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A Study on Identifying Key Players in a 3D Cadastre Citation Network

3차원지적 인용네트워크의 key players 확인에 관한 연구

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요 약

The main purpose of this study was to identify key plays in a 3D cadastre citation network. To achieve the research objective, this article examined theories and previous studies on 3D cadastre and citation networks and set up two research questions based on them. To answer these research questions, this study attemted to search for 3D cadastre research published from January 1, 2012, to October 31, 2017, using Google Scholar Search. This study constructed a citation network using the citation information of the collected data and then used social network analysis techniques such as degree centrality, closeness centrality, and eigenvector centrality to identify the influential nodes. This study also used modularity-based Louvain algorithms to detect influential communities in the citation network. As a result of the analysis, Stoter et al. (2013) were identified as the most influential nodes in the whole network and community 0 was identified as the most important community.

주요어 : 3D cadastre, citation network, key plays, node, degree centrality, closeness centrality, and eigenvector centrality, community

ABSTRACT

본 연구의 주된 목적은 3차원지적 인용네트워크에서 key plays를 확인하는 것이었다. 이러한 목적을 달성하기 위해 본 연구는 3차원지적과 인용네트워크에 대한 이론과 선행연구들을 검토하였고 이를 토대로 2개의 연구 질문을 설정하였다. 이러한 연구 질문에 대한 답을 구하기 위해 본 연구는 2012년 1월 1일부터 2017년 10월 31일 사이에 발표된 3차원지적연구들을 구글학술검색을 이용하여 검색하였다. 이러한 방법을 통해 수집된 자료의 인용정보를 토대로 인용네트워크를 구성한 다음 영향력 있는 노드들을 확인하기 위해 차수중심성, 매개중심성, 근접중심성, 위세중심성과 같은 소셜네트워크분석 기법들을 이용하였다. 또한 본 연구는 인용네트워크에서 영향력 있는 커뮤니티를 식별하기 위해 모듈성기반의 루뱅알고리즘을 이용하였다. 분석의 결과 Stoter 등 (2013)이 전체네트워크에서 가장 영향력 있는 노드로 확인되었으며 또한 커뮤니티 0은 가장 핵심적인 커뮤니티로 식별되었다.

Keywords : 3차원지적, 인용네트워크, key players, 노드, 차수중심성, 매개중심성, 근접중심성, 위세중심성, 커뮤니티

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1. Introduction

In recent years, land use patterns are rapidly changing from two-dimensional to three-dimensional. Particularly noteworthy is the three-dimensionalization of land use in large cities such as Seoul. Today, city governments in the world are spurring the development of underground space and the densification of land use due to land price surge and available land shortage.

This three-dimensionalization of land use causes various problems that we did not experience in the two-dimensional land use age. Resolving the issues of underground space ownership and air right is one of the most critical challenges land management professionals face in the era of 3D land use. However, we cannot resolve these land management problems within the framework of the two-dimensional cadastre. Therefore, many scholars have tried to investigate different aspects of 3D cadastre to respond to the change of the times. They maintain collaboration in various forms in sub-fields of 3D cadastre research. Some scholars have co-authored many research papers with other researchers, and others have citation or co-citation relationships with their colleagues. In other words, they have contributed to the development of 3D cadastre research field, forming a co-authorship network, a citation network or a co-citation network.

However, only a few easily accessible scholars can do co-authoring works. The success of co-authoring depends on the level of communication between researchers. For this reason, grasping the co-authorship relationship does not necessarily help identify the research collaboration relationship in the whole academic field. In the long run, it is possible to establish co-citation relationship among researchers, but in the short term, it is challenging to build co-citation networks. Thus, researchers' citation relationship is most frequently used to identify academic collaborations among researchers in a specific area. In general, a researcher makes citations by his judgment. Thus, to determine the most influential researchers or research papers in a discipline, we should grasp the citation relationship rather than the co-citation relationship. In general, the citation relationship between researchers forms a single vast network, which consists of several sub-networks centered on sub-topics. The field of 3D cadastre research is no exception. In 3D cadastre field, researchers have formed an enormous citation relationship network, which is composed of several sub-networks around the sub-topics. So, it is possible to identify the most influential researchers and research papers in 3D cadastre field using citation network analysis. Notably, using such network analysis metrics as degree centrality, betweenness centrality, closeness centrality, eigenvector centrality and community detection algorithms allows researchers to identify key players in a 3D cadastre citation network.

