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# Using nD technology to develop an integrated construction management system for city rail transit construction

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ABSTRACT

With the increasing demand of rail transit construction, coupled with its complexity and appearance of new technologies, an integrated system is needed to provide the stakeholders a convenient way to exchange information effectively and efficiently. This paper, from the angle of information, proposes using multi-dimensional (nD) modeling technology to develop an integrated system for participants and decision-making support for project owners in construction period. In this research, nD system is realized by corresponding 3D models to visual working units which have a direct relationship with Work Breakdown Structures (WBS) and other construction code structures so that the system can integrate different information in the same 3D model. In view of large amount of information and dynamic characteristics of construction work, using nD system to integrate the latest information on all aspects can be a convenient way to get access to necessary information and help the owners in making decisions comprehensively.



## 1. Introduction

At present, a new era with high-speed rail transit development in China comes into being. According to the news from the Ministry of Housing and Urban–Rural Development of China, the total length of rail transit network will be up to about 2259.84 km in 2015, with the investment that will be up to 882 billion Yuan [1]. Fast development of rail transit construction can release the pressure of urban traffic and facilitate the national economy. However, there are many problems which stakeholders met in the process of the construction. How the owners access information and deal with it in the process of a project will be a great challenge. On the other hand, in most rail transit projects in China, the organization structures of the owners are usually streamlined for high efficiency. So, no extra professional staff can be assigned to deal with the complicated information, which leads to the owners' weak ability in information processing. With the further development of the project, the amount of the information will increase in multiplier effect. The project owners will find it increasingly difficult to deal with the project-implementing issues. This will affect the quality of the decision-making and the progress of the project. Therefore, information communication plays an important role in construction.

Obviously, undesirable outcomes can be probably avoided if the project stakeholders get more information of site activities quickly [2]. Most of the problems occurring during the construction process are due to lack of cooperation and communication among participants according to a research result conducted by a Turkish construction industry [3]. Bateman and Snell reported that only 20% of the information passed down in the hierarchy from the top management might reach the site workers [4]. Computer technologies can provide participants in construction a convenient communication environment which can help them access information more quickly and accurately. Numerous construction firms begin to invest heavily into information and communication technologies to improve the working efficiency [5–7].

In China, the Ministry of Construction encourages construction firms to use information technology in construction management to promote competitiveness and profitability. Through field research, many rail transit corporations in big Chinese cities such as Beijing, Shanghai, Shenzhen, utilize information technologies in construction management. According to the plan, 7 lines of rail transit which extend to 70 km long are expected to be completed before 2020 in Wuhan. Because rail transit project is a complex system which involves large amount of investment and numerous specialties, it is necessary for the project stakeholders to find a way to get more information so as to make correct decisions.

Although there are some products of management information system in the market such as Primavera Project Planner [8], which focused on the exchange of two-dimensional (2D) drawings and documents among the project stakeholders. Actually, in the process of construction, different specialties describe the information in different ways; sometimes, it is difficult to exchange the information among participants effectively and precisely. Therefore, not only an information

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system, but also an efficient collaborative environment which helps participants exchange data freely is required. Actually, three-dimensional (3D) models are usually used in design disciplines at present and visualization technology is widespread developed. Therefore, the exchange of 3D data is encouraged in the collaboration process. Multi-dimensional (nD) model is expected to play a significant role in the new collaboration practices. In fact, nD is based on the 3D model, with parameters such as schedule, cost, and quality added to it, it becomes a multi-dimensional model. This model can describe the whole process of the construction. It allows direct extraction of any technical information such as object specifications and attributes from the nD model. The function of using and exchanging information based on nD model among different stakeholders provides opportunities for enhanced collaboration and distributed project development. Hence, nD model is considered as a tool to improve the interoperability during the construction process.

An nD model contains 3D geometric information, which can visualize the progress of a project when added to time factor. It's not only a virtual media which makes it possible for the users to observe the simulation of the whole progress of construction dynamically, but also a way to control and optimize the progress at the same time. By using it, managers can get thorough information about the construction site and its progress. nD technology greatly enhances the effectiveness of decision-making and helps to achieve project multi-objective optimization.

This paper is organized as follows. Firstly it reviews the related research about nD models. Then it demonstrates the key technologies used in this study, with the structure of the integrated system based on nD models discussed and implementation experience and results in Wuhan rail transit construction introduced. Finally the paper ends with conclusions and further research directions.

## 2. Related research studies

The research of 4D is the beginning of nD model. nD model evolves from 4D concept and 4D is seen as a natural progression to 3D CAD models, as it adds a further dimension [9]. Since the early 1990s, there has been a growing interest in 4D system for construction [10], because it provides the ability to present construction plans graphically [11]. 4D model technologies are always used to assist in planning schedule in construction [12], [13] and simulating the working process [11]. 4D makes it possible for all parties to communicate by using the same model and it removes the discrepancies among them [10]. Therefore, it assists collaboration in construction [10] [14].

However, researchers want to add more information to 3D models, such as cost, safety and quality. Then, nD concept is formed which aims to integrate an nth number of design dimensions into a holistic model and it will enable users to portray the project visually during its complete lifecycle [15]. nD model is defined as an extension of the building information model by incorporating all the design information required at each stage of the lifecycle of a building facility [16]. Researchers believe that nD modeling is a realistic potential to improve the construction industry [16], and many of them have begun to discuss how to use nD technology in construction industry.

