Assessing the sustainability of repetitive floor plan using Building Information Modelling-DIGITAL TWINS framework

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Abstract. Various factors, including the nature of the utilized equipment, labour expertise, availability of resources, and meteorological circumstances, might impact the efficiency of work on construction sites. As a result, site and planning engineers must continuously monitor and assess construction progress considering site conditions and the performance of used construction resources. In multi-storey buildings, repetitive floor construction plan impacts enormously construction site sustainability. To identify an optimal set of construction resources, this paper presents Building Information Modelling-DIGITAL-TWINs (BIM-DTs) framework, which planners and site engineers can use to easily monitor and control workflow progress of the repetitive floor. Using a digital model, DTs replicate the actual workflow process on a building site and guarantee a consistent information flow. To guarantee information flow between the building site and the digital model, several communication technology tools could be deployed and tested (High-definition site construction camera, regular site monitoring using drones, infrared smart sensors, etc.). The initial results of this research show an important improvement in the sustainability of construction sites. Reduced formworks oil consumption, improved human resource safety, and increased site resource profitability were observed in several treated real cases.

1 Introduction

In multistorey building, typical floor contains same structural elements which are repeated from one floor to another. Construction cycle (repetitive cycle) corresponds to the period of construction of all vertical (walls, columns, and beams) and horizontal (slabs) structural elements existing in the typical floor. The most effective way of completing the repetitive cycle is typically accomplished by defining an appropriate building plan and making efficient use of construction resources. This plan will be repeated from one floor to another impacting

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enormously the sustainability of the construction process. A sample of six-phase cycle is presented in Figure 1. Identifying the realization phase for each vertical and horizontal structural element is a strongly constrained problem with a large search space. Developing cycle plan needs deep site experience which enables the planning engineer to integrate technical construction constraints and generate a feasible solution. An efficient cycle plan could be identified but without a real possibility of optimization.

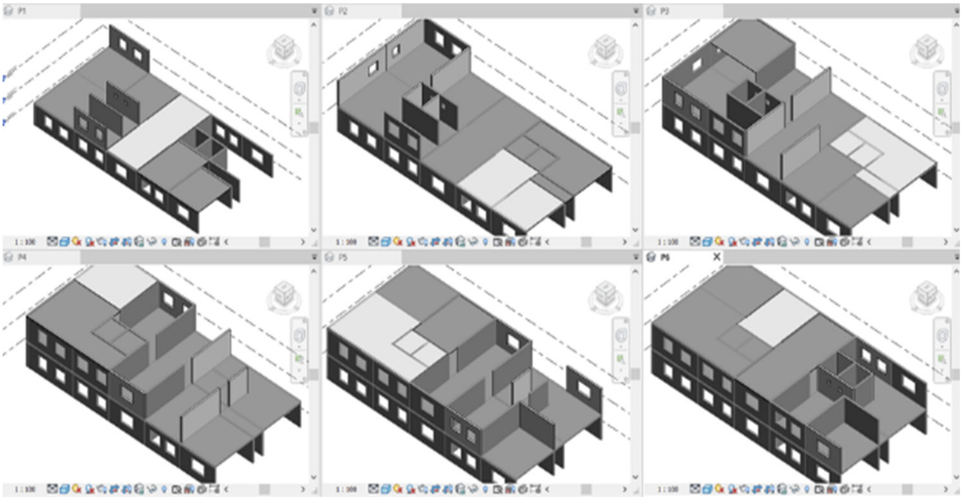

Fig. 1. Sample of six phases of the typical floor construction plan.

Considering changed site conditions and the uncertainty of used human and materials resources, the cycle plan must be reviewed and regenerated from time to time. Recently, a successful framework based on the Building Information Modelling-Digital Twins methodology (BIM-DTs) has been proposed to optimize the cycle plan [1]. However, the adopted assessment criteria consider only the balance of daily working hours. A better assessment of the cycle plan needs to consider a multicriteria function including the smooth usage of construction resources, environmental protection, and more accurate cost estimation.

BIM provides a big support for designing and planning construction process. While DTs support monitoring and validating actual context around buildings. DTs lead to better management of building processes. A dynamic re-evaluation of environmental impacts, cost, and social aspects could be achieved [2]. Information confined in BIM and specifically its 3D parametric models make it one of the most promising evolutions in the construction industry. Many BIM-based approaches are developed using automated processes of quantity take-off and accurate cost estimation [3, 4, 5]. Also, a time-cost optimization process using BIM and genetic algorithms has been developed to identify the optimal construction plan [6]. BIM facilitates the extraction of project information quickly and accurately. While genetic algorithms find the optimal solution. Digital construction facilitates the integration of new technologies, robotics, and automation in the construction industry. A lot of benefits could be achieved involving safety improvement, higher productivity, time saving, waste management, cost-effectiveness, and site monitoring [7].

