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Operation Planning of Concrete Box Girder Bridge by 4D CAD Visualization Techniques

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Abstract**—**Visual simulation has emerged as a key planning tool in built environment because it enables architects, engineers and project managers to visualize construction process evolution before the project actual commences. This provides an efficient technology for reducing time and cost through planning and controlling resources, machines and materials. With the development of infrastructure projects and the massive civil constructions such as bridges, urban tunnels and highways as well as sensitivity of their construction operations, it is very necessary to apply proper planning methods. Implementation of visual techniques into management of construction projects can provide a fundamental foundation for projects with massive activities and duplicate items. So, the purpose of this paper is to develop visual simulation management techniques for infrastructure projects such as highways bridges by the use of Four-Dimensional Computer-Aided design Models. This project simulates operational assembly-line for Box-Girder Concrete Bridges which it would be able to optimize the sequence and interaction of project activities and on the other hand, it would minimize any unintended conflicts prior to project start. In this paper, after introducing the various planning methods by building information model and concrete bridges in highways, an executive case study is demonstrated and then a visual technique (4D CAD) will be applied for the case. In the final step, the user feedback for interacting by this system evaluated according to six criteria.

Keywords**—**4D application area, *Box*-Girder concrete bridges, CAD model, visual planning.

I. Introduction

In today's urban and road conditions of developing countries like Iran and by growing urban population and vehicles, "traffic" is one of the main problems in major metropolises like Tehran. In this regard, development of urban infrastructures such as bridges, highway and urban tunnels can play a valuable role in reducing traffic. However, construction technology and executive quality play a prominent role in accepting of these projects, but management (time, cost and quality) of these projects can be impressive in their success as well [1]. Basically, urban infrastructures are holding in areas where there are high traffic jams and main artery of communication is insufficient. Therefore, construction planning of these new projects should be so that, in addition to the speed and quality of execution that leads to making projects shorter, will not interrupt the car communication.

The Project Management (planning and control) of such infrastructures is playing a vital role and alongside with advanced techniques can reduce the time and cost significantly in addition to greater ease of communication in public spaces and urban roads. Due to the massive volume of resources that can be used in such projects, resource management in particular is very important, but common methods of project management such as Gantt chart scheduling and Critical Path Methods are not suitable for managing them [1], [2]. Advanced management techniques instead of traditional ones can play an important role in reducing the time, cost and increasing the quality of infrastructure. Due to the massive activities and duplicate items in these kind projects [3], a need for online planning and control methods in the site is urgently needed. During the construction operation, this system is able to increase resource efficiency, minimize material waste and costs and enhance the quality of projects as well.

With regard to the growth of technology and the use of Building Information Model (BIM)-based software, the lack of using visual planning for urban infrastructure is still very evident. Use of this system can increase planners' awareness before and during construction in different phases. Six factors and important criteria in project life cycle from the design phase to the construction and operation ones, will benefit from the use of these 4D CAD models. By implementing this system on a real case study, the potential benefits of its application in developing countries' infrastructure are evident. Project planners by observing the visual simulation of these mega-projects process can provide effective feedback on the construction planning elements [4].

II. Visual Planning and Controlling in Construction Management

Visualization has gained an increasing credibility among researchers in construction and has been considered as one of the four main Information Technology domains in construction [5]. Visualization methods have been emerged as a helpful and coordinator instrument to analyse and communicate simulation results. Visualization of construction process can be divided in both activity and operation levels in planning phase [6].

A. Activity Base Visualization (4D CAD) of Bridge Project

Visualization can sometime be obtained by linking a 3D CAD model which displays construction component and a construction schedule. This form of the visualization has been recognized popularity as a 4D CAD [7]. Since the early 1990s,

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there has been a growing interest in four-dimensional computer aided design (4D CAD) for construction project planning [8]. The use of this commercial 4D CAD technology allows the construction planner to produce more precise schedules. Nowadays, 4D CAD are used in a wide range area of construction industry, from micro level activities to macro level ones. There is also a lot of Architecture, Engineering and Construction (AEC) software which support 4D CAD by their application in virtual environment. 4D CAD can be useful in different phases of the project from planning to control for different users who are participated in the project. Upper management, high-level executives, construction professionals (project managers) and even workers could all benefit from this method substantially.

