A Survey of Column-leaning in Korean Traditional Wooden Architecture Structures Using 3D scandata

With a Focus on the Columns of the Sungryeoljeon in Namhansanseong

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***Abstract*—Colum-leaning in Korean traditional wooden heritage structures has been emphasized in various reports since the first survey report from the 1950s. Recent technological advancements have granted researchers to use 3D scandata to examine column-leaning. This paper discusses the methods of measuring and representing column-leaning in the Soongryeoljeon in Namhansanseong – a UNESCO designated World Heritage site – using 3D scandata.**

***Index Terms*—Column-leaning, 3D scandata, Korean traditional wooden architecture, Sungryeoljeon in Namhansanseong, survey drawings**

I. Introduction

Lumber is the main building material for Korean traditional wooden architectural structures. Due to the characteristics of wood, the structures of architecture change over a period of time. This change refers to natural changes over a course of time, not man-made artificial changes such as those as a result of dismantlement or maintenance. The changes in structures are driven by a variety of forces, including the innate properties of wood, joining of wood elements, and purpose of the building. The degree of changes is also various, from minute changes that are difficult to perceive to significant column leaning that affect the entire structure. Moreover, it is difficult to pinpoint the exact cause of the change most of the time.

Since the first survey on wooden architectural heritage structures in the 1950s, researchers have consistently investigated and tracked the changes in wooden components in traditional wooden architecture. The significance of changes in wooden elements was especially highlighted in survey measurements, and changes in several wooden elements (e.g., columns, beams and cross beams) were studied. However, the large survey errors associated with the existing measurement methods using tape measures, plumb line and water levels hampered the examination of minute changes in wooden materials, only allowing researchers to record large changes.

It was only in the recent years when researchers began surveying wooden architectural heritage structures and wooden elements using three-dimensional (3D) scandata. The use of 3D scandata granted a more accurate examination of changes in wooden materials. Unlikely plumb-lines or total stations, 3D scanners can obtain multiple points automatically in a short period of time. One advantage of using 3D scandata is that exact measurements of the location, shape and size can be collected for all parts of an architectural shape.

With a more in-depth survey of the changes in wooden elements, the authors of the present study expected to provide a deeper understanding of Korean traditional wooden structures. And this study offers valuable insight into the wooden structure stability review, preservation and maintenance processes pertaining to these prized traditional heritage structures.

The objective of this study is to identify the methods of detecting changes of wooden elements with 3D scandata by inspecting the leaning columns of wooden architectural heritage structures. The authors discuss the features of such survey methods as well as the characteristics of leaning columns of Sungryeoljeon.

II. Research subjects

The study primarily examined column-leaning in a building called Sungryeoljeon located in Namhansanseong – a UNESCO designated World Heritage site. The reason behind this selection was that the preservation and maintenance of the Sungryeoljeon, a part of Namhansanseong, also became an important issue after Namhansanseong was designated as a UNESCO World Heritage site.

Because the range of changes in wooden elements is too vast, column-leaning, which was one of the changes that were vigorously studied in previous surveys, was specifically chosen for examination.

Soongryeoljeon is located in the northeastern section of Namhansanseong. It is a shrine built in the 16th year of King Injo of Chosun (1638). This shrine is dedicated to King Onjo of Baekje dynasty (reign BC18~AD28). But the ancestral tablet of Yiseo (1580~1637), the director in charge of the construction of Namahansanseong, is also kept here. As a result, Soongryeoljeon is especially deemed significant among all structures in Namhansanseong.

The Soonryeoljeon is 8.2 m X 5.83 m. There are a total of twelve columns, with four placed in the front and three in the

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sides in lattice grids. The present study specifically examines leaning of these twelve columns in Soongryeoljeon.

Fig. 1. A layout of the Soonryeoljeon in Namhansanseong

Fig 2. A front view

Fig 3. A side view

III. RESEARCH METHODS

A. Equipment and Programs Used

1) Equipment and programs used

The Faro Focus 3D was used. This is a long-range scanner using phase shift methods. The Faro Scene Ver 5.0 was used for post-processing of 3D scandata to increase the conformity to the scanner. The Autocad 2008, a graphic design program, was used to prepare the drawings.