This paper proposes a tool for the sustainability assessment of repetitive floor plan using BIM-DTs framework. Multicriteria assessment is considered. Proposed tool identifies automatically the list of structural elements to be realized in each phase of the cycle so that a sustainable cycle plan is developed and performed.

2 BIM-DTs framework structure

2.1 Workflow

Figure 2 illustrates the structure of proposed tool to generate and perform optimized cycle plans.

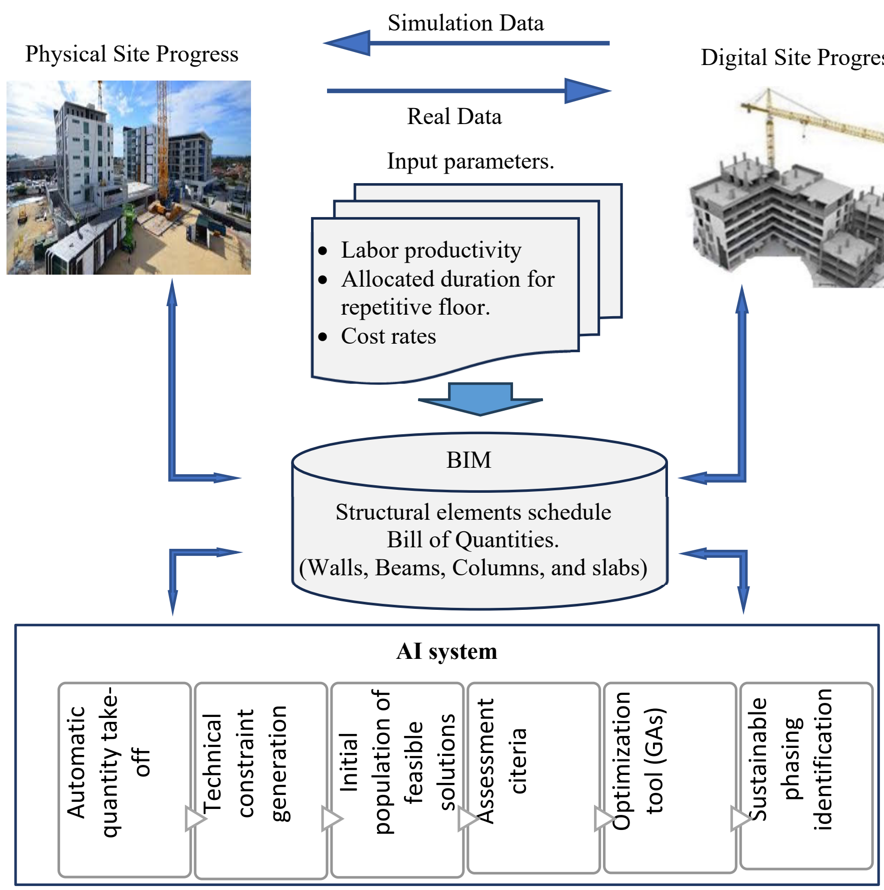

Fig. 2. BIM-DTs framework structure.

Building information model reveals needed data to generate a feasible cycle plan. Data such as bill of quantities (BoQ), position in architectural plan, and physical properties of structural elements are considered as input parameters for proposed tool. Other input parameters like allocated duration for repetitive floor, labour productivity (unit time rate), and cost rate should be provided by the user.

The developed artificial intelligence system (AI system) includes six consecutive steps. In the first step, information related to the quantities of existing vertical and horizontal structural elements in the repetitive floor are automatically extracted. Step 2 focuses on generating construction technical constraints. These constraints ensure that all vertical structural elements in the floor I are realized before casting the slab zone in the upper floor (floor I+1). Also, any vertical structural element in floor I+1 can be realized just after completing the slab zone in floor I. Therefore, in step 2, a range of feasible realization phases (RFP) is identified for each vertical structural element without breaching technical constraints related to horizontal works (slab zones). A feasible cycle plan could be assessed after assigning a feasible realization phase for each structural element included in the typical floor.

