and activities to be performed in a construction project are best described (and quantified) within cost classification. Therefore, the best approach
to defining general work sequence is to refer to groups of works in cost classification, especially since it is already linked to BIM model elements. Work sequence is defined by simply specifying relations between cost items (or their groups) and that logic shall be distributed onto spatial project structure in the generation of the construction schedule. In such way complete construction logic, which takes into account project typology and technology of execution is clearly specified through a simple matrix that shows relationships between different activities that have been defined in cost classification.

This approach, not only reduces the time needed for the planning process by eliminating repetitive work of copying work sequence logic repeatedly through schedule development (for example defining that concrete pouring is executed after formwork installation on every floor, every building, and every zone) but, since cost classification can be reused as a standardized database, by linking work sequence to it, defined construction methodology becomes reusable on multiple projects as well. Integration of non-BIM activities that are also a part of cost classification (material supply, safety measures, and elements that are not modeled) is enabled within this scheduling approach. Projects with the same cost classification and of the same typology and technical characteristics (for example, residential buildings with RC structure) could have the same work sequence definition (execution methodology) that could be transferred from project to project, customized, and improved through this process. This allows knowledge transfer between project teams and the synergy of knowledge from multiple experts. Focus is then shifted from unproductive repetitive tasks to the core of the project planning process, work execution logic, and its optimization.

The creation of the execution methodology is performed by connecting the nodes that are linked to classification cost items (or their groups) and defining standard FS, SS, FF, and SF relations with any required time lags between them. Considering that the schedule is organized on multiple levels (spatial or methodology outlines), when creating methodology, some additional features of defined relations need to be specified, in order to determine the appropriate implementation of relations between methodology and zone items that is automatically executed by the smart BEXEL Manager engine during the schedule generation process.

By specifying “Copy to Children” feature of a standard relation, it will be transferred to the lowest outline level of generated schedule. That means that FS relation between Beams and Columns, which is generally defined in the methodology, will be transferred to FS relation between tasks related to the Beams and Columns of the single specific phase within each of the levels. In this way planner is able to generate detailed construction schedules with a large number of tasks and relationships by specifying relationship on a higher level and transferring it to the lowest schedule-organization level and thus creating a detailed work sequence, avoiding unreliable SS relationships on large groups of works.

“Constructive offset” is another advanced relations’ feature, introduced to enable handling the situation where apart from time lags, the construction logic requires also a spatial buffer between the different work locations. Constructive offset feature allows the planner to specify that a relation, generally defined in methodology, needs to comply with such a spatial
constrain when the schedule is automatically generated, i.e., schedule will be generated in
that way to “leave” an offset of a defined number of spatial zones, therefore, ensuring the
technologically required spatial buffer. For example, this spatial lag approach is used to
delay curtain wall execution on a high-rise building for a specific number of floors from
cement execution for safety reasons. In general methodology, the relation that the curtain
wall is executed when the concrete structure is finalized is correct, but it needs to comply
with this zone-related lag. This is a significant improvement compared to the traditional
approach that would handle this by setting the SS+lag relation defining the time offset. Such
relations are not reliable in case the predecessor activity is stopped or delayed for some
reason, while automatically generated FS relations, by following the imposed spatial lag
thanks to defined constructive offset this situation is automatically handled.

3.6 Schedule generation and fine-tuning

Having the project spatial segmentation and the sequencing of works defined, a planner
needs to specify the order of combining them, i.e., to define the outline levels of the schedule
structure, which is referred to as the creation template (Figure 4.). It represents an expert’s
“instruction” for a computer engine to generate a schedule structure. The goal of the smart
scheduling engine is to create thousands of single location-based tasks that refer to particular
work within a particular low-level zone, following the hierarchy defined in the creation
template, as well as standard relations (and their advanced features) defined in zones and
methodologies. This allows that scheduling logic defined for the entire project is
automatically transferred to the lowest levels of schedule organization eliminating the need
for repetitive manual task creation, therefore, enabling efficient development of very detailed
construction schedules, that are linked to BIM elements and all available data domains.

