UNIFIED GEOMETRY BREAKDOWN STRUCTURE (GBS) FOR BIM: VARIABLES FOR THEORY AND IMPLEMENTATION

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ABSTRACT

Recent proliferation of building information modeling (BIM) and computer integrated construction (CIC) has actively stimulated integrated utilization of geometric and non-geometric data. Nevertheless, physically and logically, linking and maintaining these two different types of data in an integrated manner requires enormous overhead efforts for practical implementation. Adapting the concept of project numbering systems (PNS) to geometric objects would significantly facilitate the manipulation of large number of geometric objects in a systematic and automated way. In order to address this important issue, this paper proposes a unified 'geometry breakdown structure (GBS)' with a PNS. The proposed breakdown and numbering system has secure rules for organizing geometric objects in full considerations of effectively integrating with non-geometric data.

Keywords: BIM, WBS, project numbering system (PNS), geometric object

1. INTRODUCTION

Recent advances in building information modeling (BIM) have actively disseminated the utilization of multi-dimensional (nD) CAD information in the construction industry. Under this nD-CAD environment, integrated utilization of geometric (graphic) and non-geometric (non-graphic) data is one of the key features (Jung and Joo 2011). Nevertheless, physically and logically, linking and maintaining these two different types of data in an integrated manner requires enormous overhead efforts for practical implementation. A good example is manually specifying tremendous numbers of interrelationship between 3D-CAD geometric objects and CPM scheduling activities. Adapting the concept of project numbering systems (PNS) to geometric objects would significantly facilitate the manipulation of large number of geometric objects in a systematic and automated way. However, considerations and requirements of formulating a PNS for multi-functional integration (e.g. geometric object, cost, schedule and others) are extremely complex due to the different perspectives by architects, cost engineers, schedulers, and others. In order to address this important issue, this paper proposes a unified 'geometry breakdown structure (GBS)' with a PNS. The proposed breakdown and numbering system has secure rules for organizing geometric objects in full considerations of effectively integrating with non-geometric data (e.g. cost and schedule). Thorough definitions of 'standard classification and numbering system (SCNS)' including GBS and PNS variables were developed first. A case-study was then introduced by using a housing project, which was actually built as part of this research project, in order to validate the practicability of proposed GBS and PNS. Finally, benefits, managerial requirements, practical implications, and other issues and needs for this integrated numbering system are briefly discussed.

2. STANDARD CLASSIFICATION AND NUMBERING SYSTEM (SCNS)

Developing and formulating project numbering systems (PNS) is one of the major tasks in the early stage of construction projects (MOLIT 2009). Even though the PNS is utilized for almost every single project, systematic methodologies have not been actively investigated in construction literature. A well-organized PNS not only facilitates effective construction project controls but also accumulates valuable project history in an automated way. For the purpose of utilizing this PNS concept in BIM applications, a comprehensive 'standard classification and numbering system (SCNS)' is proposed and defined first in this paper.

2.1 Project Numbering Systems (PNS) in Construction

For the purpose of systematic communication and integration of project information, a project numbering system (PNS) prescribes standard procedures and methods to number all different types of data and documents within a project or within an organization. Every single document, drawing, specification, equipment, schedule activity, cost item, or inspection needs to be assigned with a unique number so that each can be clearly identified. Due to the complexity of project information, a construction PNS normally requires two basic components; a standard classification and a sequencing structure. As an example, a schedule activity of concrete work (C0300) for a footing (E0100) can be numbered as C0300-E0100. In this simple example, C0300 is a standard classification number for concrete 'commodity (work section)' whereas E0100 is the standard number of footing 'element'. It is noteworthy that this example has set a standard numbering sequence for schedule activities. Namely, the first five digits for commodity number and the last five digits for element number are assigned as a fixed sequence.

For cost management, similar rules are applied to sequence hundreds or thousands of work items by using cost breakdown structure (CBS). Even for relatively less structured data, for example, risk management items, a strict numbering system known as risk breakdown structure (RBS) is often used in practice. Among these different numbering systems, the most frequently used one in BIM research is the work breakdown structure (WBS) to integrate three-dimensional geometric objects with non-geometric schedule activities for 4D-CAD applications. Nevertheless, it is difficult to clearly define the structure and function of PNS including WBS and CBS, because there has been no literature addressing comprehensive meaning of PNS in construction. In this sense, this paper defines a hierarchical structure of 'standard classifications and numbering system (SCNS)' for the construction industry.