Identifying the best cycle plan represents a strongly constrained problem which has a large search space. For instance, 25 structural elements with 3 values of RFP for each element could lead to 25^3 (15625) potential solutions. Many optimization techniques could be used to identify the best solution. But Genetic Algorithms (GAs) are selected for its ability to conduct a rapid and global exploration of the search space.

Consequently, in step 3, a first population of feasible solutions can be reached. In Figure 3, every solution (a cycle) is shown as a chromosome with m genes (where m is the number of vertical elements).

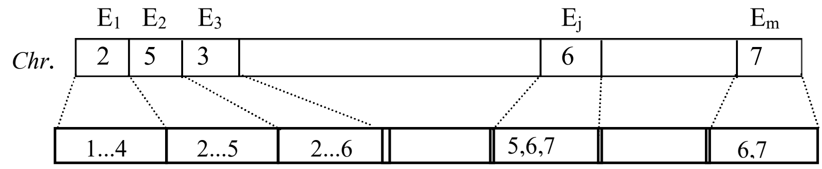

Fig. 3. The range of feasible phases (RFP).

Each gene will be assigned a value from its RFP so that a chromosome (feasible solution) is formed as a vector as in Equation (1):

$$\overrightarrow{Ch_j} = [V_i]_{i=1}^{m} \quad \forall \quad V_i = r \quad r \in [1,2,3,\ldots\ldots,n] \qquad (1)$$

n = duration of cycle

In step 4, the user will be required to provide the coefficient/importance of each assessment criteria (clarified in next paragraph) of the cycle plan so that the search for optimal solutions by GAs could be achieved (step 5 and 6).

Digital twins' technology is proposed to simulate the construction progress through BIM. Considering changed site conditions and the uncertainty of used human and materials resources, the cycle plan must be reviewed and regenerated from time to time. Accuracy and transparency of site data is ensured by combining BIM and digital twins.

2.2 Assessment criteria

The sustainability of each feasible solution is assessed based on the function as shown in Equation (2):

$$F = \sum \propto_k * F(j)_k \qquad (2)$$

$\propto_k$ represents the weight (importance) of the criteria k. Several criteria could be considered during the assessment of the cycle plan as described below.

2.2.1 The balance of phases working hours

Balancing daily working hours on construction site improves the sustainability of repetitive cycle plan through the improvement of profitability and safety of human resources. Assigning a feasible realization phase for each structural element included in the typical floor leads to estimate needed working hours *Cj(r, j)* for structural elements carried out in a specific phase (r) of the cycle. Considering t_m as average value of daily working hours needed for all structural elements in the typical floor, the balance of phases working hours could be assessed using following function as shown in Equation (3):

$$F(j)_1 = \sum_{r=1}^{n} \frac{|t_m - Cj(r,j)|}{t_m} \qquad (3)$$

2.2.2 Reducing needed quantity of formwork

Maximizing formwork usage rate leading to more sustainable solution through minimizing materials waste, increasing profitability performance, and reducing formworks oil consumption. The adopted function to assess formwork usage performance is shown in Equation (4):

$$F(j)_2 = \sum_{r=1}^{n} \frac{Lb_d(j) - Lb_j(r,j)}{Lb_d(j)} \qquad (4)$$

$Lb_d(j)$ represents the total needed length of vertical formworks.
$Lb_j(r,j)$ represents the length of vertical formwork used during the phase r.

2.2.3 Reducing times number of forms assembly and separation

The dimensions of the structural elements selected to be realized in each phase of the cycle control forms assembly and separation times number. The function in Equation (5) is adopted to assess this criterion.

$$F(j)_3 = \sum_{r=1}^{n} \frac{Acc(\mathrm{r,j}) + \mathrm{Dacc(r,j)}}{2 * \mathrm{n} * K_i} \qquad (5)$$

$\mathrm{Acc(r, j)}$ represents the times number of forms assembly in the phase r. $\mathrm{Dacc(r, j)}$ represents the times number of forms separation in the phase r. K_i is the total number of forms on building site. Reducing the value of $F(j)_3$ leads to better site safety conditions and improved profitability of formworks.

3 Results

Proposed BIM-DTs framework has been applied and validated through several real cases. Comparison between the manually generated solutions and the solutions generated by proposed framework shows important gains in site sustainability. For instance, proposed framework is used to generate 10 phases cycle plan for 70 flats building project. Table 1 shows data for 10 phases cycle generated manually by site engineers.

Table 1. Manual solution.