It is apparent that amount of scenarios and options are available for planning projects and 4D CAD only visualizes the determined scenarios for construction process according to designed scheduling models but does not visualize the undetermined ones [9]. Hence, it is very difficult for engineers to select the best option just by 4D visualization techniques. A large amount of researches have been carried out to visualize construction process in virtual environment by 4D CAD, but the planning and controlling of construction projects could not reach to the maximum potential due to the lack of visualization for resource interaction. Using visualization simulation operation techniques in parallel to 4D CAD modeling techniques is highly necessary for depiction both activities and operation [10].

B. Operation Base Visualization Planning of Bridge Project

Kamat [11] discussed difference between 4D CAD and dynamic 3D visualization of operation simulation: virtual 3D environment depicts all facilities, resources of project and their interactions on site in addition to the construction progress and production. The 4D CAD only demonstrates the evolution of construction products and is not able to illustrate all resources and their interactions in construction site. Other researchers tried to make integration between 4D CAD and visualization of simulated operation. For example, GPM is an approach for the modelling and simulation of construction processes based on geometric models [12]. In fact, the visualization of the simulated construction operation is so far limited to two environments; Virtual Reality and Augmented Reality environment.

All the AEC software depicts 3D models construction in virtual environment (Fig. 1). 3D visualization of construction operation can bring valuable, complete and clear insight to project managers and other participants in all project aspects and substantially help in understanding and interpreting project process before a project starts [13]. There are various ways to visualize the modelled construction operation in virtual environment. For example, construction Virtual Prototyping (CVP) [14] is a tool which allows project participants to visualize project assembly in 3D environment before starting real execution.

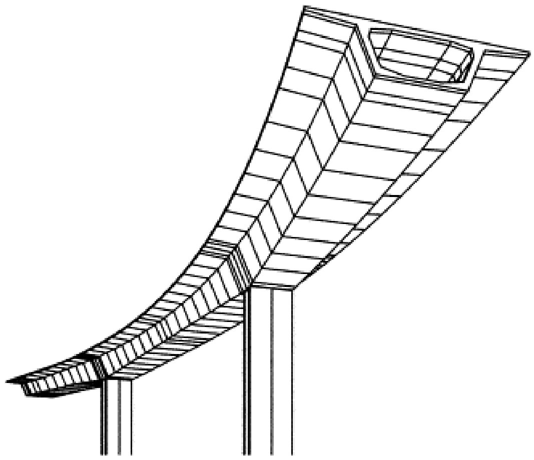

Fig. 1 3D CAD Model Sample of Concrete Box-Girder Bridge in Virtua Environment

C. Controlling Visualization of Bridge Project

For a successful construction operation, the monitoring and controlling of process should be carried out in addition to the planning. At this stage, the collection of data that represent construction status constantly is a crucial step for controlling [15]. The advanced and new method of monitoring systems seems to be inevitable. Typical practices for controlling operation are manual data collection which leads to weekly or monthly reports. Project managers usually study and interpret these reports, compare them by as-planned programmes and find project deviations in real execution. Current data collection such as graphs, bar charts and CPM which are time-consuming, labour-intensive, low quality, non-systematic and visually systems. Other advanced automating data collection techniques (laser scanner, RFID, bar coding, GPS, photogrammetry, Wi-Fi) are being used in different area according to their own potential and drawbacks [16]. For instance, RFID and barcoding are powerful techniques in material and labour tracking. Some researchers are trying to integrate these techniques to give better outputs. For instance, photogrammetry is combined with 3D laser scanner to improve the efficiency and validity of construction progress measurement [17].

III. CONCRETE BOX-GIRDER BRIDGES IN HIGHWAYS

Concrete Box-girder Bridges are the most commonly used types of bridges in the recent period. The bridges were used for short lengths with small span but today these bridges are used in wide roadways and lengthy multi-lane highways. The first group of Concrete Box-girder Bridges (Integrated in the place) which classically framed and Concreted in the place is done by two methods: Implemented in height and ground. Due to the volume and time formatting and concreting of this system, is not recommended to use them in the crowded places of urban areas. Another type of concrete bridges is Segmental Box-girder Bridges which over the past years has found many applications in urban infrastructure due to its ease and speed of construction [18].

