Research on the application of CPS intelligent construction system from the perspective of digital transformation of construction industry - Based on the case of phase II project of South China University of Technology International Campus

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ABSTRACT
This paper uses the new technology of intelligent construction to create a CPS intelligent construction platform, using the BIM three-dimensional model as the carrier to access the intelligent hardware monitoring data and project management software data. Based on the "three-in-one" mode of software + hardware + BIM, the management of prefabricated component factory production and on-site construction is realized online, visualized and intelligent, and the digital twin symmetrical management is realized, and combined with the case of the Second Phase International Campus of South China University of Technology, the scientific and effectiveness of this intelligent construction system is verified.

Keywords: *CPS; Intelligent Construction; Digital Twin*

1. INTRODUCTION

After nearly 30years of rapid development, China's construction industry has made great achievements. In recent years, with the acceleration of population aging and the impact of the development of other industries, the construction industry has experienced a phenomenon of "labor shortage" [3] [10] As a labor-intensive industry, the traditional construction industry is deeply affected by the fading population [5] [9]

The traditional construction industry has backward operation methods and a very low degree of informatization, relying on traditional "management methods" to manage the construction process of the project. Due to the impact of the overall industry environment in recent years, the profit margin of the construction industry is getting smaller and smaller, and the resource input cost of the project is almost not much different, and it is mainly necessary to rely on management to create higher benefits [7] [11] Against the backdrop of years of traditional management, the efficiency of projects has grown very slowly. The existing building construction project management system has the following main problems:

(1) The industrial chain is not integrated, and it is difficult to share information, resulting in a large number of communication costs and construction costs;

(2) The construction organization scheme is difficult to get the optimal solution, due to the complex construction process of the building, the advantages and disadvantages of the construction organization design depend on the experience and level of the construction organization designer, and there is contingency and uncontrollability;

(3) The construction process lacks effective control means, and the information transmission at the construction site is seriously lagging behind, including real-time collection of work status, real-time intelligent decision-making, and completion of corrective control;

(4) The construction data of the whole industry chain is not formatted, forming a knowledge system that can be

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used by enterprises, and enterprises lack their own knowledge base

2. CASE STUDY OF EPC OF PHASE II PROJECT OF GUANGZHOU INTERNATIONAL CAMPUS OF SOUTH CHINA UNIVERSITY OF TECHNOLOGY

2.1 Project Overview

South China University of Technology Guangzhou International Campus Phase II project (the first batch) design and construction of the general contract, the total construction area of 424350 square meters. The project is located on the north side of Xingye Avenue in Nancun Town, Panyu District, Guangzhou, and on the east side of the East Route of Nancun. After the completion of the project, it will include the campus service center, teaching building, library and archives, cultural activity center, gymnasium, student dormitory, logistics complex, bus station, garbage station, janitor, teacher's dormitory, primary school kindergarten, municipal supporting facilities, road square, greening, comprehensive pipe gallery, public works and other supporting facilities. Among them, the A4 student dormitory and the G5 teacher dormitory are prefabricated buildings.

2.2 Project Objectives

The project as a whole builds a demonstration site for prefabricated intelligent construction in Guangdong Province. The other objectives are as follows:

Campus service center, public teaching building, cultural activity center, comprehensive gymnasium, teachers' dormitory (one of them) to ensure that it won the Guangzhou Quality Engineering Award and the Guangdong Provincial Quality Engineering Award;

The library ensures that it has won the Guangzhou Quality Engineering Award, the Guangdong Provincial Quality Engineering Award and the National Engineering Award;

G5 teachers' dormitories, A4 student dormitories, and F4F5 student dormitories ensure the national standard prefabricated A-level projects;

Ensure the acquisition of guangzhou safe and civilized model construction site, Guangdong province housing and municipal engineering safe and civilized production civilization construction demonstration site, Guangdong province construction project construction safety production standardization site, and strive to create a national AAA level safety and civilization standardization site

2.3 Project Difficulties

2.3.1 The Volume is large, The Construction Period is tight, And the Resource Investment is large

The overall construction area is large, the key venue "two libraries and one center", the largest single area library of more than 50,000 square meters. The construction period is tight, and the duration of the bidding documents is required to be 562 days; Material turnover is difficult, and the amount of labor, materials and equipment is large. F1 plans to complete the initial renovation after the year, in conjunction with the completion of the exhibition hall and temporary office area transformation.