The phase r of cycle	Working hours	Needed formwork [m2]	Times number of forms assembly & separation
1	85	100	10
2	56	84	13
3	81	103	10
4	78	102	15
5	85	106	9
6	84	96	12
7	65	105	15
8	90	107	19
9	73	97	15
10	43	60	6
Max/Total	90	107	124

Results presented in table 2 and table 3 are for optimized solutions generated by BIM-DTs framework adopting different weight values of the assessment function. In the first optimized solution higher weight has been allocated to the third criterion. It is clearly stated that reducing assembly and separation times number of forms impacts negatively total needed quantity of formwork. However, higher weight has been allocated to the first criterion in second optimized solution leading to better balance in phases working hours and lower quantity of needed formworks. Comparing the manual solution to optimized ones, it is clearly stated that better balanced values of working hours and higher profitability of formwork are achieved. Unbalanced working hours highly reduces labor productivity and negatively impacts safety conditions on building sites. Also, reducing the needed quantity of formwork improves site environmental performance.

Table 2. Optimized Solution 1.

Criterion weight	**0.3**	**0.2**	**0.5**
The phase r of cycle	**Working hours**	**Needed formwork [m2]**	**Times number of forms assembly & separation**
1	83	111	11
2	69	91	8
3	79	93	7
4	76	102	5
5	71	88	9
6	69	89	9
7	80	107	6
8	81	94	10
9	51	71	5
10	75	95	4
Max/Total	83	111	74

Table 3. Optimized Solution 2.

Criterion weight	**0.5**	**0.2**	**0.3**
The phase r of cycle	**Working hours**	**Needed formwork [m2]**	**Times number of forms assembly & separation**
1	74	96	9
2	72	98	12
3	73	91	5
4	71	98	10
5	78	92	12
6	71	93	10
7	81	92	12
8	74	98	11
9	75	98	10
10	66	85	6
Max/Total	81	98	97

4 Conclusion and future work

Proposed framework generates optimized cycle plan to realize typical floor in multistorey building. Important productivity and site profitability gains are achieved. To validate the effectiveness of proposed framework, it is used to generate solutions for many real projects. Notable improvements in site sustainability are achieved through lower amount of needed construction resources, better safety conditions, and lower formworks oil consumption. More analysis and adjustment of input parameters could improve the performance of the proposed framework. In this paper, a framework combining BIM and DTs is developed. While monitoring site progress and having a continuous flow of information is ensured by digital twins, the main issue continues to be combining data in various formats from diverse technology sources. In the context of achieving sustainability objectives, more advanced construction technologies should be used. Technologies like Internet of Things (IoT), 3D printing, and robotics could be integrated to our framework, and they represent a high potential of future work and development.

References

1. A. Istanbullu, S. Wamuziri, M. Siddique, BIM Digital twins environment to enhance construction process. IOP Conf. Series: Earth and Environmental Science, Sci. 1055 012006 (2022). https://iopscience.iop.org/article/10.1088/1755-1315/1055/1/012006
2. A. Boje, Á. Menacho, A. Marvuglia, E. Benetto, S. Kubicki, T. Schaubroeck, T. Gutiérrez, A framework using BIM and digital twins in facilitating LCSA for buildings, J Building Engineering, **76**, 107232 (2023). https://doi.org/10.1016/j.jobe.2023.107232.
3. A. Fazeli, M. S. Dashti, F. Jalaei, M. Khanzadi, An integrated BIM-based approach for cost estimation in construction projects, J Engineering, Construction and Architectural Management, **28(9)**, 2828-2854 (2021). https://doi.org/10.1108/ECAM-01-2020-0027
4. M. Rahimi, H. Khan, Building Information Model for Cost Estimation and Scheduling in Building Architecture, Global Journal of Engineering Design & Technology, **13**, 192 (2024). https://www.researchgate.net/publication/378139288
5. A. Shehab, A. Abdelalim, Utilization BIM For Integrating Cost Estimation And Cost Control In Construction Projects, International Journal of Management and Commerce Innovations, **11** (1), 102-120 (2023). https://doi.org/10.5281/zenodo.7923308
6. Y. Yu, J. Han, H. Gu, Y. Yang, Dynamic Optimization of Construction Time-Cost for Deep and Large Foundation Pit Based on BIM Technology and Genetic Algorithm. Appl. Sci., **13**, 10716 (2023). https:// doi.org/10.3390/app131910716
7. C Ejidike, M Mewomo, T Olawumi, O Esangbedo, A Review of the Benefits of Automation and Robotic Application in Building Construction, in Proceedings of Computing in Civil Engineering 2023 (2024). https://ascelibrary.org/doi/10.1061/9780784485224.096