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The structure and knowledge flow of building information modeling based on patent citation network analysis

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ABSTRACT

Building information modeling (BIM) creates new business value and innovation in the construction engineering industry. This study identifies BIM technology structure and the characteristics of knowledge flow through a patent citation network. A technology patent database was collected with backward and forward citation patents currently registered in the US Patents and Trademark Office and identified by the Cooperative Patent Classification. Technology citation networks interact and follow the power law distribution. The analysis of individual patent characteristics and intermediaries revealed digital data processing and telemetry systems as core technology fields stimulating innovative BIM technology. This study overcomes the limitations of previous methods of technology forecasting that have depended on expert opinion or peer review by performing a patent big data analysis to ascertain the domain of the BIM industry. This approach could soon be applied to R&D strategy planning and competition in business and the development of cutting-edge technology.

1. Introduction

Building information modeling (BIM) is particularly salient for influential innovations that have emerged in the construction industry during the past decade [1]. BIM is defined as the digital representation of physical and functional facility characteristics. BIM serves as a shared knowledge resource for facility information and forms a reliable basis for decisions during a facility's life cycle from inception and beyond [2,3]. BIM is an integrated concept that manages life cycle management [2], and its characteristics render it an appropriate tool for application in the construction industry. Due to the potential but limited use of BIM in practice [4,5], increasing research has been devoted to theoretically or empirically investigating BIM-related issues in the past decade [2–4].

Analysis of patent information provides insights on the status of industries and technology flow to determine strategic direction to maximize research and development (R&D) performance. As the performance of R&D is applied for patent and carry over, patented technology commercialization, competitive patent creation, and the identification of patent strategy are becoming increasingly important. According to Market Research on Marketing [6] conducted by the Global Industries Corporation across the United States, 70% of executives said patents are needed for innovation, and 87% of top managers said they respect patent rights. As the importance of patents increases, the methodology using data mining and social network analysis (SNA) allows to build networks with information relationships to identify the structure of the industry. Although the SNA on the construction field [7–9] has been recommended, it is limited to understand the relationship between technologies.

Therefore, this paper will effectively ascertain the structure of the construction BIM industry and BIM technology flow through the patent citation network analysis. Because the US is currently the largest manufacturer and consumer of BIM technology [10], we analyzed the domain of BIM through the citation information of BIM patents registered with the United State Patents and Trademark Office (USPTO). Using the Cooperative Patent Classification (CPC), which complies with the current state of technology to effectively search and manage a significant amount of patent information [11], we built a technology field citation network to understand BIM technology structure and the characteristics of technological knowledge flow.

2. Literature review

2.1. Traditional methods and current trends in patent analysis

A patent is composed of the content of technical embodiments,

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technology classification codes, citation information, and owner information. Technology change trends, technology levels, and commercial values can be understood through the analysis of the component factors in the patent [12]. Thus, patent makes it possible not only to conduct quantitative analysis by providing standardized information on the technologies, but also to provide important information to relevant persons in charge of R&D, technology policies, or strategies [13]. Therefore, patent analysis is suitable for understanding a technological flow and development direction in various industries, exploring new research fields and the creation of new technologies [14].

The previous patent analysis studies are covered in construction field using the bibliometric analyses of patents and publications in energy technology [15], the fuzzy inference system [16] and theory of solving inventive problem (TRIZ) [17]. The patent analysis also includes regression analysis and correlation analysis using strategic variables and evaluates the impact of patents by applying patent statistics to economic models or theories. However, there are limitations to this method because it provides only partial information on technological knowledge diffusion. To examine the technological knowledge diffusion process from a comprehensive perspective, more studies have addressed patent citation relations in terms of network theory [18]. Within patent literature, patent citation information have recently been used to analyze a technological evolution such as technology flow, diffusion, and fusion [19,20] as well as forecasting new technologies [21–23]. Co-classification analysis and citation analysis of technology codes are often developed to reflect linkage relationships between different technological knowledge domains [15]. Researchers also understand the relationship between industries and technology information in industries and discover key technology advancements by forming a patent network based on citations [24].