Automatically created schedule structure includes all tasks and relations, while, following
the location-based and takt time planning, the duration of every task is equal and set to the
defined value. Having in mind that location-based planning, in general, recommends same
duration for mutually interconnected activities aiming to organize the construction process
according to principles of assembly line manufacturing, a detailed schedule structure with
default duration, set to the time period in which most of the activities (in one spatial unit)
could be completed, represents a great starting point for creating a fully optimized schedule.
The schedule can be further optimized by shortening or extending an entire group of tasks related to a specific activity, or by setting the As Late As Possible constraint to some works (mostly applicable to finishes and architectural works) in order to optimize resource use and minimize idle times which are clearly visible in the flowline chart. Since the whole process is performed within an integrated BIM environment, having defined the entire schedule logic based on cost classification items, created schedule already has a direct link to model elements and fully integrated quantities, costs, and resources information. Based on this, from the moment of creation, the schedule can be monitored and assessed through analytics such as cash flow, cumulative cost, and resource and activity charts. By looking at this data, a planner is able to evaluate schedule performance - cash flow peaks, not optimal S-curve and unbalanced resource needs are immediately identified, so the schedule can be optimized. Automated algorithms for resource-leveling and task duration calculation based on defined daily outputs that utilize the fact that each leaf task is related to precise quantities are available to facilitate the optimization process. Thanks to automation enabled within the presented BIM-LBP, creation of more realistic and optimized schedules is enabled. Considering that schedules could be generated efficiently with significantly less time and effort, the methodology provides planners an opportunity to develop and test multiple What-if scenarios, compare them in terms of execution time, optimization of resource usage, financial risks, etc., and find the best solution in line with specific project environment.
3.7 Construction plan updates with progress, design or on-site changes

As explained in the previous sections, the entire workflow for implementing the BIM-LBP methodology is fully integrated and results from one step are the inputs for the next one. Considering it is a BIM model-derived process during which links to corresponding BIM elements are continuously maintained through BIM queries, automated updates of the construction plan are enabled with any updates of the source IFC files. Based on BIM queries, cost items and smart selection sets automatically include new elements that comply with defined rules, altering or excluding changed or deleted BIM elements automatically updating the BoQ, as well as elements linked to zones and methodologies “nodes”, finally updating the construction plan’s quantities, cost and/or resources domains. Task durations are not automatically updated, since changes could be managed by changing engaged resources or duration, depending on the project manager’s decision. Of course, any changes in task durations are automatically reflected in schedule-based 5D estimations.

Location-based scheduling enables improved control over the construction execution (Olivieri et al., 2019). BIM-LBP provides detailed construction schedules and thanks to their structure and the advanced integrated 3D, 4D and 5D BIM technology, even further enhancements of the construction monitoring process are available. This is enabled by generating very informative multi-domain BIM-based look-ahead plans that are held to be a powerful Lean construction tool, considered to increase reliability and productivity in the execution of construction projects (Chen et al., 2020). BIM look-ahead plans can be exchanged using openBIM collaboration format (BCF) and together with accompanying analyses (quantities, required resources, etc.) they enable project managers to clearly define planned on-site activities, as well as systematically collect actual progress data. BCF files with adjusted look-ahead plans to match actual progress are imported to the integrated BIM environment such as BEXEL Manager, creating the element-based progress entry. Thanks to a fully interconnected network 4D/5D BIM construction schedule is automatically updated instantly enabling advanced analytics and planned vs actual analyses (Figure 5.).
4. RESULTS

4.1 Construction plan analytics and the quality of developed construction plan

In the literature, “location-based scheduling” is more often met compared to “location-based planning”, while in this paper, authors purposely insist on the “planning” term to emphasize the multi-domain analytics of the created project plan considering that, apart from the continuous and optimized flow of work activities, each of the plan’s analytical domains – quantities, resources (material, labor and equipment), and of course costs need to be analyzed, confirmed, managed and timely implemented for successful execution. Also, thanks to a highly developed schedule structure, following location-based principles, the schedule is clearly represented in the flowline chart, which ensures that any unnecessary time reserves or activities that overlap within the same zone are easily spotted and resolved, optimizing the construction plan.