The primary purpose of this study is to identify key players in a 3D cadastral researchers' collaboration network using social network analysis. This study consists of 7 sections. Section 1 deals with the introduction of this research and Section 2 gives an overview of the related literature on 3D cadastre and citation network analysis. Section 3 focuses on developing research questions based on literature review, and Section 4 pays attention to the research methods. Section 5 is devoted to analyzing and interpreting the results, and Section 6 pays attention to the discussion of the results. Finally, Section 7 concludes this study.

2. Literature Review

2.1 3D Cadastre Research

2.1.1 The definition of 3D cadastre

Researchers define 3D cadastre as a cadastre that efficiently registers and manages various rights and restrictions on 3D property units, not on parcels (Stoter, 2004). Conventional cadastre focused on recording and maintaining only two-dimensional information of a parcel of land. However, as the urbanization progressed, 3D land use was accelerated in almost all cities in the world. Notably, as the development of the underground space became full-scale, various disputes arose among stakeholders. Moreover, high-rise buildings caused numerous legal problems that we did not experience the two-dimensional cadastre age.

2.1.2 Review of 3D cadastre related literature

Recently, many scholars have been trying to study various aspects of 3D cadastre. Primarily, researchers were devoted to the development of a new model of 3D cadastre. Stoter et al. (2013) presented a new model for registering 3D rights and restrictions in the Netherlands. This model is composed of two stages. In the first step, the researchers tried to solve the problems in the framework of the existing system without requiring the change of the current cadastre-related law or policy. In other words, the first step is a transitional phase to go to the full-scale 3D cadastre. They insisted that they can realize the full-scale 3D cadastre only when they reach the second stage. This study has significantly influenced other 3D cadastre research (El-Mekawy et al., 2014; Shi et al., 2013; Jamali et al., 2013). Vandisherva et al. (2012) also developed a new 3D cadastral model of the Russian Federation and implemented it in a pilot fashion.

Besides, some scholars have focused on the legal aspects of 3D cadastre. In particular, Ho et al. (2013) studied the legal barriers that emerged during 3D cadastre implementation process. Kitsakis et al. (2016) studied the legal concept of 3D property and cadastral system. They selected several countries as a sample and analyzed the differences in the legal aspect of 3D cadastre among these countries. Some researchers have also studied the technological elements of 3D cadastre. Ying et al. (2012) applied 3D GIS technology to construct 3D cadastre in Chinese urban environment. Their findings show that much of 3D GIS technology can be used to build 3D cadastre. Shojaei et al. (2013) studied 3D visualization of cadastre in an Australian context. They proposed a 3D cadastre visualization method to display land ownership and related information efficiently. Meanwhile, Li et al. (2012) attempted to apply aerial photogrammetry techniques to the construction of 3D cadastre. Their findings reveal that the use of LIDAR and advanced aerial photogrammetry techniques is a great help in building 3D cadastre. Some researchers have also studied the standards of 3D cadastre (Lee et al., 2014; Bydlosz et al., 2014; Janecka et al., 2017). Especially Bydlosz et al. (2014) reviewed the international standard of 3D cadastre and then suggested a new solution.

2.2 Citation Network Analysis Research

2.2.1 Citation network analysis

A citation network is a social network that contains articles and citation information. In a citation network, a node[2)] means the author or title of an article, and an edge[3)] indicates a citation relation. The main purpose of citation network analysis is to identify the most influential articles or sub-topics in an academic field (Zhang et al., 2016). In general, scholars use degree centrality, betweenness centrality, eigenvector centrality, closeness centrality and PageRank[4)] to detect the most influential papers or authors in a citation network. Degree centrality means how many nodes are connected to a node. In a directed network, this can be divided into in-degree centrality and out-degree centrality depending on the direction of the edge (Tsai et al., 2001). In citation network analysis, out-degree centrality is often used rather than in-degree centrality because out-degree centrality indicates the effect of nodes on the other nodes. Closeness centrality can be obtained by using the sum of the shortest path between a node and other nodes in a graph (Okamoto et al., 2008). In general, the higher the closeness centrality of a node, the closer the node is to other nodes. That is, nodes with high closeness centrality can have a significant impact on other nodes. Betweenness centrality is a method of finding centrality based on the shortest path in a network (Brandes. 2001). In a graph, there is the shortest path between nodes. The betweenness centrality value for each node means the number of the shortest path passing through that node. In a citation network, nodes with high betweenness centrality act as mediators between nodes. Eigenvector centrality measures how much influence a node has in a network (Bonacich, 2007). It assigns a relative score to all nodes in a network and grasps the connection relationship of one node with another node. In particular, eigenvector centrality assumes that nodes connected to high scoring nodes are more influential than nodes connected to low scoring nodes. A citation network consists of multiple sub-networks which have similar characteristics. The nodes belonging to the same sub-network are connected more closely than the nodes belonging to the other sub-network. The nodes of these sub-networks, i.e., papers, form a community centering on the same topic. Thus, scholars use community detection algorithms to identify sub-topics that exist in a citation network. Among these community algorithms, researchers widely use modularity-based Louvain algorithm. This algorithm starts from the community consisting of only one node and proceeds to integrate with