2.2. SNA measures

SNA, a quantitative technique derived from graph theory, identifies how actors influence other actors and the implications of any relationship within a network [25,26]. Various SNA use the patent citation information to identify technology knowledge flow in organic photovoltaic cells [27], organic solar cells [18], and dye-sensitized solar cells [28]. Sternitzke et al. [29] identifies that, through citation networks, the position of applicants within citation networks is useful in explaining applicant behavior in the marketplace such as cooperation or patent infringement trials. Wang et al. [30] examines whether patent quality is predicted by analyzing information embedded in a patent citation network. Yoon and Park [13] propose a network-based patent citation analysis and show the overall relationship among patents of wavelength division multiplexing as a visual network. The analysis assists users in determining the relative importance of individual patents, and it facilitates the analysis of up-to-date trends in high technologies and the identification of promising avenues for new product development.

SNA methods are likewise evolving, and network topological analysis and node centrality analysis are commonly used [27]. Network topological analysis explains topological structure using characteristics and provides a holistic perspective of knowledge flow particularly in the scientific literature and patent citation [31,32]. However, network topological analysis cannot provide quantitative information on the importance and value of individual nodes [27], so centrality analysis is required to assess the value of each node and the measurement of the structural location. The actual value of the center, that is, the extent to which a node is located at the center of the entire network, has been proved [27,33]. This study analyzes each node using the three types of centrality; degree centrality, closeness centrality, and eigenvector centrality. Additionally, we investigate which technology field acts as an intermediary or bridge in the network using the brokerage analysis. Brokerage analysis recognizes every triad and the role of each node in that triad based on the partition vector [34].

3. Materials and methods

The purpose of this paper is to confirm the structure and characteristics of the technological knowledge flows by comparing and analyzing the overall data and data for the last three years. We first collect BIM patent data including citation information. Second, we investigate the overall structure of the patent citation network through the network visualization and topological analysis. It can grasp the general structure of the network using the various SNA measures shown in Table 2. Then, we identify the value and importance of an individual node by centrality analysis. Finally, we perform the broker analysis for the intermediary role or the bridge between the technology fields. This study uses Netminer [35], a SNA program, to analyze a citation network based on patent citations.

3.1. Data acquisition

Patent citation analysis is required to understand technology flow and forecast the direction of technology in any industry. Although it is particularly important, there is still no research that supports construction industry. Thus, in this study, we adopted the BIM patents which are promising issue these days to experimentally verify the technology flow for promising technology forecasts. The research data is composed of the number of patents currently registered in the USPTO through Worldwide Intellectual Property Service (WIPS) [36] which provides patent search service. Some steps were applied to collect and finalize the data. First, the BIM is an integrated concept, therefore, we performed the keyword expansion and searched the title, abstract, and exemplary claim. In the second step, we refined the unnecessary data using the CPC. The CPC system is divided into nine sections, A-H and Y that, in turn, are sub-divided into classes, sub-classes, groups, and subgroups [37]. Therefore, in this study, we excepted irrelevant CPCs such as “A61: Medical or veterinary science; hygiene,” “B29: Working of plastics, substance in a plastic state” and “G01N: Investigating or analyzing materials by determining their chemical or physical properties.” Through this process, finally, this research was conducted in August 2016, and 113 patent data were extracted from 1998 to 2016.

Fig. 1 shows the status of registered BIM patents by applicant origin. By the early 2000s, less than five patents were registered each year, from the late 2000s, 84% of the total data were registered.

The citation information related to 113 patents was extracted to construct a BIM patent citation network with 3120 backward citations and 1803 forward citations. Fig. 2 shows the top 6 technology fields, which occupy 85% (4272 of 5036) of the whole data. The main CPCs on BIM technology fields from the collected patent data are explained as indicated in Table 1.

The distribution trends of these key CPCs are shown in Fig. 3. “G06” shows the most critical technology field, which has been cutting-edge BIM technology during the last 10 years; “H04”: represents the next fastest growing proportion. Moreover, continuous expansion of new technology fields shows that BIM technology has been converging into various state-of-the art technologies.

3.2. Network analysis measures

3.2.1. Network visualization and topological analysis

A patent citation network is a directed network and can be constructed in various forms by analytical units [27]. This selected technology field for the analytical unit establishes the patent technology field citation network. In the citation network, a node is a subgroup of the CPC as a technology field, and a link is a citation relationship (citing and cited) among patents.

We first establish the patent technology field citation network, and visualize a network map to assess a general overall structure of the network. Then, we analyze the structural and topological characteristics of the network by using various indices in the Table 2. These