The 3D to nD researchers at the University of Salford have started to explore some soft factors in design dimensions, such as people, cultural and process factors that fundamentally affect the uptake of the new technology [15]. Tse et al. discuss the data interface and adoption barriers of building information models in nD modeling [17]. The VIRCON tool is developed to assist construction planners to make accurate and informed planning decisions based on the allocation of the execution space [18], [19], [20]. 4D technology is relatively mature in construction management by now, and even quantitative analysis methods are introduced to evaluate 4D models [21].

In China, a 4D system has been developed to integrate Work Breakdown Structures (WBS) and 3D models. It incorporates the 4D concept into fields of construction resource management and dynamic site planning, by furnishing construction progress information and performing a number of management functions over space and time [22]. However, using nD technology in railway construction has not been found until now.

It has been proved that nD technology can be used in construction management and improve the management efficiency by previous approaches. Especially, in large-scale projects covering a wide range of professional participants, it is necessary to communicate with each other through 3D construction entities.

This paper proposes an approach to build an integrated collaborative construction management system based on nD model. Various information such as time, cost, safety and quality are integrated on the basis of nD model in this approach. Different stakeholders can extract and update information via the nD model by accessing the system through internet. This approach has been used to set up an integrated construction management system, which has been applied in Wuhan rail transit construction. The framework of the system is shown in Fig. 1.

## 3. Key technologies

According to the framework of nD system, there are two technical problems while building the nD rail transit construction management system. First of all, nD model should be built to transfer information during the whole project lifecycle. Building information modeling (BIM) technology can solve the problem by building 3D information model which can be understood by all the stakeholders throughout all the stages of construction projects. In addition, visualization technology can make the system clearer and more vivid.

Secondly, because the system is based on web, different access rights to the system matched with different roles in construction should be considered. This can be solved by the application of web service technology.

### 3.1. BIM

BIM which was introduced nearly ten years ago aims to provide an environment that any related information of 3D entity models could be retrieved by end-users during the whole lifecycle of a project [17]. Management information such as progress, cost, safety and quality will be integrated via 3D model so as to provide useful information for project managers. Actually, BIM is an additional model for a lot of engineering information database, storing all the architectural design with geometric information and the corresponding technical information of all the works. Take schedule management for example, since BIM-based nD model includes 3D geometric information and the factor of time will be added to the construction progress visualization, it allows users to see the changes of buildings and helps them to be able to control and optimize the construction process.

As BIM already has rich information about the basic components, such as geometric data and engineering technical data. After different information is integrated, an information integration system is formed. Moreover, the system can be used throughout the whole lifecycle of the construction, from the architectural design, structural design to operation management, and it also realizes the uniform management. Uniform management means that resources are used and managed in a uniform way, eliminating the heterogeneity of different devices and geographically distributed resources.

BIM is expected to bring information technology into the construction industry and change the way of information-sharing.

### 3.2. Visualization technology

Visualization technology enables project managers to monitor the progress of the project and have a more intuitive understanding of the

