Automatic 3D CAD Model and 2D Drawings Generation in Construction Engineering

Sheng Jin¹, Yuanrui Zhang¹, Tomohiro Yamazaki², Jiang Zhu³*

¹Tech Communications Co., Ltd, Tokyo, Japan
²Gouriki Construction, Co., Ltd, Tokyo, Japan
³Department of Mechanical Engineering, Tokyo Institute of Technology, Tokyo, Japan
* Corresponding author: zhuj@mep.titech.ac.jp

Abstract—Automatic CAD design is difficult in construction field, since the construction environments vary case by case. Although the steps are similar, each creation is very time-consuming. Therefore, in this research a method that could automatically generate 3D CAD models and 2D drawings from the onsite measured geomorphological features is proposed to solve the complicated and similar process. This proposed method was implemented through the API (Application Programmable Interface) of CAD system and has been verified in practice that labor costs and time costs have been greatly reduced. In addition, mixed reality is applied to verify the assembly results, and an effective and realistic experience is provided to the user and the customer.

1. INTRODUCTION

CAD (computer aided design) system are widely used to assist the design and manufacturing process nowadays. However, in the construction field, creating 3D CAD models and 2D drawings is a very time-consuming task, because the construction environments are different case by case. Even the tasks are very similar, it is still very cumbersome to repeat such similar works when creating 3D CAD models and 2D drawings through the commercial CAD software. An automated system that could automatically analysis the completed projects, and generate 3D models and 2D drawings directly from the measured geomorphological features has long been expected.

In recent years, many studies have used API of various CAD systems in order to develop applications and tools, and the conclusion is that the advantages and benefits of API are huge. Manrique et al. [1] proposed a methodology for automatically generating shop drawings for wood-framing design using a developed application which is developed by Visual Basic for Applications as an add-on to AutoCAD. Kim et al. [2] presents a 3D CAD library which is implemented using API of CATIA. It can easily create a 3D model of the standard components of press die when a die designer inputs geometric feature values and the BOM (Bill of Materials) of the assembled parts. Tzotzis et al. [3] created a collection of tools that can be easily accessed through a simple user interface. These tools provide a variety of functions, such as automatic design of mechanical systems, automatic creation of mechanical drawings for each component of the design system, and extraction of assembly characteristics. Salunkhe, et al. [4] present an expert system which is developed by AutoLISP in AutoCAD. The system can finally generate the drawings of die components and die assembly of compound die automatically in the drawing editor of
AutoCAD software. J. Shankar et al. [5] describe how the automation of design tasks with Pro/E can be integrated with MS-Excel using VB (Visual Basic) programming language. Through these studies, it can be seen that the API can achieve many tasks, and one of its main advantages is the ability to build simple and easy-to-use applications that can provide convenience when repetitive and time-consuming tasks are involved.

Based on the idea that similar construction projects can be constructed by similar processes, this research proposes an automated 3D CAD model and 2D drawing generation method, based on extensive study and analysis of previous construction projects. The proposed methodology was implemented by developing the API (Application Programmable Interface) of a commercial CAD system. By conducting a special application for the task of constructing parking decks, it was confirmed that the labor cost and time cost for CAD modeling and 2D drawing generation were greatly reduced by this proposed method and developed system. In addition, mixed reality is applied to verify the assembly results, and an effective and realistic experience is provided to the users and the customers.

2. METHODOLOGY

The methodology of this research is shown in Figure 1. First, extensive analysis and digitization of previous construction projects are carried out. After that the projects are classified through the analysis results, and the rules are also formulated according to the patterns. On the other hand, according to the analysis and digitization results of the project, it is necessary to decide which parameters are required in the formulated rules from the onsite measurement. Subsequently, the 3D CAD model can be generated by combining the classified projects and the parameters taken on site. Finally, 2D drawing can be easily obtained through the 3D model data, and the 3D model data can also be used to create MR (Mixed reality) to provide real experience to the users.

![Figure 1. Schematic of the proposed 3D CAD model and 2D drawing generation method](image)

3. CASE STUDY OF PARKING DECK CONSTRUCTION

3.1. Task Description

In this research, the construction of parking decks was taken as a practical project to prove the effectiveness of the proposed methodology. Smart Deck is a construction product designed and developed by Gouriki Construction Co., Ltd. in Japan. Smart Deck is a structure in which lightweight steel pillars and girders are assembled in a cavity after a mechanical parking lot is dismantled, and steel boards are placed on the top of it. It is an economical and effective way to reform the mechanical parking lot. Although the structures are similar in each individual project, since the local environments are different case by case, 3D modeling and 2D drawings creation are necessary for each construction case, which is very time consuming and low efficiency.
After study and analysis over 100 construction projects, it was concluded that in most cases, the cavity of the parking deck can be mainly determined by three parameters: length, width, and depth. In addition, it can be divided into three patterns according to the shape, which will be explained in the next section. Therefore, when forming one Smart Deck, the length, number and position of the parts used will be determined by these three parameters. The following are the main parts of Smart Deck.

- **Steel board**: According to the shape, the steel board can be divided into the placed on both sides and placed in the middle, as shown in Figure 3. Each steel board needs three girders to support, and two adjacent steel boards will share one girder. The number of each steel board can be determined by the width of the cavity.

- **Girder**: As shown in Figure 4, there are three types of girders, namely girder3 placed between the front wall and the first row of pillars, girder2 placed between the first row of pillars and the second row of pillars, and girder3 placed between the second row of pillars and the back wall.