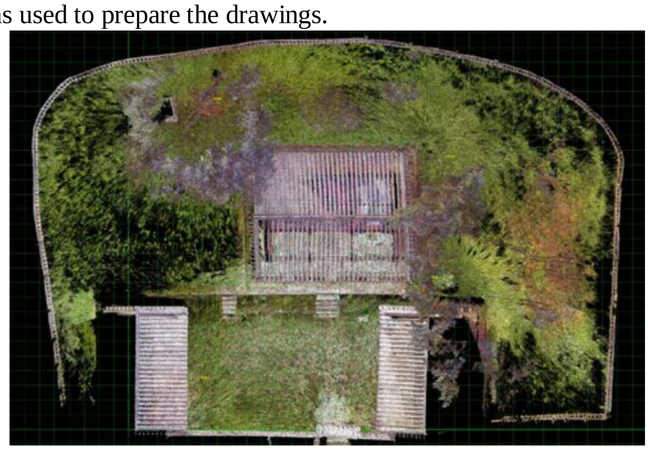

Fig 4. Layout(3D scandata)

B. Survey Methods

① Setting reference points for measurement: Place three reference points near Soongryeoljeon as unmovable points. Reference points are required because the long-range scanner must be moved to various points in order to scan Soongryeoljeon. Hence, the reference points were set in areas observable from the various long-range scanner positions.

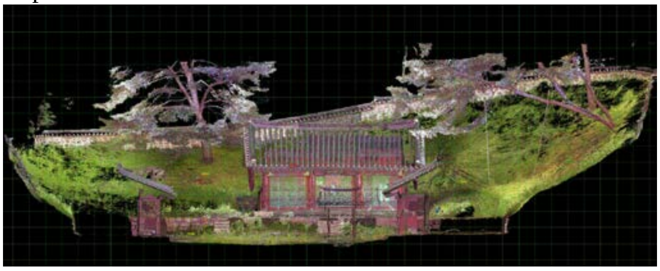

Fig 5. Front view(3D scandata)

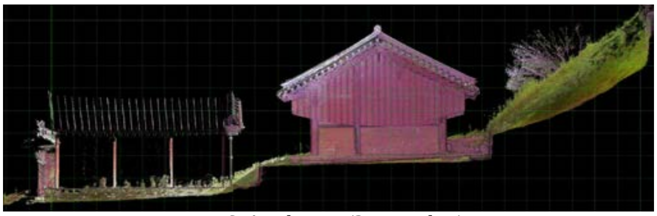

Fig 6. A side view(3D scandata)

Fig 7. A cut view(3D scandata)

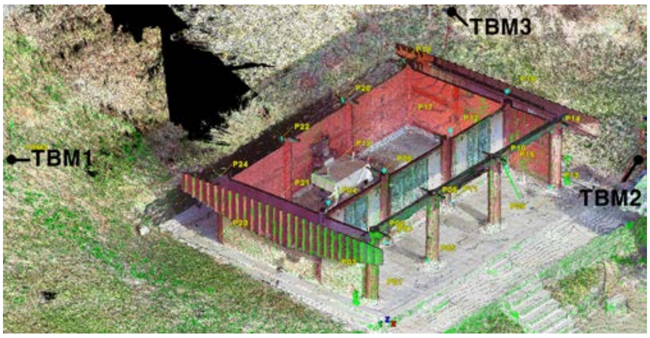

Fig 8. Measurement reference points

TABLE I. MEASUREMENT REFERENCE POINTS(UNIT:M)

	X	Y	Z
TBM1	100.0000	100.0000	400.0000
TBM2	101.0331	108.2751	401.5619
TBM3	85.2311	112.1418	402.0417

② Scanning: Scan the reference points and the Soongryeoljeon using the long-range scanner. Place the scanner inside and near the Soonryeoljeon structure to obtain multiple scandata.

③ Post-processing of the data: Register each scandatum in the post-processing program; align and merge the data to compile the multiple scandata into one combined data set.

④ Review the combined data and eliminate unnecessary data that are irrelevant to the Soongryeoljeon.