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2) In graph theory, a node is a key element that constitutes a graph. This is also called a vertex.
3) In graph theory, an edge is one of the two key components of a network. An edge connects a node with a node and is also called a link.
4) PageRank is the algorithm that Google Search uses to rank search results.

other nodes based on the modularity value. This task continues until the modularity value is no longer increased (Saoud et al., 2016).

2.2.2 Review of citation network analysis related literature

Many researchers in various disciplines have studied citation networks. Bilke et al. (2001) identified the topological structure of citation networks. They confirmed that citation networks have a tree-like structure. Page et al. (1999) developed PageRank algorithm to rank web pages retrieved by the Google search engine. Using this PageRank algorithm, researchers could identify influential authors and papers in a citation network. Ding et al. (2009) used PageRank algorithm to rank nodes in a co-citation network. They compared PageRank value with other network statistics such as degree centrality. However, they only tried to rank authors in the citation network but did not rate papers. Zhang et al. (2016) developed a new algorithm called DAG[5] to identify influential articles in a citation network. The results of their study show that this algorithm is much more efficient than the method of detecting influential papers using centrality or PageRank. Muñoz-Muñoz et al. (2017) used degree centrality, closeness centrality, betweenness centrality, clustering coefficient and structural holes to identify who is the most influential author in violence research related to women. In particular, they intensively used degree centrality, betweenness centrality, and closeness centrality to identify the most prominent researchers and papers in the area of violence against women. The results of their study reveal that centrality metrics are very useful in determining influential nodes, i.e., papers or researchers, in citation networks.

2.3 3D Cadastre Research and Citation Network Analysis

As in other academic disciplines, 3D cadastre studies are also closely linked to each other to form an extensive citation network. In general, 3D cadastral research is subdivided into 3D cadastre model development research, 3D cadastre-related law research, 3D cadastre technology research, and 3D cadastre standard research. 3D cadastre studies with similar characteristics are closely linked to each other in a citation network. To identify influential researchers or papers in 3D cadastre citation networks, we need to use degree centrality, closeness centrality, closeness centrality, eigenvector centrality and PageRank. Using these network metrics, we can identify the most influential nodes in a 3D citation network. However, unlike the previous studies, this study attempts to detect the most influential sub-network or community in a 3D cadastre citation network. To understand the nature of the citation network, we need to identify not only the most influential nodes but also the most prominent communities. These communities are intimately connected sets of nodes, i.e., sets of researchers or papers. Understanding community structure in such a citation network can provide researchers with valuable information that was

5) DAG stands for a Directed Acyclic Graph and generally has a transitive relation (Zhang et al., 2016).

impossible with conventional methods.

3. Research Questions

The primary purpose of this study is to identify the most influential nodes and communities in a 3D cadastre citation network using social network analysis techniques. To lay the groundwork for achieving this research purpose, this study reviewed the literature on 3D cadastre and citation networks. The literature review results reveal that there exists some gap between practice and research. To bridge the gap, this study developed the following research questions.

Research Question 1: Who is the most influential researcher in 3D cadastre field?

There are various sized communities in a 3D cadastre citation network. In general, the size of a community determines its impact on the entire network. The most significant sub-network plays a pivotal role in a 3D cadastre citation network. In other words, the most important subcategory is a research topic in which scholars are most interested. To identify the most influential sub-network in a 3D cadastre citation network, we need to use a modularity based community detection algorithm.