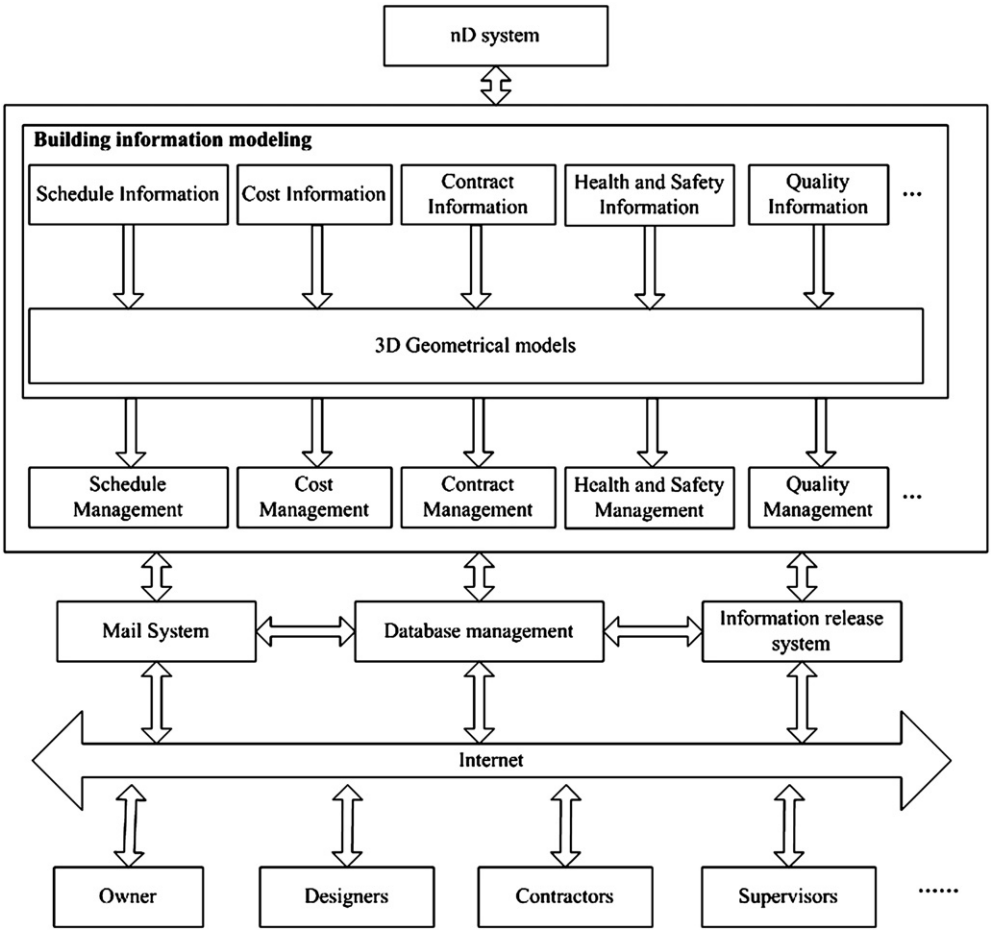



**Fig. 1.** Framework of nD system.

project in all aspects. It can integrate heterogeneous servers, storages and networks, and make full use of all kinds of resources. BIM is perceived as an efficient tool for visualizing construction process [23]. It is not difficult to realize visualization by using BIM.

Visualization Technology has been widely adopted in construction to facilitate construction planning [24], constructability reasoning [25] and site layout planning [26]. Therefore, it can be used to implement resources uniform management and provide service on demand. On demand means that resources should be used to fit for actual applications or priority of business.

Expression patterns of traditional information remain at the two-dimensional (2D) level. However, people's perception of the building is three-dimensional. Performance of 2D graphics is limited, especially when dealing with the shape and size of the component as well as spatial relationships among the components. BIM-based visualization can express information more intuitively. It can realize real-time construction visualization. Besides, engineers can develop other management modules such as schedule, cost and quality management based on this.

### 3.3. Web services

Web services allow different applications from different sources to communicate with each other without time-consuming custom coding, and because information is exchanged in XML format documents, web services are not tied to any specific operating system or programming language. That makes web services a desirable approach to connect remote software applications with information sources, utilizing well established internet protocols and commonly used machine readable representations [27].

Different systems can use XML encoding format of SOAP messages to interact with the WEB Service which is independent to the platform. Therefore, interactive format of the message between the owner's server and the World Wide Web server should be determined while developing integrated system and web services should be developed in accordance with this format by the owner. Thus, the owner, supervisors, contractors, and other stakeholders can exchange information fluently.

## 4. Methods of building nD model

The basis of nD technology is to build nD model. In China, the delivery standard of design drawings is still two-dimensional. Therefore, the owners cannot get 3D models from designing institutes directly. On the other hand, owners need to control construction schedule, cost, safety and quality integrally during construction process. Using 3D model of construction components as information control unit can help owners understand the whole situation of the construction more accurately. According to the characteristics and scope of application, 3D model can be divided into three types which are solid model, wireframe model and surface model [28]. Solid model is always used in architecture designing; wireframe model is used in structural analysis while surface model is used in construction management and operation management [28]. From the view of the owners, they always put focus on the constructive and operational phases of the construction. Moreover, the geometric information of surface model is fairly complete. Therefore, surface model is used in this study.

Currently, methods of surface modeling include:

(1) Transfer solid model into VRML document format, and display it through VRML controls. Advantage of this approach is that VRML is a universal graphics exchange standard which can be displayed directly by internet browsers. However, relevant plug-in needs to be installed to make sure that VRML can be displayed in the browsers. Limited functionality of its plug-in does not support the re-development. In addition, because VRML does not support the Boolean operations, it cannot be appropriately manipulated, such as digging holes in components [29].
(2) Transfer solid model into surface model through developing a convertor, and display it through a graph engine such as OpenGL, Direct3D. However, the workload of this approach is too heavy and it can't be used by other application programs due to the lack of unified storage format of converted data [28].

Considering the requirement of end-users, it is necessary to provide a dynamic platform which can be accessed through the internet. They are required to be allowed to enter the virtual construction site and interact with the equipment components and architectural elements like doors and windows. Therefore, VRML modeling approach was used in this project to uniform model data and store them in the database. It can realize visual management both in construction and operation periods.

## 5. System schematic design

### 5.1. System structure

Ahmad and Ahmed noted the construction industry is highly fragmented [30]. The majority of construction projects involve several participants such as owners, contractors, subcontractors and supervisors who are always in different places. Therefore, it is necessary to build a system which is an internet-based integrated management platform based on Browser/Server (B/S) mode. The system has three-tier (boundary layer, logical layer and data storage layer) distributed and collaborative structure.

Interface layer corresponds to the client and logical layer corresponds to the World Wide Web server in which the main program of the system is deployed. Data storage layer corresponds to the database server. Generally speaking, one set of equipment is enough to work as both World Wide Web server and central server. However, the owners have other application programs such as personnel management system and financial management system which are installed in other equipment. Therefore, World Wide Web server and central server are separated and data of the main programs is exchanged through web service.

### 5.2. Function description

As a platform for information exchange, nD model system can break the constraints of time and space and provide smooth information sharing among all the stakeholders involved. Nevertheless, there are a large amount of construction participants, such as government departments, property owners, the construction companies and supervision companies, and each company or department uses certain professional software satisfying its needs. This requires nD system to be capable of integrating varieties of heterogeneous data so as to make smooth exchange of information possible.

According to the framework of nD system shown in Fig. 1, the key point is to build the nD model consisting of 3D model coupled with a series of management information.