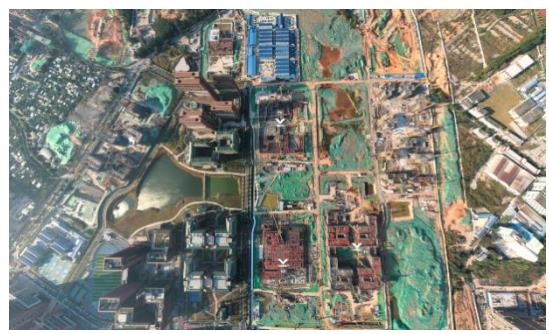

Figure 1: Aerial panorama of the project construction process(photo credit:original)

2.3.2 The Project Positioning is high and the Quality Requirements are high

The project contract requires high quality, campus service center, public teaching building, cultural activity center, comprehensive gymnasium, to ensure that it wins the Guangzhou Quality Engineering Award and the Guangdong Provincial Quality Engineering Award; The library ensures that it has won the Guangzhou Quality Engineering Award, the Guangdong Provincial Quality Engineering Award and the National Engineering Award. The project positioning has become a demonstration benchmark project for quality and safety management and EPC management.

2.3.3 Safety control is difficult, and civilized construction requires strict requirements

There are many large-scale equipment in the project, many major sources of danger, many cross-operations of personnel, and it is difficult to control safety. The project is located in Guangzhou, the pressure of environmental protection inspection is large, and the green construction requirements are high. The campus has been completed near the first phase of the project, and attention needs to be paid to noise, sewage and waste management after the start of the school year. 2# The main gate, the visit to the humanoid passage, the office living area, etc. are all

located within one part, and the civilized construction needs to ensure strict daily management.

2.3.4 The Structure is Complex and the Construction is difficult

The structure of each single body is complex, the on-site construction is difficult, the selection of the program needs to be considered in many aspects, and the on-site implementation process requirements are high.

2.4 Project Site Issues

The total construction area of the project is 424350 square meters, which is composed of 1 4-storey gymnasium, 1 5-storey library, 1 9-storey logistics complex, 2 20-storey, 4 27-storey, 4 32-storey teacher dormitories, 1 6-storey, 1 15-storey, 2 21-storey student dormitories, other 1-5 floor supporting facilities and a partial 1-storey basement.

The management decision-making level obtains construction site information through regular production meetings and on-site inspections. The project area is large, and the efficiency of grasping the overall situation of the site is too low.

The A4 student dormitories are prefabricated buildings and G5 teachers' apartments, with a total prefabricated building area of about 166,000 square meters, and the assembly rate has exceeded 60%, up to 64.1%. In order to ensure the "national prefabricated A-class" and ensure the quality of the prefabricated type, the management of the PC component factory is very critical, which is one of the major difficulties in the construction progress of the project.

The project PC components are supplied by three factories at the same time, and the project needs to focus on the production, quality control and logistics and transportation of the components of the three factories. How to control the PC factory efficiently and cost-effectively is one of the key points of control of the project prefabricated building.

The project is multi-faceted, and the management manages the progress of the site through meeting reports and on-site inspections. PPT reports are carried out every week through weekly meetings to show the construction progress, quality and safety management status of the project, etc., which is not intuitive and the data cannot be analyzed in relation to each other.

In terms of the traditional engineering project site, this case also has the following problems: the offline quality rectification cycle is long, the efficiency is low, and the process traceability is difficult; Construction highlight photos are not retained in time, follow-up project summary, data archiving, etc. lack highlight records and photos; On-site measurement requires multiple people to cooperate with the record, and returning to the office needs to reorganize the records and ledgers, which is inefficient. The temperature and humidity of the on-site standard maintenance room need to be controlled within the standard range, and special personnel need to be arranged to manage it, which is time-consuming and time-consuming; Offline safety rectification cycle is long, the efficiency is low, and the rectification process is difficult to trace; There is no reflective clothing and no helmets on the site, and such safe and civilized construction problems are often difficult to manage and there are greater safety risks; The actual number of workers and types of work on the site cannot be counted, and the location cannot be obtained at the first time when the on-site personnel are in danger; On-site material acceptance through the traditional method, inefficient, unformatted data, and data can not be traced; In the operation process of large-scale equipment, risk control is the most critical; On-site dust and noise monitoring have a great impact on green construction and require strict management.