4. Methodology

4.1 Research Design

To find the answers to the above research questions, this study used the following methods. First, I collected articles on 3D cadastre using Google Scholar Search and constructed a citation network based on articles' citation information. To identify influential nodes in the graph, this study utilized such social network analysis metrics as degree centrality, closeness centrality, closeness centrality and eigenvector centrality. Finally, this study used the modularity based Louvain algorithm to detect essential communities in the 3D cadastre citation network.

4.2 Data Collection

This study used Google Scholar to search for articles in 3D cadastre. First of all, I entered '3D cadastre' as a search term in the search box and then set the search condition to search only the title of the papers. I also set the search period from January 1, 2012, to October 31, 2017. As a result, I was able to search 112 titles containing a search term, '3D cadastre', in the title. I saved bibliographic information such as authors, titles, citation information, issue years, and sources of all papers as CSV [6]file.

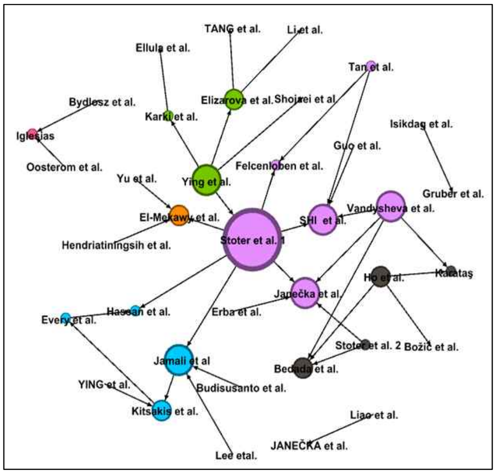
4.3 Data Analysis

In this study, I analyzed the data collected from above in three steps. First, I constructed a citation network using the citation information of the papers. I could quickly build a citation network with the help of the social network analysis program, Gephi. In this process, I selected only 38 academic articles linked with

6) CSV is an abbreviation for comma-separated variables, which is mainly used when text files are stored in separate fields.

each other by citation relationships and constructed a citation network. Next, I used such social network analysis metrics as degree centrality, closeness centrality, closeness centrality and eigenvector centrality to detect the most influential nodes in the citation network. Third, I used the Louvain algorithm to detect the most influential communities in the 3D cadastre citation network. Because the Louvain algorithm is based on modularity, it accurately and quickly detects communities in large networks. Finally, I used Fructerman Reingold layout to represent communities in the citation network visually.

5. Results



〔Figure 1〕 3D cadastre citation network

[Figure 1] shows a 3D cadastre citation network. The number of nodes in this citation network is 38, and the number of edges is 39. As can be seen in this figure, some nodes are more closely connected with neighboring nodes than others. In this figure, each node represents the author who wrote a paper on 3D cadastre, and the size of each node reflects degree centrality value.

5.1 Research Question 1

Research Question 1 was about who was the most influential researcher in 3D cadastre research. To identify the most influential node in the citation network, I utilized such social network analysis metrics as degree centrality, closeness centrality, closeness centrality and eigenvector centrality. As expected, the results of the research show that there are significant differences in the influence of the researchers.

5.1.1 Degree centrality

〈Table 1〉 Degree centrality of the most influential researchers

Authors	Degree centrality
Stoter et al. (2013)	7
Vandysheva et al. (2012)	4
Ying et al. (2012)	4
Jamili et al. (2013)	4
Shi et al. (2013)	4
Janecka et al. (2017)	4

<Table 1> shows the degree centrality of the most influential researchers in 3D cadastre field. Degree centrality means the number of relationships that a node has with other nodes in a network. In other words, it refers to the number of other researchers directly connected to one researcher in a citation network (Muñoz-Muñoz, 2017). In general, a researcher cites others' articles in the course of conducting his research, and others cite this author's articles as well. In this process, researchers build mutual

partnerships in their field. The authors with the highest degree centrality value in the 3D cadastre citation network are Stoter et al. (2013). They are connected with seven researchers in the citation network, confirming that they are the most influential authors. Vandysheva et al. (2012) and Ying et al. (2012) have also been identified as authors who have a deep relationship with other authors in the 3D cadastre citation network. When we use degree centrality, we ignore the direction of edges. However, since the 3D cadastre citation network constructed in this study is a directed network, degree centrality must be classified according to the direction of influence. That is, degree centrality can be divided into out-degree centrality and in-degree centrality, depending on edge direction.