Segmental Box-girder Bridges are made from fragments which can be formed cast in situ or might be precast. Basically, the components after being fitted together would connect in a Post Tensioning way that provides an integrated structure. Segmental Box-girder Bridges in prefabricated method are required a smaller amount of installation and the temporary pier and bridge segments are manufactured at the workshop and then transferred to construction site. Hence, the aforementioned system provides a specific functionality to overpass highways where limited access and overcrowded urban areas can be seen. Prefabricated method also might be very convenient for major projects that have a massive volume and repetitive operations. For Precast Segmental Box-girder Bridges, various methods such as span to span, precursory, launching and Balanced Cantilever Methods are introduced [18] (Fig. 2).

Fig. 2 Concrete Box-Girder Bridge in Real and Virtual Environment

A. Precast Segmental Box-girder Bridges with Balanced Cantilever Method

In this system, foundation type is a semi-deep foundation and can be done mechanical - manually. The concreting of pier segments in the system can be prefabricated or cast in-place. The components of a cantilever bridge are including: Pier segments, Zero segment, Deck segments [19].

In cantilever method, the piers are made first. Then by the formatting in place, the Zero Part will locate on the pier by In situ concreting. This part might be integrated with the pier or relied on a Neoprene as a juncture. In the next step, Deck Parts are placed on each side of Zero Part and are pulled by cables. These cables are known as cantilever cables. In the bridge deck procedure, after installing the Zero Part on the basis, other parts of the deck are installed equally on each side of Zero Part and will be braced through the designed tensioning cables. Finally, the main cables alongside the further actions will be performed and pursued as well. For installation of prefabricated components as span to span Method Bridge a Gantry Crane is used. Balanced Cantilever Method is appropriate for the areas where there is no possibility of casting and pilot implanting such as deep canyons, waterways or through crowded roads. Launching Truss, Lifting Frame and crane are used to locate the prefabricated segments on the piers. Launching Truss Structure is kind of space trusses and often composed of king beams. To enforcing the Launching Trusses sometimes a temporary column will be placed in the middle of it and from different parts of the truss some cables would scrub to the column; along with the progress of the segments installation, truss is moved forward and in any case, its basis' reliance are on the pervious and later segments which are made. Cranes are mounted on the bases and will lift segments on ground or on a transfer truck and move them along with the deck. All parts of a span are jammed on the scaffold until the applied epoxy adhesive be tightened to the junction of the parts and temporary and permanent tension steps to be taken. Scaffolds will be disarticulated by installation of a sufficient number of the permanent tension cables and the span is going to be mouthed on temporary seating which is located in permanent Neoprene. Then, the scaffold is moved to the next span and in the next step, Neoprene are replaced with permanent seating by raising the deck with temporary jack [20] (Fig. 3).

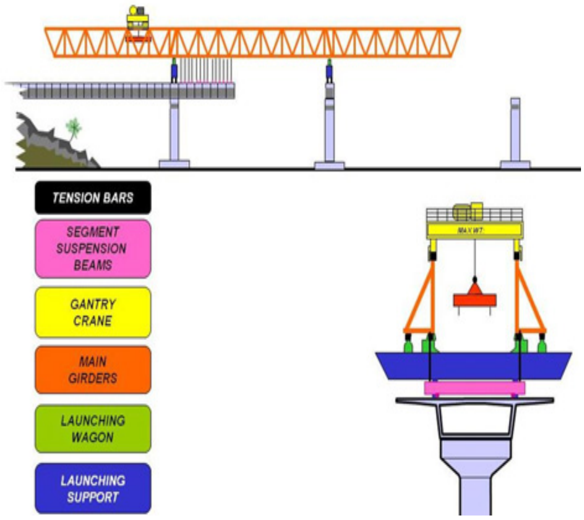

Fig. 3 Gantry Crane and Equipment in Precast Segmental Box-girder Bridge

IV. Methodology

To examine the system of planning construction projects by visualization techniques, this study after introducing the case project, provides three general steps to apply this technique in it. (Diagram 1). In fact, this methodology is divided into three steps for planning stage: 1) documents like 2D drawings and scheduling plans are extracted from various disciplines and 3D model of them are created by BIM software, 2) The 4D CAD model of project are created in simulation software (Naviswork Manage) by linking the Product breakdown Structure (PBS) of 3D models and Work Breakdown Structure (WBS) of Project Schedule and 3) model are Geo-located in its geographic coordinate.

In order to assess the usefulness of designed model, 30 experts and technical director review the simulation system and announce their opinion. The effect of this visual simulation on helping users to understand the real project situation are evaluated. Implementation of the six criteria: construction document production, time and cost estimation, analyzing construction operations, analyzing design options, virtual design review and also photorealistic rendering were collected by questionnaire. This questionnaire will help to planners and engineers in the design, planning and construction process of large infrastructure projects such as multi-layer bridges in developing countries such as Iran.