3. COPING STRATEGIES - CPS INTELLIGENT CONSTRUCTION SYSTEM

The CPS intelligent construction system uses the BIM 3D model as the carrier to access intelligent hardware monitoring data and project management software data [2] [8] Based on the "three-in-one" of software + hardware + BIM, it realizes the online, visualization and intelligence of the production and construction site management of the prefabricated component factory, and realizes the symmetrical management of digital twins [14] Based on the BIM model, the hardware monitoring data and management software data of the actual project are accessed in real time, and the virtual space is highly consistent with the actual site through the data-driven model, so as to achieve the goal of managing the actual project through the CPS system [12]

By realizing the organic combination of software, hardware and BIM, the CPS intelligent construction system includes the following characteristics: virtual and real access, software and hardware combination, and symmetrical management.

(1) The virtual reality is opened, and the actual factory production and on-site construction data are synchronized with the CPS system of the virtual space in real time, that is, the CPS system reflects the scene that is highly consistent with the factory and the site [4];

(2) Combination of software and hardware, CPS system will be on-site software management data and hardware monitoring data, real-time integration, through the common application of software and hardware, the factory and site supervision;

(3) Symmetrical management, through the management of virtual space that is highly consistent with

the site, combined with the application of actual management software and hardware equipment in the factory and the site, to achieve symmetrical management [1]

On this basis, the project CPS intelligent construction system integrates schedule management, quality management, safety management, green construction, smart party building, cost management, supply chain management, technology and technology, and comprehensive management. Fully apply the new generation of information technology such as 5G, Internet of Things, big data, blockchain, GIS+BIM, etc., focusing on the whole life cycle of the project, as well as the control of the five key elements of "man, machine, material, law and environment", and basically achieve the three goals of construction site visualization, risk pre-control automation, and multi-party collaborative platform [6]

4. SOLVE THE SOLUTION

4.1 Digital Twin

Through the application of project management software, combined with intelligent hardware monitoring, and the integration of software and hardware data through BIM models, a "digital twin" project is automatically built with a high degree of consistency with the site. Through the command center screen, the on-site progress, quality, safety, personnel, equipment, etc. are visually managed, and the overall management of the project is realized through the command center.

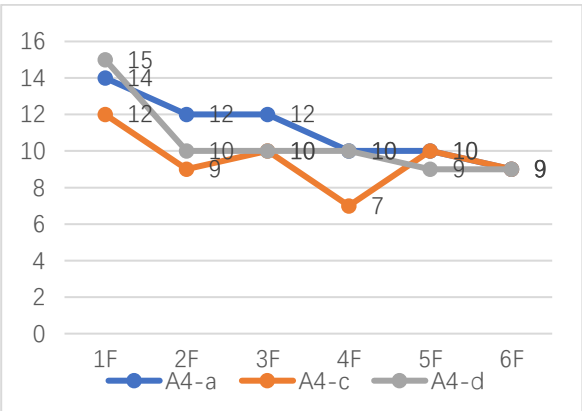

Figure 2: A4-a, c, d prefabricated building construction(photo credit:original)

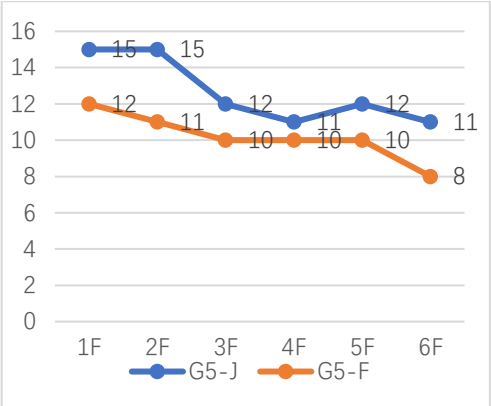

Figure 3: G5-F, J prefabricated building construction schedule(photo credit:original)

4.2 Integrated Management based on CPS

After all the data is imported into the virtual data platform, the factory and the site can realize the mutual sharing of factory and field data through the use of intelligent construction systems. Improve the data collaboration efficiency between the site and the factory, and provide online scheduling, task online execution and feedback functions, automatically synchronize the progress to the 3D model, the on-site progress is synchronized with the model in real time, and realize the real-time 3D visualization of the progress, the automatic warning of the progress lag, Progress data is traceable.