〈Table 2〉 Out-degree centrality of leading researchers

Authors	Out-degree centrality
Stoter et al. (2013)	6
Vandysheva et al. (2012)	4
Ying et al. (2012)	4
Ho et al. (2013)	3
Elizarova et al. (2012)	2
Stoter et al. (2012)	2

<Table 2> shows the out-degree centrality of leading researchers in 3D cadastre field. The out-degree centrality value of a node in a network indicates the direct impact of that node on other nodes. Authors with the highest out-degree centrality values in the 3D cadastre citation network are Stoter et al. (2013). They are connected with six nodes in the network, confirming that they are the most significant researchers. As can be seen in Table 2, Vandysheva et al. (2012) and Ying et al. (2012) have also been found to be researchers who have a significant impact on other researchers.

〈Table 3〉 In-degree centrality of the most influential researchers

Authors	In-degree centrality
Shi et al. (2013)	4
Janecka et al. (2017)	4
Jamili et al. (2013)	3
El-Mekawy et al. (2014)	3
Bedada et al. (2012)	3
Kitsakis et al. (2012)	2

<Table 3> shows the in-degree centrality of the most significant researchers in 3D cadastre. Nodes with high in-degree centrality values in the citation network indicate that they are citing a lot of articles written by other authors. The nodes with the highest in-degree centrality value in the 3D cadastre citation network constructed in this study are Shi et al. (2012) and Jannecka et al. (2013). They each cite four papers on the network in writing their articles.

5.1.2 Betweenness centrality

〈Table 4〉 Betweenness centrality of the most influential researchers

Authors	Betweenness centrality
Jamili et al. (2013)	0.0079
Kitsakis et al. (2017)	0.0079
Stoter et al. (2013)	0.0063
Every et al. (2012)	0.0040
Elizarova et al. (2012)	0.0016
Karki et al. (2012)	0.0008

Betweenness centrality is a measure of how well a node performs as an intermediary in a network. That is, there is the shortest path between the nodes of a network. If these shortest paths pass a node frequently, the node has a high betweenness centrality value. Nodes with high betweenness centrality value play a vital mediator role in the network. Table 4 shows the betweenness centrality value of 3D cadastre researchers. The findings reveal that Jamili et al. (2013) and Kitsakis et al. (2016) are authors with the highest betweenness centrality values in the 3D cadastre citation network. Therefore, they seem to play essential roles in controlling and mediating the flow of information in the 3D cadastre citation network.

5.1.3 Closeness centrality

Closeness centrality is based on the assumption that the more important nodes are, the shorter the paths reaching other nodes. In general, closeness centrality is calculated by computing the average distance of the shortest path from a node to the remaining nodes and taking the reciprocal of the value.

〈Table 5〉 Closeness centrality of leading researchers

Authors	Closeness centrality
Every et al. (2012)	1.0
Elizarova et al. (2012)	1.0
Karki et al. (2012)	1.0
Guo et al. (2013)	1.0
Vandysheva et al. (2012)	1.0
Stoter et al. (2012)	1.0
Ho et al. (2013)	1.0
Tan et al. (2013)	1.0
Erba et al. (2012)	1.0
Yu et al. (2012)	1.0

<Table 5> shows the closeness centrality value of the most influential researchers in the 3D cadastre citation network. As can be seen in the table, ten nodes including Every et al. (2012) are found to be the nodes with the highest closeness centrality. Nodes with such high closeness centrality values play essential roles in citation networks because they can reach directly to other nodes. However, it is uncommon that some nodes with high degree centrality value have a lower closeness centrality than other nodes.

5.1.4 Eigenvector centrality

〈Table 6〉 Eigenvector centrality of the most influential researchers

Authors	Eigenvector centrality
Hassan et al. (2012)	1.0000
Every et al. (2012)	0.6291
Kitsakis et al. (2017)	0.3075
Shi et al. (2013)	0.1068
Janecka et al. (2017)	0.1068
El-Mekawy et al. (2014)	0.0939
Jamili et al. (2013)	0.0939
Felcenloben et al. (2013)	0.0812
Tang et al. (2012)	0.0812
Li et al. (2012)	0.0812

<Table 6> shows the eigenvector centrality values of leading researchers in the 3D cadastre citation networks. In a network, nodes are connected to other nodes. Degree centrality considers only the number of nodes connected to one node. However, some of the nodes have a significance influence on other nodes, and others have little effect. The eigenvector centrality assumes that nodes connected to an influential

node are essential. That is, the high eigenvector centrality value of a node means that the node is connected to an influential node in the network.