- **Pillar**: The pillar is an I-beam structure, and its length is determined by the depth of the cavity. Usually two aligned rows of pillars are formed in the width direction of the cavity, and the number of pillars in the length direction is determined by the length.

- **Support beam parts**: It is installed on the front and back wall to cooperate with the pillar to support the girder. Its installation depends on the shape of the wall. Figure 4 shows the installation with or without convex on the front and back walls.

![Figure 3. 2D drawing of Smart Deck viewed from the front (Regular pattern)](image)
3.2. Pattern classification
According to the collected data, the shape of the cavities can be mainly divided into 3 patterns.

1) Regular pattern: The cavity is cube-shaped, no tilt and raised walls.
2) Tilt pattern: The bottom of the cavity is inclined, as shown in Figure 5.
3) Raised walls pattern: There are several raised walls dividing the cavity, which can be seen as several cavities merged together, as shown in Figure 6.

3.3. Design application
In this study, an application was developed using the API of Inventor, and the designed user interface of regular pattern is shown in Figure 7.
Figure 7. User interface of regular pattern

First, the user needs to select the number of columns according to the dimension of the cavity, then input the dimension of the cavity to calculate the X parameters. The X parameters can be automatically calculated by the law which is formulated through the study and analysis of previous projects. Here the X parameter is the distance between each pillar and the side wall of the cavity, as shown in Figure 3. Y1 is the distance between the front wall and the first row of pillars, and Y2 is the distance between the first row and the second row of pillars as shown in Figure 4. After pressing the Generate/update model button, the system can automatically generate a 3D CAD model according to these parameters. Furthermore, these parameters can be manually modified by the user to fine-tune the model, if there are any obstacles on the floor or on the wall. In addition, in order to improve the generated results, the developed program also adds many additional options, such as generation of obstacles, obstacles are the objects that affect the assembly process, such as pipes beneath the actual cavity.

In other two patterns, the different points of application design are as follows,

- In the tilt pattern, the user needs to enter the front depth and back depth in the cavity dimensions. Then the length of the pillar is determined by considering the $Y_1$ and $Y_2$ parameters.

- In raised walls pattern, first the number of raised walls needs to be selected, then the $X$ parameters are calculated in several independent cavities as shown in Figure 8. In addition, if the thickness of the raised wall is longer than a certain value, considering the strength of the steel board, steel board 1 will be automatically replaced by steel board 2, and a short steel board 3 will be added in the middle, as shown in Figure 9.

Figure 8. 2D drawing of Smart Deck viewed from the front (Raised walls pattern)
3.4. Generate 3D CAD models and 2D drawings
In order to generate the 3D CAD model, this study pre-modeled all the parts which will be used in the assembly process. After the key parameters are decided, the parts are assembled using a special designed program. The 3D model of the main parts is shown in Figure 10. It can be seen that the cross-sectional shape of each part is unchanged, only their length needs to be changed according to the parameters introduced before.

Subsequently, the 2D drawing can be generated through the function of converting the 2D drawing from the 3D model that comes with the CAD software. Here, the 2D drawing is pre-converted and saved in the predefined way. The user can directly open the 2D drawing which has been updated by the current parameters.

3.5. Verification via Mixed reality
Mixed reality is a new technology, which merging real worlds with virtual worlds. It provides a new approach to visualize the digital objects to co-exist with the physical object. In this research, in order to visualize the automatically designed 3D CAD models in the real environment, a special application was
developed using Unity and Windows mixed reality SDK. This developed application will read the designed Smart Deck CAD model, and display it virtually in the real environment using Microsoft Hololens 2. The user can also interact with the designed CAD models. Figure 12 shows the images from the view point of the users.

![Figure 12. Hololens user and images from the view point of user](image)

4. EXPERIMENTAL RESULT

Figure 13 shows the process of a project from orders received to delivery. It can be seen that the creation of 2D drawing was done by the outsourcing company in the past, and the drawing for each project took 2 weeks to complete. According to user feedback, this work can now be completed within 5 minutes using the developed application. It can be concluded that labor costs and time costs have been greatly reduced.

![Figure 13. Process flow chart from request for quotation to delivery](image)

5. CONCLUSION

This research aims to automatically generate 3D models and 2D drawings based on geomorphological features. A method to solve the complicated process to create 2D drawings for similar projects in construction engineering was proposed. In practice the Smart Deck project was tested using this proposed method, the developed application successfully saved time and labor cost to design the construction plan of parking deck. In addition, the designed 3D models can be visualized and interacted via mixed reality technology to verify the designed construction plan.

REFERENCES

[1] J.D. Manrique, et all. “Automated generation of shop drawings in residential construction”, Autom. Constr.,55(2015),pp.15-24, 2015.
[2] C.W. Kim, et all. “An Automated Design system of Press Die Components Using 3D CAD Library”, ICCA2007, LNCS4706, Springer Verlag, pp961-974, 2019.
[3] Tzotzis A., et all. “Engineering applications using CAD based application programming interface”, in MATEC Web of Conferences, 94, p.7, Jan. 2017.
[4] S.Salunkhe, et all. “An expert system for automatic design of compound dies”, in AI Applications in Sheet Metal Forming. Topics in Mining, Metallurgy and Materials Engineering, 2017.
[5] S. J.Shankar, et all. “Automation of Design by Integrating Pro/Engineer with Ms-Excel”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), pp.69-72, 2014.