4.3 The whole Process of Software Covers

In view of the practical problems of various sub-items in the implementation process, the article proposes an online platform to realize the synchronous management of the implementation of the project site. In the project, based on the WeChat application module, the construction process timely recorded the application highlights, as well as authorized sharing, as of now, the project has recorded more than 9 00 quality highlight photos and passed WeChat terminal actual measurement module, online recording of on-site measurement data, positioning floor plan, on-site measurement efficiency increased by about 2 times, saving data collation working time, the system to achieve automatic statistical analysis and measurement report generation, as shown in the following figure

Based on the mobile terminal safety rectification module, online problem initiation, rectification and review. Among them, green indicates that the rectification of this part is complete, yellow indicates that rectification is in progress, and red indicates that it has not been rectified. Through this method, the rectification information is immediately delivered to the responsible person's WeChat, which greatly improves efficiency, traces the process rectification data, and instantly reminds the rectification status of the problem. The project rectification and closure rate reached98%, and the

comprehensive assessment of the monthly rectification situation and the issuance of the bill was included in the monthly assessment, and the subcontracting was quantitatively evaluated.

4.4 Hardware Real-time Monitoring

In terms of field equipment, the project combines hardware detection to achieve refined management of field equipment through the collection of status data:

Sensors are installed in the standard nursery room to monitor the temperature and humidity online in real time, and the system automatically adjusts and notifies the management personnel in the event of an abnormality. As an example in the figure below, a total of 5 times of automatic adjustment of temperature anomalies and 8 times of automatic adjustment of humidity anomalies in this period ensure the normal maintenance of the test block.

In terms of personnel that are difficult to manage, the project installed AI algorithms on the cameras at the gate and the commanding heights to identify violations of the on-site personnel in real time. When violations such as not wearing reflective clothing or wearing a hard hat are found, voice broadcast reminders and photo recordings are automatically carried out on the spot. At present, a total of3,09 times have been reported to the police, and 1,29 people have been punished. At the same time, the personnel wear positioning labels, install the positioning base station on the spot, synchronize the personnel information to the command center platform, so that the personnel position can be visualized in real time, and when it is necessary to count the actual types of work and the number of people on the work surface, when a dangerous situation occurs, the location of the personnel can also be quickly identified 。

Figure 4: 2021 South China University of Technology Project Personnel Positioning and Attendance Statistical Analysis

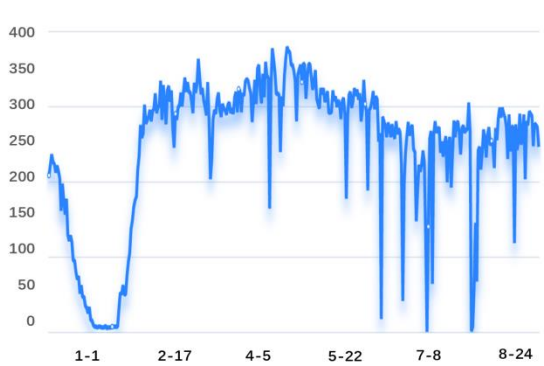

Figure 4: Statistical analysis of the attendance rate of South China University of Technology project personnel in 2021(photo credit:original)

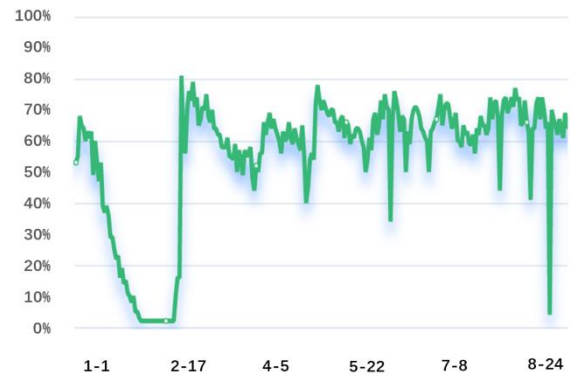

Figure 5: Statistical analysis on the positioning attendance rate of project personnel of South China University of technology in 2021(photo credit:original)

