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Planning algorithms for in-situ production of free-form concrete panels

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ABSTRACT

Various materials are used when fabricating free-form panels, including glass, aluminum, titanium, and glass fiber reinforced concrete (GFRC), in addition to steel and concrete. Concrete has excellent structural stability, constructability, and economic efficiency, as well as the advantages of shape, thickness, forming of the finished surface and homogeneity of material. As a result, fast, low-cost technology has been developed to ensure the quality of free-form concrete panels (FCPs). FCPs, like precast concrete members, are generally constructed during in-plant production, on-site transportation, and installation. However, if FCPs are produced in site, cost savings of approximately 20% can be achieved due to savings in transportation and overhead at plants. In order to produce and install FCPs in site with restricted time and area, it is necessary to analyze and systematically link the related processes and influence factors. The purpose of this study is to develop planning algorithms for the in-situ production of free-form concrete panels. For this study, the relationship between the factors affecting the production plan of FCPs was mathematically established. The algorithms proposed in this study support the quick and easy establishment of in-situ production plans, contributing to cost reduction, according to various influencing factors such as the number of CNC machines, number of production cycles, production time, production area, and lead time.

1. Introduction

Free-form design is an increasing trend in construction projects around the world due to the development of 3D digital technology. Free-form building is more expensive than stereotyped building [1]. In the case of free-form panels, various materials such as glass, aluminum, titanium and glass fiber reinforced concrete (GFRC) have been used in addition to steel and concrete [2]. Free-form panel production technologies using materials such as high-performance concrete (HPC) and GFRC have been developed for the efficiency of production, installation and maintenance. One well known example of free-form building design is the Louis Vuitton Foundation for Creation building, which is made of precast concrete panels using a glass curtain wall and ultra-high performance concrete (UHPC) as exterior materials, together producing about 18,800 panels in various shapes. The UHPC used in this building has excellent structural stability due to a compressive strength of 200 MPa and a high tensile strength [3,4].

Lee et al. have conducted research on the production technology of FCPs with excellent performance characteristics such as economy, constructability, strength, and durability [5]. Lee et al. developed computerized numeric control (CNC) equipment for the production of FCPs and a recyclable composite phase change material (PCM) mold [5]; however, additional research is needed to reduce production and installation costs when the developed technology is applied in practice. In the case of FCPs, as with precast concrete members, factory production, transportation, and installation on site are common. Hong et al. showed it is possible to save 14.5–22.7% due to reductions in factory profit, overhead, and transportation costs when producing precast concrete (PC) members in site [6]. FCPs produced in a similar manner to PCs can achieve considerable cost savings when they are installed on site, while satisfying the conditions of limited production time and area. In-situ production here means the production of PC members within the working radius of the crane. In the case of tower cranes, it means production in the working radius. In case of mobile cranes, it means production within the range of transportation for the horizontal movement of members. In order to produce and install FCPs in site with limited time and area contributing to cost reduction, it is necessary to analyze and systematically link the related processes and influence factors. To solve this issue, the purpose of this study is to develop planning algorithms for the in-situ production of free-form concrete panels. This study proceeds as follows. First, the authors review previous research on the in-situ production and installation of FCPs. The problems and improvements of previous research are analyzed and applied to the algorithms of this study. Second, after analyzing the relationship between in-situ production and installation, the authors analyze the factors affecting FCPs production plan