2.2 Standards for Classification and Numbering

In order to develop a geometry breakdown structure (GBS) with unified capacity for integrating many different construction business functions, a comprehensive SCNS structure and its components are proposed first as listed in Table 1. An SCNS in this paper has two major parts.

The first part is standard classifications (CLN in Table 1) that categorize relevant items and specify a unique number to each item. Examples of CLN include MasterFormat (2012), Uniclass (1997), and OmniClass (2006). Each master list has somewhat different structure, however, all of them basically follows the international framework set out by ISO TR 14177 (ISO 1994) which was later established as ISO 12006-2. ISO (1994) standard for classifications of construction information defines eight facets, including "facilities, spaces, elements, work sections, construction products, construction aids, management, and attributes". The standard classifications (CLN) in this paper also follow ISO eight facets, however, the ISO facet of "construction product" is named as 'construction materials and assemblies' (CLM in Table 1), instead of "construction products" in order to comprehend architectural, residential, civil, and industrial construction projects. For example, a standard table of CLM facet can list all different materials and equipment (e.g. concrete, tiles, pipe, vessels, and pumps). It is always an effective approach to adapt global standards as much as possible in order to have better interoperability as well as in order to minimize the required efforts in developing long lists. The second part of SCNS is project numbering systems (PNS). Though single numbering system (e.g. WBS) can be utilized universally for many different construction business functions (e.g. cost, schedule, materials, etc.) within a project, it is extremely difficult to satisfy complex managerial requirements. This paper lists eleven different breakdown structures as shown in Table 1.

Table 1: Components of Standard Classification and Numbering System (SCNS)

Level I	Level II	Level III	Remarks
Standard Classification and Numbering System (SCNS)	Standard Classifications **(CLN)** *	(CLF) Facility Facet	e.g. Building, Airport
		(CLS) Space Facet	e.g. Office, Bed room
		(CLE) Element Facet	e.g. Column, Beam
		(CLW) Work Section Facet	e.g. Steel structure, Piping
		(CLM) Construction Material & Assembly Facet	e.g. Vessel, Re-bar, Concrete
		(CLA) Construction Aid Facet	e.g. Wood form, Crane
		(CLG) Management Facet	e.g. Scheduling, Contracting
		(CLP) Attribute and Property Facet	e.g. Heat transmission
	Project Numbering Systems **(PNS)**	***(GBS) Geometry Breakdown Structure***	Multi-facet for 3D design
		(WBS) Work Breakdown Structure	Multi-facet for scheduling
		(CBS) Cost Breakdown Structure	Multi-facet for cost control
		(EBS) Equipment Breakdown Structure	Multi-facet for procurement
		(OBS) Organization Breakdown Structure	Multi-facet for participants
		(RBS) Risk Breakdown Structure	Multi-facet for risk
		(MBS) Measurement Method Breakdown Structure	Multi-facet for estimating
		(SBS) Specifications Breakdown Structure	Multi-facet for specs
		(DBS) Drawing Breakdown Structure	Multi-facet for drawings
		(PBS) Physical Breakdown Structure	Single facet numbering
		(FBS) Functional Breakdown Structure	Single facet numbering

* Eight facets defined by ISO (1994)

3. GBS CASE-STUDY WITHIN PROPOSED SCNS CONCEPT

The objective of this paper is to applying the concept of PNS to BIM geometric objects. In order to effectively illustrate the proposed concept of GBS its applications under SCNS, an industrialized housing project is used as a case-project.

3.1 Case-Project: Modernized Korean Traditional Housing (Hanok)

A comprehensive research effort to develop and disseminate modernized Korean housing (Hanok) has recently been initiated by Korean government. This large scale research project encompasses a wide spectrum of housing development including public policy, architectural plans, modules, construction materials and methods, prefabricated assemblies, automated production, construction management, and advanced information systems. Major objectives of this research include 1) inheriting Korean traditional style in modernized housing, 2) achieving high energy performance throughout entire project life cycle, and 3) reducing construction cost by 40% comparing to traditional building materials and methods.