A method to build nD models by linking construction code structures with 3D models is introduced and shown in Fig. 2. nD models are built by linking 3D models with construction code structures such as WBS, Cost Breakdown Structures (CBS) and Risk Breakdown Structures (RBS). Take schedule management for example, engineers on site usually control the project progress by WBS plan. In WBS plan, each activity has time information and associated resources.

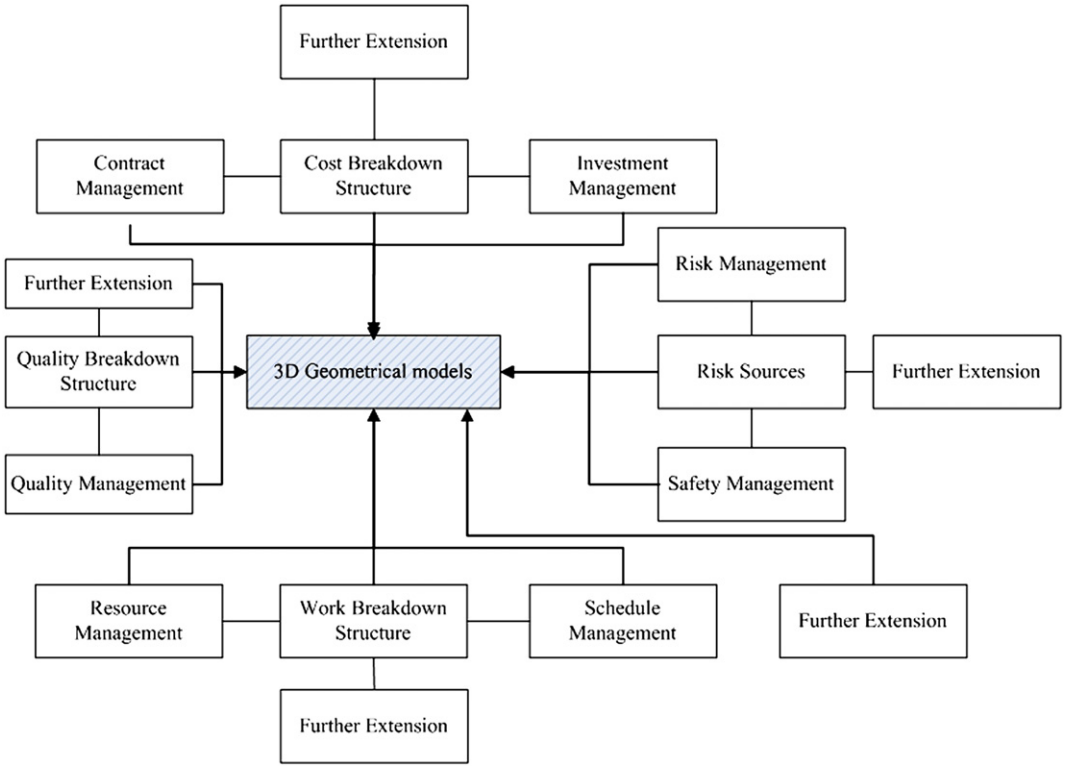



**Fig. 2.** The structure of integrated construction management system based on nD technology.

Therefore, connecting 3D models with WBS can visualize the project progress and show the status of schedule and resource simultaneously. The system will display the actual progress of the project immediately by updating the latest WBS information. Similarly, the relationship between 3D models and CBS could be built in the same way. CBS has been used to follow up the cost information by most project managers. Each CBS item has its corresponding purchase order. Price and contractor information can be linked to CBS through a purchase order. After the linkage between CBS and 3D models has been established, cost information can be integrated on the basis of 3D models. Quality and safety information will be added to the models in the similar way.

The advantage of this method is that the nD model is extendable, i.e. any further information can be integrated by combining related code structure and 3D models without affecting the existing data.

Besides the construction management functions based on nD technology, general functions of the system are as follows:

(1) Standard data interface should be provided to realize the data exchange among different systems in different stages of the whole life-cycle of a construction project. In order to integrate modeling software seamlessly, the system needs to have a standard data interface to import the existing 3D models which are designed by common tools such as AutoCAD, and then, dimension information is given in IFC tools.
(2) Visualization platform should be included in the system. The visualization platform enables all participants to observe 3D model intuitively and helps them exchange information with each other based on the unified model, which is conductive to improve the efficiency of the communication. What's more, B/S system structure makes it possible for users to gain access to the visualization platform at any time and in any place to exchange information with other participants. Effective visual graphics platform enhances dynamic simulation results.
(3) The system should be functioned as a real-time interactive online tool, which allows end-users to access the client at anytime in anywhere. Newly updated information can be delivered quickly among the systems. Meanwhile, users can organize online meetings at any time by means of the system, rather than spend too much time to convene the site meetings.
(4) Information security of the system's network should be considered. Especially, the system should be built based on B/S mode, which requires a high-quality network information security. Meanwhile, the system should set strict access rules to ensure the information transferred between the specified roles quickly and safely. System administrator can add and configure new users and give different users different operating privileges according to the needs.
(5) System should have varieties of expression forms of data, such as diagrams and report forms. Statistics of accomplished quantities and performed investment analysis are provided to support making management decisions.

## 6. Test and implementation

### 6.1. Background of Wuhan rail transit construction

The Wuhan rail transit network which is about 220 km long has 7 planned lines and 182 stations with a total investment of 100 billion Yuan. Line 1 has been completed and operated successfully up to now. Line 2 and line 4 are planned to be completed in 2012 and line 3, line 5, line 6 and line 7 will also be built in the near future.