The project also adopts an intelligent material acceptance system to record the online recording of the material acceptance of the project's entry and exit sites, and now the seamless connection between the on-site material receiving and acceptance data, improve the work efficiency and management quality, and realize the project and the supplier The two sides exchanged information. By installing black boxes on the tower crane and issuing electronic driver's licenses to drivers, the operating status of the equipment is detected in real time. When the risk is detected, the automatic alarm reminder, 2# tower crane limit warning 2 times, 3# tower crane torque warning 8 times. Bind the dangerous behavior of drivers and equipment, and carry out targeted education and punishment.

Meteorological monitoring equipment is installed on the field to automatically analyze and push early warning information on the monitoring data. When the dust and noise exceed the set standard, the CPS system automatically alarms and pushes WeChat messages to the corresponding management personnel.

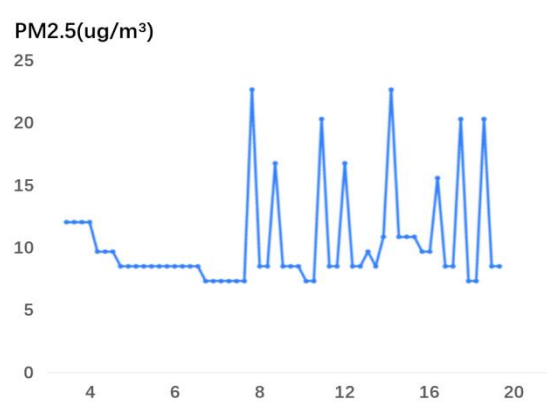

Figure 6: PM2.5 daily monitoring data(photo credit:original)

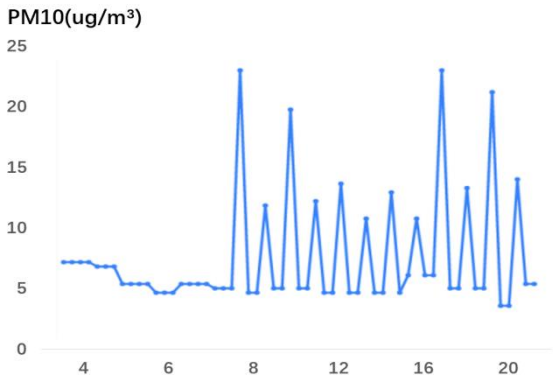

Figure 7: PM10 daily monitoring data(photo credit:original)

5. BENEFIT ANALYSIS

Based on the full application of the CPS system, the progress of the prefabricated project is maintained at an average of 6.2 days/layer, which ensures the construction progress of the project. The rectification cycle of quality and safety issues was saved by nearly 1.5 days/ article, the rectification closure rate was increased to98%, and the comprehensive effect of the project was about 5.6 million yuan.

5.1 Brand Benefits

(1) Passed the Guangdong Provincial Construction Engineering Quality Structure Award and the Guangzhou Construction Engineering Structure Quality Award and preliminary evaluation;

(2) Won 1 guangdong provincial engineering construction excellent quality management team first-class achievements, the group won the title of excellent publisher;

(3) Obtained the demonstration site of safe production and civilized construction of housing municipal projects in Guangdong Province and Guangzhou City;

(4) Complete the establishment of green construction demonstration projects in the construction industry in Guangdong Province;

(5) Passed the acceptance of the construction process of the green construction evaluation project of the China Securities Enterprise Association;

(6) Approved through the Guangdong Construction Industry New Technology Application Demonstration Project;

(7) Accepted 6 utility model patents, 1 invention patent, and published 5 papers;

(8) Won the first prize of the second national construction industry BIM competition.