The results show that the node with the highest eigenvector centrality value in the 3D citation network is Hassan et al. (2012). As you can see in Figure 1, it is connected to the most influential node in the network. This node plays important intermediary roles between the most prominent node, Stoter et al. (2013) and other neighboring nodes. Every et al. (2012) and Kitsakis et al. (2017) also have high eigenvector centrality, indicating that they are also connected to important nodes in the network.

5.2 Research Question 2

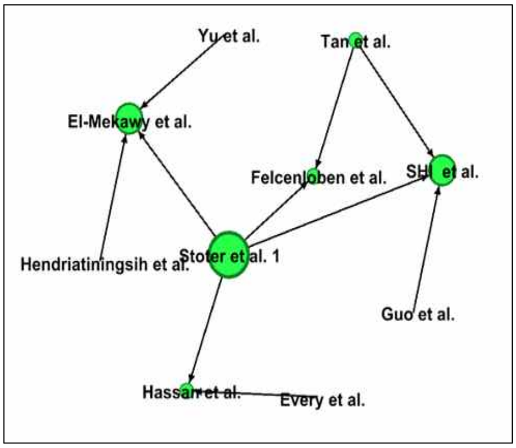
Research Question 2 was about what was the most influential topic in 3D cadastre research. To find answers to this research question, I attempted to detect communities in the 3D cadastre citation network using modularity-based Louvain algorithm.

〈Table 7〉 Communities in the 3D cadastre citation network

communities	ratio (%)
community 0	27.03
community 1	21.62
community 2	18.91
community 3	5.41
community 4	13.51
community 5	8.11
community 6	5.41

<Table 7> shows the number of communities in the 3D cadastre citation network and the share of each community in the total network. These values are obtained by filtering based on the modularity value. There are seven communities in this 3D cadastre citation network. My results show that the largest sub-network is Community 0, occupying 27.03% of the whole network. Community 1 and community 2 are also communities that play significant roles in the citation network. The three communities above occupy more than two-thirds of the network, making them the most influential communities. On the other hand, the smallest communities turn out to be Community 3 and Community 5, accounting for 4.6% and 4.6% of the whole network, respectively. In the following, I will explain the structures and topics of major communities which occupy more than 10% of the whole network.

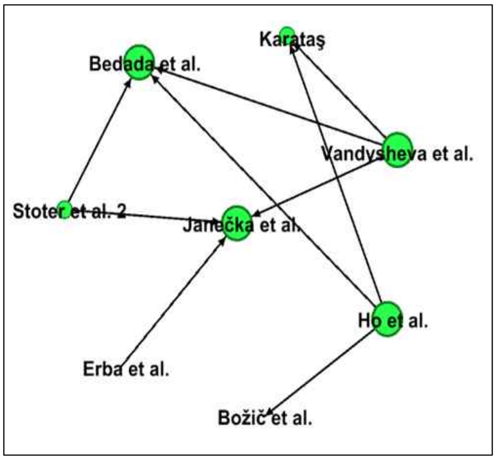
5.2.1 Community 0



〔Figure 2〕 Community 0

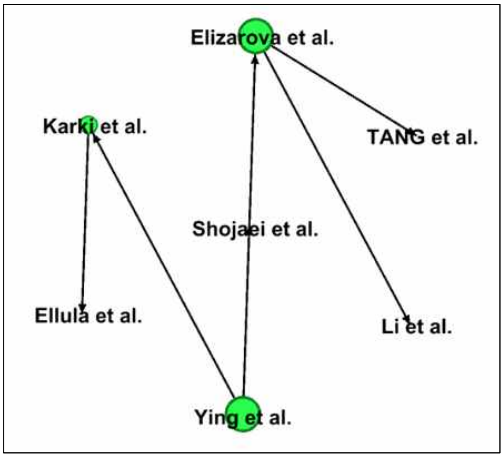
[Figure 2] shows the network structure of community 0 of the 3D cadastre citation network. As described above, community 0 is a sub-network that plays the most important role in the entire network. This community dominates the entire network in terms of influence. The core nodes of this community are Stoter et al. (2013), El-Mekawy et al. (2014), Shi et al. (2013). Researchers in this community are also focusing on the development of 3D cadastre models.