At present, there is a computer center in Wuhan Railway Group Co., Ltd. which is connected to the internet by specific line and guarantees the network safety by firewall. Switching equipments are used to build network in its office building. And remote office locations are connected to the internet by optical fibers or ADSL. Project departments located in both Wuchang district and Hankou district gain access to the intranet by VPN.

As the owner of the rail transit project, group leaders get the information about the construction mostly from regular meetings and paper-based reports. But with the progress of the project, it becomes more and more necessary for the leaders to get information about construction in process comprehensively, timely, intuitively and dynamically. For them, the information should be displayed more vividly to be understood and data analysis should be provided while they make decisions. Therefore, it is urgent to establish an integrated system based on 3D model (i.e. nD system) so as to collect data and provide analyzed information for the leaders and managers of the company.

### 6.2. System development process

According to the framework of nD system described in Fig. 1, nD models should be built in the first step. After related construction code structures, such as WBS and CBS are defined, the key procedure is to set up relationships between those structures and 3D models of real construction, which is described in Fig. 2. Thus, WBS, CBS and RBS are integrated with 3D models in the system. Other information can be integrated in a similar way. As a result, nD model can be established. The process of integration is shown in Fig. 3.

#### 6.2.1. 3D building information model

The core of nD system is the establishment of a 3D building information model of the construction. In order to associate 3D information model with the actual engineering data, the minimum control unit of 3D model needs to be defined to make sure that 3D model can interact with actual construction field data. In this project, it was realized by 'visual working units'. Rail transit construction is composed of many 'visual working units'. The original concept of 'visual working units', which is derived from project visual progress, refers to those project structure components that can be used to show the project progress, namely entity components of rail transit construction which have a certain physical shape and can be measured in physical units. For example, the standard range of each tunnel construction contains such 'visual working units' as 'excavation support', 'structure waterproofing' and 'support secondary lining'. In practice, designers of a rail transit construction consider these 'visual working units' as key component compositions and they always design those 'visual working units' in detail. In the design process of a construction, each 'visual working unit' is designed with the information of structure attributes, geometric attributes, corresponding billing items and related resources. In addition, because of the linear characteristics of rail transit construction, it is possible that 'visual working units' can be used to describe the progress of construction.

Therefore, 'visual working units' can be used as a minimum control unit for 3D models in rail transit construction and 3D models of 'visual working units' were built in this project.

*6.2.1.1. Model elements.* The establishment of 3D model elements for 'visual working units' is on the basis of design drawings. Model elements include information of two aspects, geometric and management information of building elements.

Geometric information is defined according to the design parameters and attributes of design drawings. After the geometric information is given to each 'visual working unit', management information such as schedule, quantities, resources and quality can be integrated by connecting related code structures to 3D models.

In this project, geometric information was defined in VRML software and stored in .wrl documents while management information is stored in Oracle database. Geometric information and management information were connected by an identification tree.