5.2 Social Benefits

(1) Received a total of 9 government inspections by the provincial government and other governments;

(2) Received a total of 6 exchanges between quality and safety supervision departments;

(3) Receive a total of 19 inspections from the owner unit;

(4) Received a total of 65 times from other units in the construction industry;

(5) Organize prefabricated exchange meetings and observation meetings in the construction industry for a total of 5 times;

6. CONCLUSION

The second phase of the Guangzhou International Campus of South China University of Technology makes full use of new intelligent construction technologies to create a CPS intelligent construction platform, using the BIM three-dimensional model as the carrier to access intelligent hardware monitoring data and project management software data. Based on the "three-in-one" of software + hardware + BIM, it realizes the online, visualization and intelligence of the production and construction site management of the prefabricated component factory, and realizes the digital twin symmetrical management.

Through the daily application of WeChat terminal, the progress, quality, safety, materials, personnel, equipment, environment, etc. of the project are comprehensively controlled in an all-round way, and the construction site is truly realized. The on-site management personnel completed the management of the construction frontline through WeChat.

Through the installation of hardware monitoring equipment on the spot, it realizes automatic monitoring of tower cranes, construction elevators, personnel positioning, video monitoring, environmental monitoring, labor real-name system, large-volume concrete, etc., as well as intelligent analysis of monitoring data, realizes early warning of abnormal situations, and automatic intelligent alarms.

The comprehensive application of the INTELLIGENT CONSTRUCTION SYSTEM BASED ON CPS not only assists the actual production management of the project, but also actively explores and applies it in the process of digital development, information promotion and assembly transformation and upgrading of the overall industry.

REFERENCES

[1] Aceto G, Persico V, Pescapé A. Industry 4.0 and Health: Internet of Things, Big Data, and Cloud

Computing for Healthcare 4.0[J]. Journal of Industrial Information Integration, 2020, 18(C).

[2] Ander G, Xabier O, Unai A, et al. Methodology and Tools to Integrate Industry 4.0 CPS into Process Design and Management: ISA-88 Use Case[J]. Information, 2022, 13(5).

[3] Chen Changsheng, Xu Wei, Lan Zongmin, et al. Research on the Internal and External Environment of China's Development during the 14th Five-Year Plan Period[J]. Management World, 2020, 36(10): 1-14+40+15.

[4] Choi S, Kang G, Jun C, et al. Cyber-physical systems: a case study of development for manufacturing industry[J]. Int. J. of Computer Applications in Technology, 2017, 55(4).

[5] Chu Xiaobang. Research on the impact of rising labor costs in construction industry on the transformation and upgrading of construction industry[D]. Anhui Jianzhu University, 2020.

[6] Culot G, Nassimbeni G, Orzes G, et al. Behind the definition of Industry 4.0: Analysis and open questions[J]. International Journal of Production Economics, 2020, 226(prepublish).

[7] Flavio T, Melissa D, Massimo P, et al. Cyber-physical systems (CPS) in supply chain management: from foundations to practical implementation[J]. Procedia CIRP, 2021, 99.

[8] He Qinghua, Qian Lili, Duan Yunfeng, et al. Research on the application status and obstacles of BIM at home and abroad [J]. Journal of Engineering Management, 2012, 26(01): 12-16.

[9] MA Jun, SHEN Kunrong. Research on the Influence Mechanism and Countermeasures of Chinese Population Aging on Economic Development[J]. Journal of Zhejiang Gongshang University, 2021(04): 72-83.

[10] Peng Fei, Yuan Wei, Wu Yilin China Development Report [M]. 1 Chinese Min University Press: 242

[11] Shen Shuxian. Analysis on the development status of migrant workers in construction industry[J]. Chinese and Foreign Entrepreneurs, 2016(30): 225-226.

[12] Tao Fei, Liu Weiran, Liu Jianhua, et al. Digital Twins and Their Application Exploration[J]. Computer Integrated Manufacturing Systems, 2018, 24(01): 1-18.

[13] Tao Fei, Liu Weiran, Zhang Meng, et al. Five-dimensional model of digital twin and its application in ten fields[J]. Computer Integrated Manufacturing Systems, 2019, 25(01): 1-18.

[14] ZHANG Hui, SHI Lin. Digital Economy: A New Driving Force in the New Era[J]. Journal of Beijing Jiaotong University (Social Science Edition), 2019, 18(02): 10-22