BIM-LBP methodology and integrated 4D and 5D BIM environment enable full advanced analytics considering that each schedule task is bidirectionally linked to corresponding BIM elements and cost structure items with calculated quantities, prices, and resource productivity rates. Therefore, analysis of monthly or weekly quantities, material charts, and construction cost charts are instantly available for the project and top management in order to confirm the schedule feasibility – Is the project financing in line with the plan? Are the concrete factories available to deliver the required weekly or daily quantities? Is the required man force available? – different questions are risen by different project roles and stakeholders. Some of the available charts are shown in Figure 6. Additionally, multi-domain data available on a leaf task and element level enable various analyses and color-coded
visualizations – such as marking elements on a critical path, identifying tasks based on the element selection, isolating tasks with elements of value higher than a defined threshold, etc.

![Figure 6. 4D and 5D construction plan analyses: Construction costs S-curve (top-left) and monthly histogram (top-right); activity quantities (low-left); flowline (line of balance) chart (low-right)](image)

### 4.2 Methodology applicability to various project types

Presented BIM-LBP methodology has been successfully implemented using BEXEL Manager platform in a number of use cases of various types of projects – residential or commercial high rise, sports complexes, road and railway infrastructure, etc. Slight differences are noted in linear infrastructure projects where zoning is strictly horizontal and usually related to chainages where the importance of IfcAlignment is pointed out. Also, some limitations of widely spread infrastructure BIM modelling tools in terms of IFC export are noted, and may cause some additional manual work in initial steps of BIM-LBP methodology, namely development of cost classification structure.

While most of the steps of the methodology are automated based on model data, it has been seen that construction methodologies defining the work sequencing are indeed very similar and reusable within the same project type, which provides a sound basis for capturing planning expertise by developing BIM-LBP knowledge base, alleviating repetitive scheduling tasks and efficiently generating information-rich construction schedules.

### 5. CONCLUSION

The presented BIM-LBP methodology, fully implemented within the innovative BEXEL Manager platform, enables the highly efficient development of very detailed information-rich construction schedules, with a fully developed network having a majority of FS relations.
which is enabled by introducing advanced relations’ features (generation rules) utilized by smart schedule generation engines. Thanks to applied location-based principles, the schedules natively impose balanced resource requirements as well as expected productivity rates and could be analyzed and optimized in terms of construction flow. Multiple 3D, 4D, and 5D data domains precisely linked to each task provide the possibility to fully optimize the schedule in line with the project goals. Finally, 4D and 5D construction simulations are analyzed and could be exported as one of the results available within the fully integrated environment, since providing 4D and 5D data in a visual way is often identified as one of the main benefits of 5D BIM since it increases mutual understanding and strengthens collaboration among the project team (Hasan and Rasheed, 2019).

Export of BIM-based look-ahead plans broken down by various criteria (zones, types of work, subcontractors) for the custom upcoming period with all the quantities and visualizations is also enabled, as a project managers’ tool for operative planning and imposing the expected productivity during the execution phase. They help in avoiding any misunderstanding, conducting efficient meetings, and conducting regular control of execution on takt basis, by receiving actual progress in a form of adjusted look-ahead plans matching the actual progress. Finally, thanks to attribute-based links of BIM model elements with developed analysis and schedule, automated update of the construction budget, simulations, tasks’ quantities and costs, resource estimations, etc. is enabled, providing up-to-date insight into the project performance during the entire execution process.

By enabling vast automation, the BIM-LBP methodology addresses the industry-wide lack of planning issue, improving the level of development of construction schedules, and the quality, precision, and timeliness of performance and productivity analysis, aiming to establish highly efficient and effective construction management and achieving overall better project results.

REFERENCES

24. Koskela, L. (1992), Application of the New Production Philosophy to Construction. Technical Report No. 72,
Center for Integrated Facility Engineering (CIFE), Stanford University.