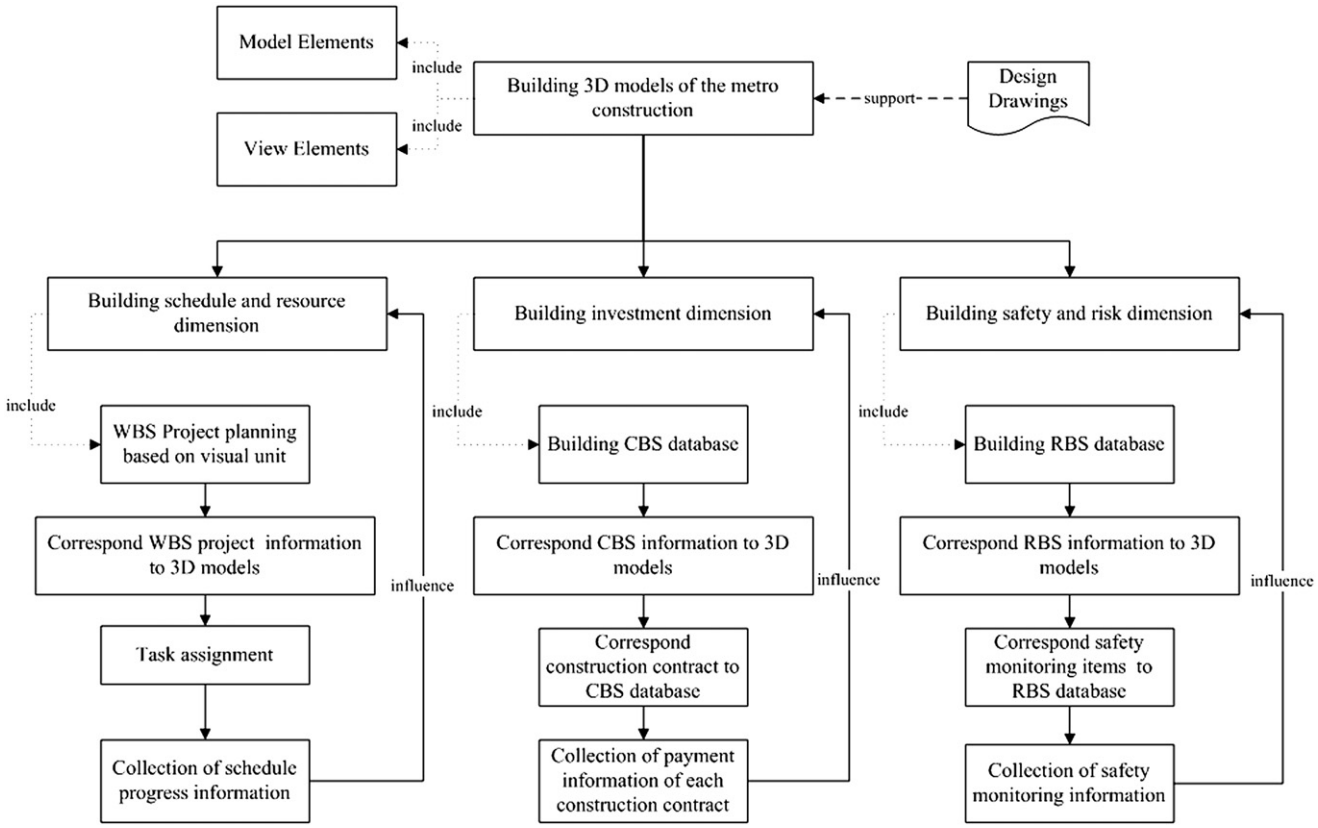



**Fig. 3.** Development process of nD models flow chart.

*6.2.1.2. View elements.* After completing the building model, view elements need to be assigned to it so that users can browse 3D model from different angles.

*6.2.2. Schedule and resource dimension of the 3D model*

In order to endow 3D model with schedule and resource information, decomposition of WBS based on 'visual working units' should be done firstly which means 'visual working units' of rail transit construction need to be shown in project WBS plan. In this project, in order to track the progress of the construction and reflect them in 3D model, three-tier planning system was used. Schedule management of the construction involves the owner, the supervision companies and construction companies. In the whole project system, construction companies control the most detailed construction procedures which are the bottom of the project. The owner controls the key milestone tasks. And managers in construction companies report the latest schedule information and resource (it refers to construction material in this project) information through the integrated system at the end of every month. Consequently, the schedule of construction can be adjusted by the system automatically and this can be reflected in 3D models.

System administrator relates 3D models of 'visual working unit' to the construction procedures, sections and the contractors or suppliers in WBS. Thus 3D models follow the progress of the construction. In this project, transparency of 3D model had proportional relationship with the progress of the construction, which means when the schedule is completed 100%, 3D models display in solid state while in semi-transparent state when 50% completed (in Fig. 4). In addition, the resource consuming information can be listed after selecting every 'visual working unit' 3D model.

*6.2.3. Investment dimension of the 3D model*

Project investment varies with the performance of different types of contracts. Meanwhile, the minimum information unit is CBS code structure. In order to reflect investment status of the construction in 3D model, the first step is to relate 'visual working unit' with CBS. With the

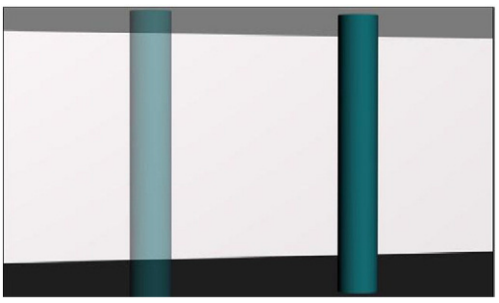


**Fig. 4.** 3D Model of a half completed pillar (left) and a fully completed pillar (right).

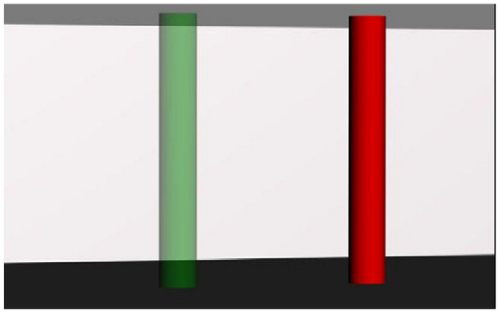
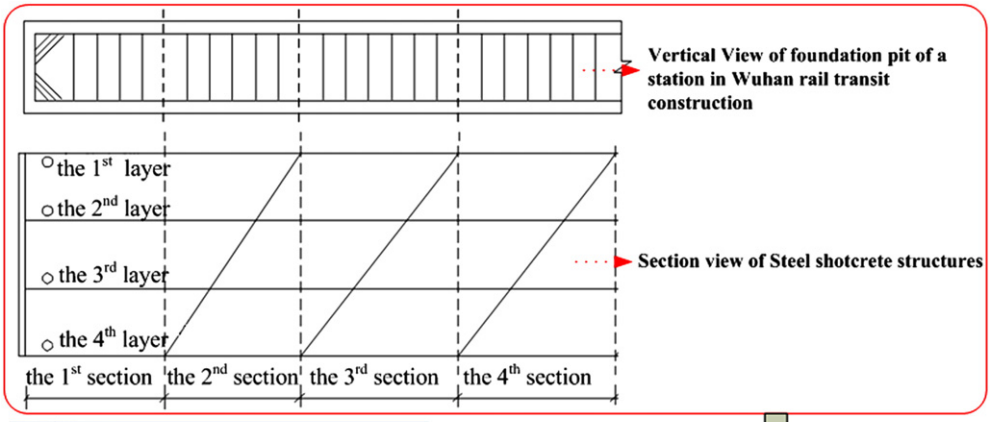
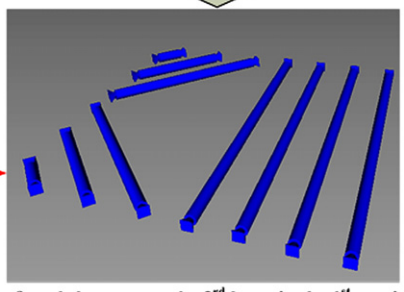