Based on three major research objectives, researchers in charge of developing building materials, building methods, project management techniques, and information systems have closely worked together. More construction-specific objectives are also formulated by this group; including construction duration within 120 days, construction cost under 1,800 dollars per square meter, and over 45 % pre-fabricated materials of total construction cost. In order to meet these objectives, complete industry-level standards must be developed for unspecified architects, engineers, contractors, even home owners to easily use for everyday business.

For the purpose of integrating and automating the whole processes from this industry perspective of modernized Hanok, it is of great importance to develop a standard classification system and project numbering system (PNS) for the modernized design, construction, maintenance as well as materials supply.

3.2 SCNS for Case-Project (HanClass)

Information systems developed in this project include 3D-library, automated preliminary design, structural analysis, automated CAM for wood members, standard cost data, standard estimates, standard schedule, 4D-simulation and other. Many researchers from different discipline areas have developed Hanok applications. Therefore, a thorough mechanism for delivering interoperable data throughout project life cycle is needed. In order to meet this need, a SCNS for Hanok (named as 'HanClass') was developed.

The distinct characteristics and managerial requirements were explored and embedded into the proposed HanClass. Considerations and requirements of formulating CLN and PNS of one single type of facility (industrialized traditional housing) for multi-functional integration (e.g. geometric object, drawings, specifications, estimating, cost, schedule and many others) for unspecified users (architects, cost engineers, schedulers, or others) are developed.

Adapting existing standards including several Korean standard classifications, Uniclass, and MasterFormat were evaluated first. It was concluded that existing standards cannot fully describe distinct components of traditional housing. Therefore, the MasterFormat and UniFormat were partially used for HanClass. Finally, four standard classifications (CLN) of 'facility (CLF)', 'space (CLS)', 'element (CLE)', and 'work section (CLW)' were developed for HanClass. For the PNS part of HanClass, GBS, WBS, CBS, MBS, SBS, DBS have also been developed or under development as listed in Table 2. These complex numbers of HanClass were embedded into 3D-CAD, excel sheet, CPM schedules, and many other applications developed for Hanok. Therefore, unspecified users can utilize these applications without knowing the complex numbering system behind the screen, and also they can better utilize these systems by manipulating the HanClass numbers with minimum training.

Figure 1: Hanok Mockup Site at Myongji University in Korea

Table 2: Component and Example of HanClass

SCNS	Components	Number of items*	Example of list / PNS sequence	Remarks
HanClass **CLN**	HanClass_CLF	4	**1:** Main building	
	HanClass_CLS	7	**L10:** First floor	
	HanClass_CLE01	6	**B:** Structure	UniFormat if available (1st digit)
	HanClass_CLE02	35	**B1010.1:** Wood structure	UniFormat if available (5 digit)
	HanClass_CLE03	49	**B1010255:** Column	UniFormat if available (8 digit)
	HanClass_CLE04	120	**B1010255.01:** Wood column <180mm	
	HanClass_CLW01	15	**C06:** Wood works	
	HanClass_CLW02	50	**C0610:** Wood framing	
	HanClass_CLW03	231	**061113.11:** Glulam column < 180 mm	MasterFormat if available (6 digit)
HanClass **PNS**	HanClass_GBS	6390	***CLF-CLS- CLE02-CLE04***	No. of geometric objects
	HanClass_WBS	56	*CLF-CLS-CLW02*	No. of CPM activities
	HanClass_CBS	183	*CLF-CLS-CLW01-CLW03*	No. of cost items
	HanClass_MBS	291	*CLW03-Serial*	No. of SMM
	HanClass_SBS	-	*Under development*	No. of spec chapters
	HanClass_DBS	-	*Under development*	No. of drawings

* Number of items for CLN is the line number of standard lists, and the number of items for PNS is the case of fist mock-up project.