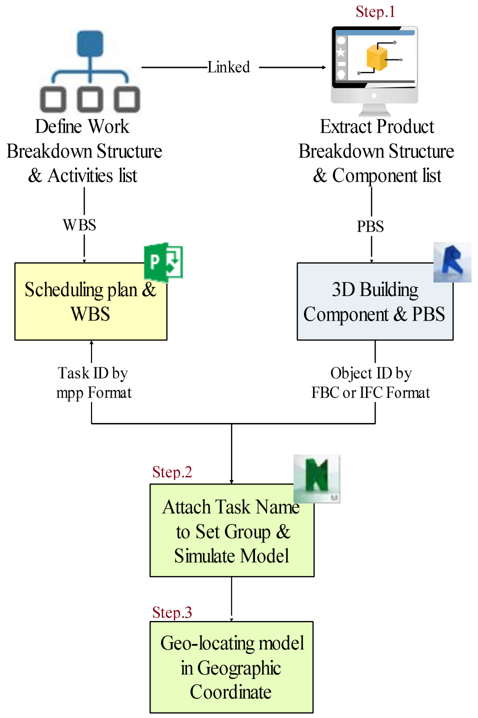

Fig. 4 Diagram of Planning Stage Steps by Visualization Techniques

V. Case Study Implementation

Sadr Multi-layer Highway Bridge is constructed in east north of Tehran in Iran (Fig. 6). The project is considered as the first single pier bridge in the country with the length of construction is Eleven Km by considering accessibly ramps. The deck of the bridge consists of a total 3400 prefabricated segments and includes 234 piers. Constructions of prefabricated segments of the main bridge deck were manufactured in a specialized factory. The client of this project was Deputy of Technical & Development Affairs - Tehran Municipality and preliminary studies for this project began in 2010. Executive operations of this infrastructure began in 2012 and just finished after 26-month with two months delay

One of the advantages of Sadr Multi-layer Highway Bridge is avoiding of massive form-working and in situ concreting that lead to reduction of difficulties during construction operation. The main advantage to using the Precast Concreted Segment Method is its construction speed compared with in situ concrete systems and it may lead to mitigate the effects of operations on the environment, especially in urban environments. another important factor in this system was to keeping open main Highway for passing a routine traffic during construction phase of the project because it built on intersection of busy area [20].

A. The Documents Extraction

Extracting project documents is the first step to design the system. Design phase of infrastructure projects begin after feasibility and preliminary study. In the design phase, the conceptual form and the general plan must be submitted and then structural and design calculations will be done. By emerging BIM tools, all the designed components could have properties and identification to the project and from the beginning are created as a 3D model in software. By combining these components, the overall structure of the project takes shape.

The system enables designers to work interactional and by changing or editing the properties of the 3D model in its box, its' form and shape will automatically change. For instance, if any column is removed from the project then the plan views and sections are automatically updated and there is no need to edit the items in each level. In the Building Information Model systems, 3D Models have been created with components properties and are object-based which have a special feature in the visual management and 4D CAD planning. The required 3D Models of structural components in Sadr Multi-layer Highway Bridge project are generated by Autodesk Revit software into three sets: machinery and equipment (Launching Truss and Gantry Crane), pier components and deck prefabricated segments with unique properties code for each component (Fig. 5).

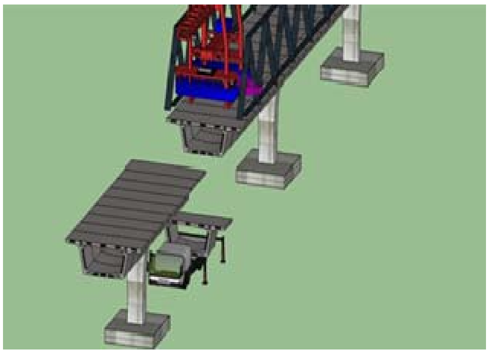

Fig. 5 3D Model Of Bridge Components by BIM Properties

These components were created according to the properties and technical feature of the project. For instance, components and prefabricated deck segments were modeled with a length of 3 meters and a width of 22.7 meters and the all detailed executive were considered in the model for a real illustration.