**Fig. 5.** 3D Model of a pillar in normal status (left) and exceeding estimate status (right).




| WBS | Task name |
|---|---|
| 1 | MingDu Station in Wuhan rail transit construction |
| 1.1 | Foundation pit construction |
| 1.1.1 | Excavation in the 1st Section |
| 1.1.1.1 | Excavation at the 1st layer |
| 1.1.1.2 | Erection of steel shotcrete at the 1st layer |
| 1.1.1.3 | Excavation at the 2nd layer |
| 1.1.1.4 | Erection of steel shotcrete at the 2nd layer |
| 1.1.1.5 | Excavation at the 3rd layer |
| 1.1.1.6 | Erection of steel shotcrete at the 3rd layer |
| 1.1.1.7 | Excavation at the 4th layer |
| 1.1.1.8 | Bedding work |
| 1.1.2 | Excavation in the 2nd Section |
| 1.1.2.1 | Excavation at the 1st layer |
| 1.1.2.2 | Erection of steel shotcrete at the 1st layer |
| 1.1.2.3 | dismantlement of steel shotcrete at the 3rd layer in 1st Section |
| 1.1.2.4 | Excavation at the 2nd layer |
| 1.1.2.5 | Erection of steel shotcrete at the 2nd layer |
| 1.1.2.6 | Excavation at the 3rd layer |
| 1.1.2.7 | Erection of steel shotcrete at the 3rd layer |
| 1.1.2.8 | Excavation at the 4th layer |
| 1.1.2.9 | Bedding work |



3D models of steel shotcrete at the 3rd layer in the 1st section

(1) Linkage between 3D models and WBS

(2) Linkage between 3D models and CBS

(3) Linkage between 3D models and RBS

| RBS | Risk Item | related monitoring items |
|---|---|---|
| 1.2 | supporting system | |
| 1.2.1 | flexural deflection | ZL01-10158; ZL01-10078; TY1-03 |
| 1.2.2 | torsional buckling | YCX2; YCX4 |
| 1.2.3 | slippage buckling | ZL01-10158; ZL01-10078; TY1-03 |
| 1.2.4 | breakage | 10158; ZL01-10078; TY1-03; YCX2; YCX4 |

| CBS | Cost Item | Unit |
|---|---|---|
| 1 | MingDu Station in Wuhan rail transit construction | |
| 1.1 | main structure | |
| 1.1.1 | fabrication of reinforcement | t |
| 1.1.2 | fabrication of structrual steel | t |
| 1.1.3 | Steel shotcrete | t |
| 1.1.4 | C30 Concrete | m3 |
| 1.1.5 | C30 Concrete, rock-socketed pile | m3 |
| 1.1.6 | Dewatering | |

**Fig. 6.** The implementation process of building the 6D model.

increase of payment resulting from the accomplished working unit every month, the investment of the construction grows gradually and 3D models change accordingly.

By comparison of actual investment and actual progress, different colors are used to express the investment status according to the general estimate of the construction. In this project, green color stands


**Fig. 7.** Access to the rail transit construction management integrated system.


**Fig. 8.** Detailed information about specific station construction.

for normal status of the investment and red color stands for exceeding general estimate status (in Fig. 5).

*6.2.4. Safety dimension of the 3D model*

Because of the complexity of rail transit construction, accidents occur frequently. Safety plays a significant role in construction management. An effective method is to monitor important structures in the process of construction and each stakeholder needs to know real-time monitoring situation. Actually, monitoring items can be related to the 'visual working unit' by RBS. Hence 3D models can reflect the current safety situation and history data can be provided with a click of certain button.

An example of building 6D model is shown in Fig. 6. It focuses on foundation pit of a metro station. The foundation pit is divided into 19 sections and 4 layers. 3D models of the steel shotcretes at the 3rd layer in the 1st section were built according to the actual 2D drawings. Related activities, such as '1.1.1.6 Erection of steel shotcretes at the 3rd layer' and '1.1.2.3 Dismantlement of steel shotcretes at the 3rd in the 1st section' were linked to 3D models by WBS so that 3D models possess the time and resource properties. In this way, schedule and resource information can be integrated with the models. Purchase order item '1.1.3' related to the steel shotcretes at the 3rd layer in the 1st section was linked to the models by CBS. Thus investment status can be tracked through the models. Similarly, relevant risk properties and corresponding monitoring items were integrated by linking RBS to 3D models. Any monitoring information can be traced through the models.

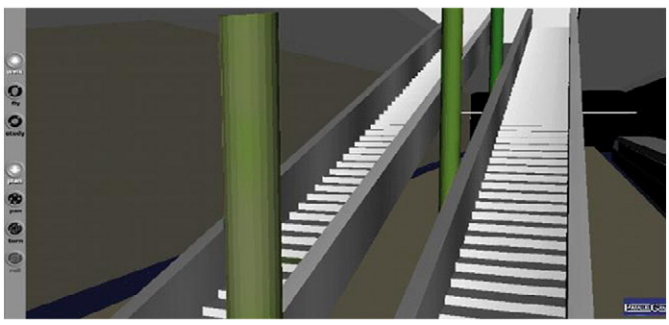


**Fig. 9.** Wandering in the specific station through internet browser.

*6.3. Results of system application*

The integrated system has been applied successfully in Wuhan rail transit construction and it involves more than 40 construction companies and 20 supervision companies. The system integrated schedule information, investment information and safety information through 3D models which were built on the basis of visual working unit, WBS, CBS and other information code structures. In general, it realized integrated and dynamic management in the construction period by unified 3D models. The system can be accessed online and the access page is shown in Fig. 7.