Table 2 shows the list of CLN and PNS for HanClass. The list of items for CLF, CLS, CLE, and CLW will be published as a public guideline for Hanok construction. Because current Hanok is a single family home, number of items is quite limited, for example, 231 work items are listed at this moment. HanClass has tried to use MasterFormat and UniFormat numbers whenever an item is appropriate to be represented by them in order to secure international interoperability.

4. GBS NUMBERING AND VARIABLES

Based on the HanClass CLN and PNS, the concept of GBS was applied to Hanok mock-up construction projects. The first mockup project was built in the campus of Myongji University in South Korea in 2012. Now the second mockup site is under construction in Seoul, Korea.

As shown in Table 2, the sequence of HanClass_WBS is in the order of CLF, CLS, CLE02, CLE04, where 1, 3, 6, 10 digits are used respectively. For example, in this case-project, a family of geometric objects for fist floor glulam columns (180 by 180 mm) is encoded as 1L10B10101B101025501. The first digit with number 1 is CLF code for ‘main building’ as shown in Table 2. Next three digits of L10 are the CLS code for the ‘first floor’. Following six digits of B10101 are for ‘wood structure’ (CLE02), and last ten digits of B101025501 represent ‘180 by 180 glulam columns’. This family has several columns with the exactly same size and materials. Thus, twenty digit GBS number was assigned to each of this family, and each lowest level geometric object within the same family were then assigned with GBS number plus a serial number. There were 120 families and 6,390 objects in the first mockup project.

It looks like that just GBS number assignment would take a lot of efforts. However, it was only required to number 120 geometric objects for an entire housing project. Of course, those GBS numbers were already embedded into Hanok 3D library, which means users do not need to concern about the GBS numbers. After assigning 120 GBS numbers, 6,390 geometric objects are automatically numbered by adding a serial number to the GBS. Again, there is no burden for unspecified users to number or manipulate GBS numbers. Even for system developers, embedded GBS in the 3D-CAD library can be easily used for further automated extensions of code numbers.

The sequence of GBS number shown in Table 2 was designed after thorough simulations and analyses of integration with other business functions including cost and time. In the GBS sequence of CLF-CLS- CLE02-CLE04, the CLE04 gives a connecting mechanism to cost (CBS) and schedule (WBS). In other words, once a standard mapping is defined, the connection between GBS and CBS/WBS are performed automatically.

The proposed method of assigning GBS to each geometric object is a new approach to handle BIM integration. Previous researches (Chau et al. 2005; Ding et al. 2012) also tried to interconnect the geometric and non-geometric data by using WBS and CBS. However, their approach had secure numbers in WBS and CBS only, focusing on numbering non-geometric data. In this sense, the GBS in this study is a novel method as it defines identification numbers in geometric objects. Korean patent (0-2013-0003321) and United State patent (13/830,705) are pending by Myongji University for this method.

By using embedded GBS in 3D-CAD and embedded WBS in CPM schedule, 4D-CAD representations can be performed in an automated way. Because the HanClass system has a pre-defined mapping matrix for general Hanok construction, users for different plan types do not need to link each geometric object to schedule activities. No additional efforts required even after revisions of either 3D-CAD or WBS. This feature is this study's one of main contributions, because users have to manually redefine the interrelationships of 4D-CAD in current practice.

The proposed mechanism of automated linking in BIM can be also used for many different applications in SCNS. For example, this case-project has utilized automated linkage between WBS and CBS by the same method. This integration is in between non-geometric entities, however, integration between WBS and CBS can facilitate 5D-CAD applications in an automated way as well.

5. DISCUSSIONS AND CONCLUSIONS

Active use of BIM in practice will need better integration with project management information systems (PMIS). Another important issue is the overhead efforts required to connect and maintain this integration between BIM and PMIS. This study proposed a comprehensive 'standard classification and numbering system' (SCNS) both for BIM and PMIS first. In order to facilitate this integration, a concept of unified 'geometry breakdown structure' (GBS) was then developed. The result from a case-study of GBS applications under SCNS shows that an automated integration can be achieved with minimal efforts. The pre-defined and pre-embedded use of GBS numbers would enhance BIM interoperability in many ways.

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