5.2.2 Community 1



〔Figure 3〕 Community 1

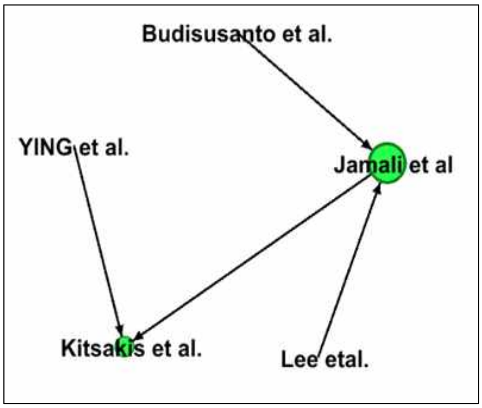
[Figure 3] shows the network structure of Community 1 in the 3D cadastre citation network. Community 1 is the second largest community in the entire network. The core node of this community is Ho et al. (2013). Since the out-degree centrality value of this node is higher than that of the other nodes, the influence of this node is the most considerable in the community. The results of this study show that researchers belonging to community 1 are interested in studying legal aspects and prototypes of 3D cadastre.



〔Figure 4〕 Community 2

[Figure 4] shows the network structure of Community 2 of the three-dimensional citation network. Community 2 is the third largest community in the entire network. The most central node in this community is Ying et al. (2012). The nodes of this community are closely related to 3D cadastre technology among the fields of 3D cadastre research. In particular, Ying et al. (2012) attempted to apply the 3D GIS technology to 3D cadastre in the urban environment in China.

5.2.3 Community 4



〔Figure 5〕 Community 4

[Figure 5] shows the network structure of community 4 of the cadastre citation network. Community 4 is a medium-sized community in the network. The key nodes of this community are Jamili et al. (2013). As can be seen in Figure 5, most of the key nodes in this community have a higher in-degree centrality value than the out-degree centrality value. This means that the critical nodes in this community are primarily affected, rather than affecting neighboring nodes. Scholars in this community are interested in applying LADM and GIS technology to 3D cadastre. The topic of this community is related to the technical aspects of 3D cadastre.

6. Discussion

6.1 Research Question 1

Nodes in a citation network are playing various roles. Some nodes exert overwhelming influence over neighboring nodes while others are unilaterally influenced by surrounding nodes. In this respect, the most influential node in the 3D cadastre citation network is Stoter et al. (2013). This node has an in-degree centrality value of 1 but an out-degree centrality value of 6. These unbalanced degree centrality values mean that this node is almost unilaterally affecting the surrounding nodes. However, we can not grasp the impact of any node on other nodes with only degree centrality value. Even if they are the same nodes, the nearest node can have a greater effect on other nodes than the far node. Thus, to understand the influence of one node on another, we also have to consider the distance between two nodes. Closeness centrality is a method of measuring the impact of a node on other nodes considering the distance between two nodes. The results show that ten nodes including Every et al. (2012) are prominent in terms of closeness centrality value.

Also, some node plays a broker's role between two other nodes in the 3D cadastre citation network. If there is no node acting as a broker, the flow of information between two other nodes is blocked. To find broker nodes in a network, we need to calculate the betweenness centrality value of all nodes. In the 3D cadastre citation network, the node with the largest betweenness centrality value is Jamili et al. (2013). The node is doing a good job of acting as an intermediary between other nodes. The eigenvector centrality value of a node is based on the centrality value of its neighboring nodes. That is, nodes are not necessarily influential because they are connected to neighboring nodes. The important thing is whether they are connected to the influential nodes. My results show that the node with the highest eigenvector centrality value in the 3D cadastre citation network is Hassan et al. (2012). This node plays an important role throughout the network because it is connected to the influential nodes such as Stoter et al. (2013).

6.2 Research Question 2

In general, a network consists of several sub-networks. Nodes belonging to the same sub-network are connected more densely to each other than to nodes belonging to other sub-networks and share various characteristics. A community is a set of nodes, or sub-networks, that have these common features and are densely connected to each other. These communities also exist in various forms in the 3D cadastre citation network. In citation networks, communities are formed around researchers with a common interest. Authors usually cite more articles from researchers belonging to the same community than those from researchers belonging to the different community. Scholars are forming academic partnerships through the establishment of such citation relations.