On the other hand, scheduling of executive items is needed for visual programming. Operational planning processes are specified due to a time period by project and control planning software. For each item, start and finish date, cost, resources and the other information are defined according to WBS which is needed for planning. The most commonly used scheduling software for construction projects is Microsoft Project (MSP) that used in this research. The Work Breakdown Structure was defined based on the construction procedure of Sadr project and scheduling for the project was carried out in MSP. The Work Breakdown Structure of the project was divided into four main phases: The foundation and pier construction, equipment installation, prefabricated segments production and final installation of segments in the project site.

B. 4D CAD Model Production

According to the two created documents and files in the previous sections, namely 3D Models and Project Scheduling, these structures should be integrated to visualize construction process and evolvement of each executive project item based on the time progress. First, the projects' 3D file in BIM system software (Autodesk Revit) and projects' scheduling from Microsoft Project will be imported to Autodesk Naviswork Simulation which is a CAD simulation software; in the following, each executive item should be defined according to its WBS and them should be linked to construction elements together to produce 4D CAD planning model. For instance, if Segmental Box-girder Bridge project have a scheduling period for 24 days, physical progress of the project and the items that have already been scheduled to perform can be shown as a 3D Model by moving and interacting on timeline. (Fig. 6)

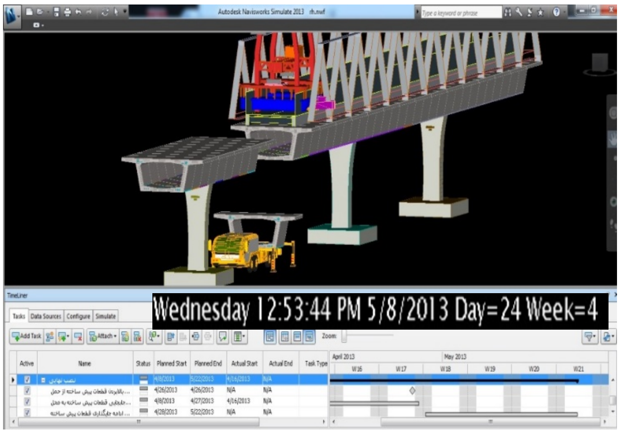

Fig. 6 Project Physical Progress of Bridge by 4D CAD Model

C. Geo-Locating 4D Model

The produced 4D CAD Model is geo-locate based on geographic three-dimensional coordinate (xyz) of the main project in Naviswork software so that virtual models are designed to be placed in its final location. (Fig. 7) In fact, the 4D programming of the project depicts evolvement of construction components on its real location in virtual environment based on its specified time period. The system enables project managers to have proper visual simulation of the project before operation phase and all possible methods for construction are predicted. Geo location project in its original place helps the planners to visualize realistic operation process by regarding site constraints and environmental situation. (Fig. 7)

By this technique project managers capable to examine many potential conflicts and problems as well as interaction of resources and equipment on project site so making some improvements in all aspects of the construction process is possible [21]. Meanwhile, this kind of visual planning techniques will provide a situation for visualize control methods which is the next stage of visualization construction management.