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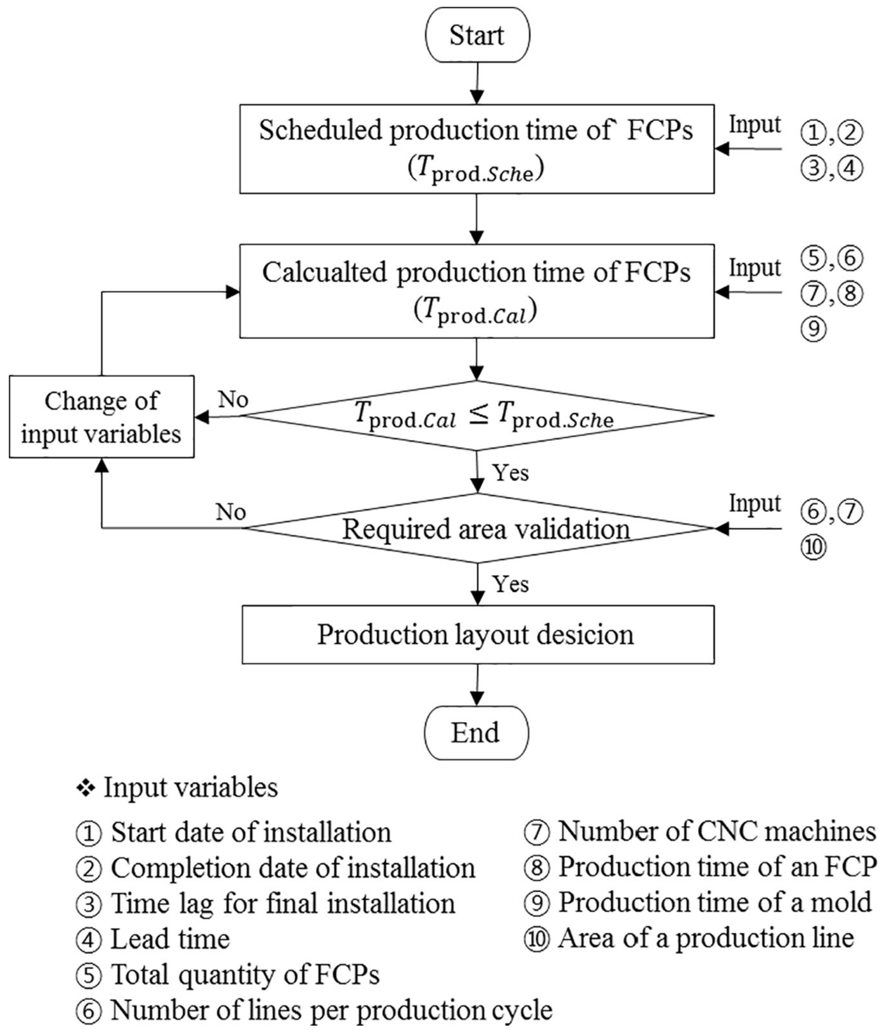

Fig. 1. Planning flow for the in-situ production of FCPs.

mathematically. Third, a case study is conducted to verify the proposed algorithms. The algorithms developed in this study support various simulations of in-situ production planning of FCPs under given site conditions and increase cost savings opportunities. In the future, these algorithms will be used as basic data for the efficient planning of free-form building projects.

2. Preliminary study

A study on the production and installation of free-form concrete members was surveyed. Lim et al. conducted a study on the influencing factors of FCP production and installation. The production-installation process of FCP was classified into 11 stages, and the factors affecting each stage were analyzed [7]. The main factors were defined as PCM shape implementation, PCM curing, concrete pouring, and concrete curing. Although this study explores the influence factors of the FCP production-installation process, further research is needed to understand the close relationships among the influence factors. Therefore, in the current study, these influence factors are parameterized and the relationship between them is mathematically analyzed.

Kim defined three types of layouts for the in-situ production and installation of FCPs: linear, parallel, and radiation. In addition, Kim proposes an algorithm to estimate the total production time via classification based on the number of iterations of each layout and the relationship of each process [8]. The proposed algorithm only calculates the total production time for each layout based on the unit time of each FCP production, as it is not enough to perform a simulation that simply reflects various conditions.

Lee sought to establish an optimal management plan that takes into account the cost of a free-form building project by controlling the number of resources used [9]. In order to obtain maximum productivity with minimum initial input cost, the production and installation plans were verified through case analysis according to the amount of CNC equipment used; however, this assumes that the required production area does not exceed the available production area, which is an important variable of in-situ production. In addition, it is insufficient to simulate various conditions in the site.

The algorithms proposed in this study calculate the number of production lines needed to complete the production within the installation time and examine the possibility of production within the available production area. Therefore, this work differs from previous studies in that various simulations are possible. The proposed algorithms were designed to estimate in-situ production time according to the installation plan. Accordingly, it is necessary to grasp the relationship between installation and the in-situ production plan.

Glenn and Arbulu conducted a study to minimize the lead time for shortening the production process of PC members [10]. The factors affecting the lead time were drawn and reviewed in the shop drawing, material procurement, pre-assembly, production and delivery time through case analysis.

Lee [11], as a necessary condition for the in-situ production of PC members, includes the vehicle access roads, building area, crane