My results show that there are seven communities in the 3D cadastre citation network. The most influential community among the seven communities turns out to be community 0. This community is a community that accounts for more than a quarter of the total network and plays a key role in the entire network. Scholars belonging to this community maintain an academic partnership with each other on a common topic called 'the development of 3D cadastre model.' The researchers who play a key role in this community are Stoter et al. (2016). He seems to have a great influence on other scholars in this community. Community 1 and community 2 have also been identified as communities that play essential roles in the overall network. While researchers in Community 1 are interested in 'the legal aspects and prototypes of 3D cadastre', scholars in Community 2 have focused their attention on the study of '3D cadastre technology.' The results show that community 0, community 1, and community 2 are responsible for more than two-thirds of the total network, leading recent 3D cadastre research. However, Community 3 and Community 5 are identified as very small communities consisting of only two nodes, and their impact on the entire network may be minimal.

7. Conclusion

This study sought to detect the most influential nodes and communities in a 3D cadastre citation network. This article used such social network analysis metrics as degree centrality, betweenness centrality, closeness centrality and eigenvector centrality to identify the key nodes of the 3D cadastre citation network. In addition, this study employed the modularity based Louvain algorithm to detect the core communities of the whole network. The findings reveal that Stoter et al. (2013) is the best node in terms of degree centrality. And ten nodes including Every et al. (2012) have the highest closeness centrality value while Jamili et al. (2013) is the node with the highest betweenness centrality value. Hassan et al. (2012) is identified as the node connected to the most influential nodes in the network. That is, the most prominent nodes identified seem to differ depending on the type of centrality metrics used. So, the results of this study confirm that the nodes detected above play key roles in the 3D cadastre citation network, but they do not alway have high value in all centrality metrics.

To find out the answer to Research Question 2, this study has detected communities using the modularity-based Louvain algorithm. The results show that there are seven communities in the 3D cadastre citation network. The most influential community among these seven communities is identified as community 0, and the researchers in this community are mainly focusing on the development of 3D cadastre models. Community 1 and community 2 have also been revealed as sub-networks that play important roles in the 3D cadastre citation network. Researchers in these communities seem to focus on 3D cadastre technology and its legal aspects. These three communities account for more than two-thirds of the 3D cadastre citation network, so the findings of this study confirm that researchers in these communities are leading the latest 3D cadastre research.

This study can contribute to 3D cadastre research field in some respects. First, this research was the first attempt to apply citation network analysis techniques to 3D cadastre research. The use of citation network analysis allows researchers to detect the key papers and authors in 3D cadastre research easily. Identifying the key nodes in a citation network is a great help in predicting research trends in that discipline. Second, in this article I attempted to detect communities in a 3D cadastre citation network for the first time. In particular, the modularity based Louvain algorithm is used to identify various sub-networks existing in the 3D cadastre citation network. In a 3D cadastre citation network, communities are closely related to the sub-topics of 3D cadastre research field. Therefore, using Louvain algorithm makes it easy to see what is the most influential sub-topic in 3D cadastre field today. The research method used in this study can be fully utilized in the analysis of the citation network in other fields in the future. Especially, the Louvain algorithm used for community detection in the 3D cadastre citation network will be very useful in identifying community structures in other networks.

Despite its usefulness and practicability, this study has the following limitations. First, I could not grasp the citation relationships of the whole 3D cadastre research because I included only the research papers published in the last six years in my analysis. Second, I included only papers published in foreign countries and did not include papers published in Korea. Thus, I could not grasp the academic cooperative relationships among the authors in the 3D cadastre field in Korea. Finally, I used just degree centrality, closeness centrality, betweenness centrality, and the eigenvector centrality among the centrality metrics of social network analysis. That is, I did not utilize PageRank, which is very effective in identifying the most influential nodes in the network. If I had used the PageRank metric, I would have had completely different results. These limitations can be overcome if sufficient time is available in future studies and new social media analysis tools are used. So future research should analyze the citation network for the entire 3D cadastral research. In addition, future study should also attempt to analyze the citation network for the research articles in the cadastre field that have been published in Korea. Finally, future research should also use new analytical techniques such as PageRank to discover the most influential node in a citation network correctly.

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