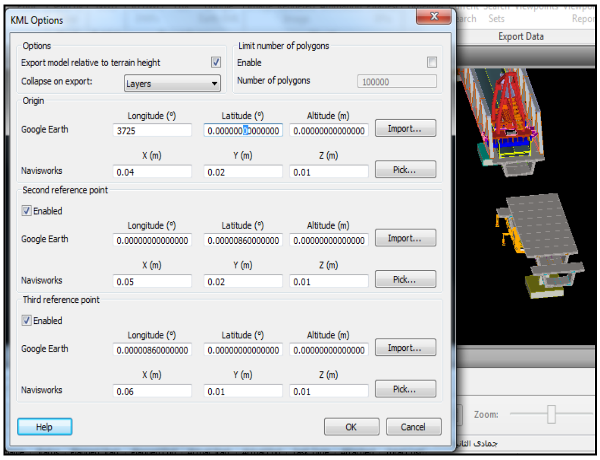

Fig. 7 Geo-locate 4D CAD Model In Geographic Coordinate

VI. User's Feedback

In this section, six fields of 4D CAD models application that have been defined and developed by Hartman and Fisher [4], were used for users in sadr modular-concrete-bridges project. Thirty users who were engineers and construction managers in bridges and urban infrastructure sector in Iran, responded to the six criteria by observing and surveying designed model. In fact, the effect rate of the simulation model in understanding and implementation of the proposed six factors and criteria measured and evaluated. The first criterion is Photorealistic Rendering, which enables the user to view three-dimensional and photorealistic of design with the human dimension. Virtual design review for the investigation of complex geometry of construction and also investigation of designing clashes between different disciplines, which is considered as the second criterion. Analysis and evaluation of design alternatives to choose the best option is remarked as the third factor. Time and cost activities estimation in BIM software can be conducted base on automatic quantity take off and is dependent on the design changes. Logical sequence activities, movement and storage of materials and resources and also review the logistics conditions of the site and contractors can be considered as the main feature of 4D Systems. Construction document production using these models and also creating databases and design standards can be considered as a last applicability of these systems. Function of designed visual model was examined in proposed six criteria on the range of four answer: without impact, low-impact, high and absolute impact. Information obtained from the questionnaire has been displayed in Table I.

TABLE I
INFORMATION OBTAINED FROM QUESTIONNAIRE

Criteria & Area of application	Option Rang			
	No Impact (Effect less)	Low Impact	High Impact	Quite Impact (Effective)
Photorealistic rendering	4	6	9	11
Virtual design review & Clash Detection	2	4	10	14
Design Options Analysis	1	9	13	7
Time & Cost Estimation	2	9	7	12
Construction Operation analysis	0	5	8	17
Construction Documents	3	9	11	7

Analysis of this information shows that construction process analysis and surveying logical sequence activities is considered as the most systems' efficiency for experts of this field. Virtual design review and identifying design clashes and interferences is the second factor for helping to users understand the working conditions. The average of obtained answers showed that 70 percent of the responses are in the full impact and high-impact areas and only 30% answers are no or low impact. 23.3 percent responded answer to low-impact options and only 6.7 percent of answers were without the impact. This information also shows that this modeling has the least help in construction document production and creating databases and design standards (Fig. 8).

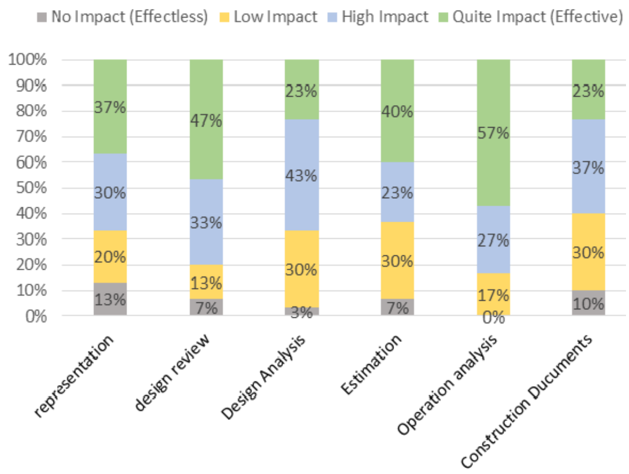

Fig. 8 Analysis of the Percentages Obtained from Questionnaires in Six Simulation Models' Application

Although the buffer period of simulation model, level of design details (LOD), the number of activities and many other factors can effect on users' perceptions and responses, but this model can reflect the main applicability orientation of visual simulation in infrastructure projects. This study showed that the simulation models have great efficiency and help in the perception of users and experts in the field of urban infrastructures, especially bridges. So in creating infrastructures like modular concrete bridges in developing countries such as Iran, these models can be created and developed with low cost to save the total project time and cost.

VII. CONCLUSION

Despite great progresses that have been achieved in the area of visualized construction management, still a lack of efficient and effective use of visualization techniques in infrastructure projects is making a sense. Problems and other important factors in the construction of Mega-Bridge projects can be understood by visualization and simulation techniques like 4D CAD in the initial phase of construction project. Projects with massive activities and duplicate items such as bridges have the potential to be managed by this technique. This research introduced a method in three phase for planning of bridge projects. The mentioned model are applied in real case project and evaluated by experts' user in six criteria. The applicability of model in Sadr bridge project showed that 93.4 percent of users' response are beneficial.

By this perspective, managers are able to make their decisions based on reliable information. Due to the high sensitivity of infrastructure projects and management capabilities of visualization techniques, this technique can reduce the time, cost and enhance the quality of the project result. This system can be described as the most powerful tool for the management of large infrastructure projects such as multi-layer highway bridge and urban buildings and provide valuable results as well. This research can be upgraded by the creation of standard construction component in BIM environment and make a standard database.

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