Users can get detailed information about the construction and it is shown with a click of the specific station name, which is shown in Fig. 8. In Fig. 8, nD model of the station, which supports users' wandering in the virtual station (in Fig. 9.), is shown on the left, with related information on the right. With 3D model combined with WBS plan, the process of construction can be visualized. And Fig. 10 gives an example of the progress status of a metro station. Related resource information can also be extracted and shown in Fig. 11. Users can access cost status via the same models as well (in Fig. 12) and color of the 3D models indicates the cost status of the construction. Moreover, related monitoring information is shown in Fig. 13.

From the current practice in application, the difficulty of the system implementation is on how to update 3D models when construction plan is changed in the progress of the construction.

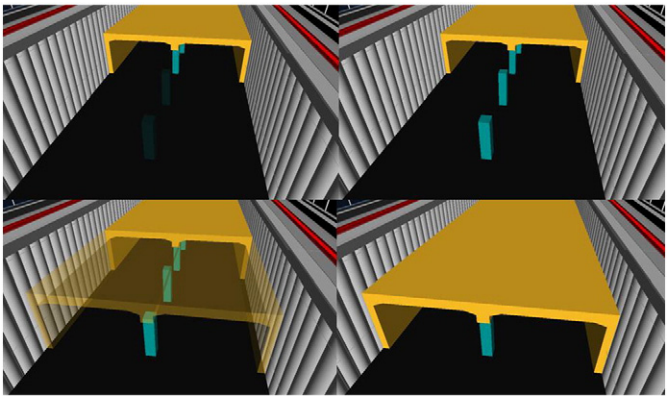


**Fig. 10.** Schedule visualization of a metro station: semi-transparent entities are in process and solid entities are finished.


**Fig. 11.** Related materials information about the station.

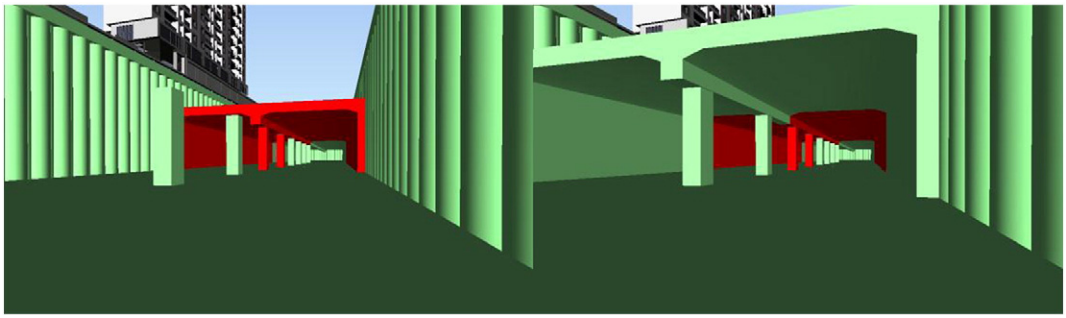


**Fig. 12.** Cost status of a metro station: green entities are on budget and red entities are cost overrun.

Currently, the computer center is responsible for repainting the changed 3D models and relating them to the WBS, CBS and RBS database. However, because of frequent modifications, information in system always lags behind the actual construction data.

Application of the system not only provides leaders of the owner company a visual management platform but also offers an information disclosure window for higher-level government agencies and the public. It is well received by users in these aspects.

## 7. Results and conclusion

It is the first time for nD technology to be used in the actual rail transit construction management in China. The method adopted in this project is a little different from those adopted by researchers in other institutes or universities. Previously, scholars have suggested building 3D models in design period and making geometric information corresponding to management information by means of some IFC tools. Their method is based on the idea of 'integrated design and construction'. Nevertheless, their method is not feasible in China in that design drawings are always in 2D format and information in design and construction phase is always separate. In this project, 3D models are built after design drawings are finalized and it costs a large amount of workload and money so that owners are reluctant to pay the additional cost. As a result, management information and geometric information are stored separately in the system and the owners selected several stations to implement nD technology. nD models for other stations can be built later if needed.

Through the project practice, further study is needed in the following areas:

(1) It is necessary to study the feasibility of implementation of integrated design and construction in China and promote the concept of 3D design to avoid repetitive work in 3D modeling


**Fig. 13.** Safety monitoring information about the station.

so as to set a solid foundation for using nD in construction management;

(2) In this project, the management information of nD model is based on WBS, CBS and RBS. However, because of the complex management workflow and numerous stakeholders, progress of information gathering is too long so that management information in nD models lags behind the actual progress. Further study is needed to explore a way to make construction data interact with 3D model more effectively so as to reflect the value of nD technology.

(3) Users of the system consider nD technology as a good method to control the construction. System described in this article is actually a 6D system which integrates time factor, investment factor and safety factor with 3D models and it can be extended to be an nD system.

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