⑤ Prepare a snap shot of the regulated data: In the post-processing program, manipulate the view of the scandata to find the most effective view that reveals the column-leaning of Soongryeoljeon. Slice the manipulated data and show it on the screen. Capture a screenshot of the entire screen and create an image. Make a snap shot of the lower plane and the upper plane of the column. The snap shots must include the reference points. The snap shots were shown with grids in 1m intervals to show the sizes.

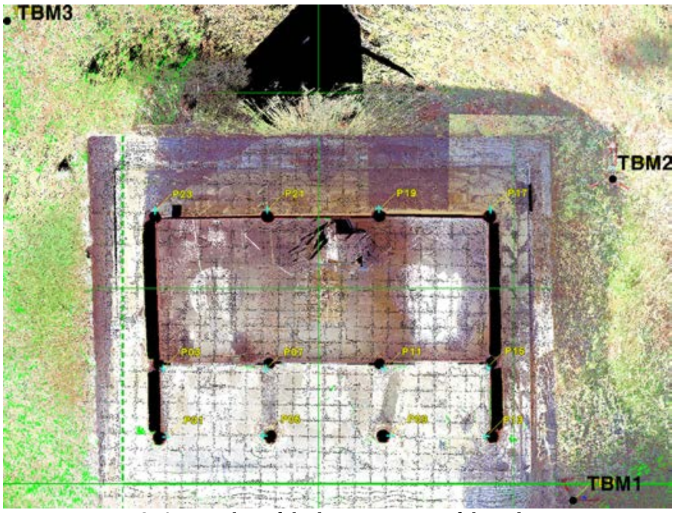

Fig 9. A snap shot of the lower sections of the columns

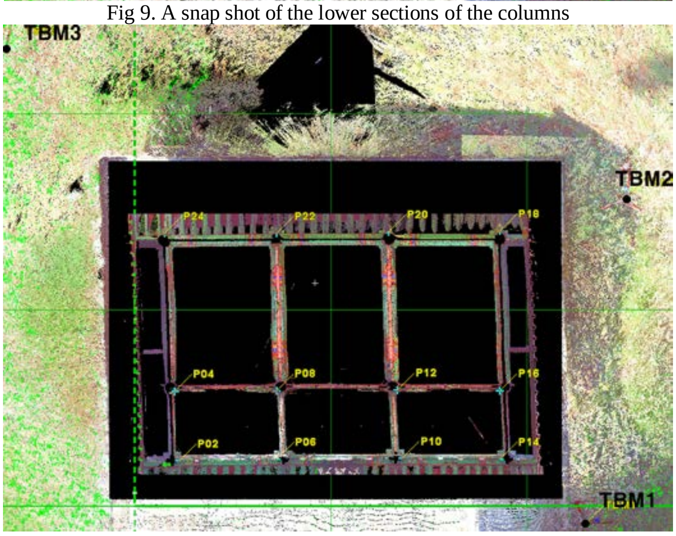

Fig 10. A snap shot of the upper sections of the columns

⑥ Inserting the snap shots into a graphic program: Insert the snap shots of the upper and lower sections of the columns into the autocad. Resize the snap shots to scale with reference to the grids shown; then the two snap shots will be in the same scale. Align the reference points of the two snap shots; this will correctly overlap the lower and upper cross sections.

⑦ Preparing the drawing: In the overlapped snap shots, draw a line along the cross section of the lower column and another line along the upper cross section. Draw a line to connect the center points of the upper and lower cross section lines (Fig 11).

⑧ Measuring column leaning: The line that is connecting the upper and lower cross section lines represents the size of the column leaning. The direction of the line represents the direction towards which the columns are leaning (Fig 12).

C. Special notes

① Using the snap shots: When the architectural heritage structure is 3D scanned, too many sets of 3D scandata are obtained so the volume of file becomes too big. This makes it difficult to insert them directly into a graphic program to prepare a drawing. Thus, in Korea, researchers usually create an image file in a commonly used post-processing program via the print screen option; then the image file (snapshot) is inserted in a graphic program to prepare a drawing.

② Represent column-leaning in 2D on autocad: Drawings are prepared in two-dimension (2D) even with 3D scandata because existing survey drawings are done in 2D.

IV. Results and Analysis

A. Individual column-leaning

TABLE II. Individual Column Leaning (unit:m)

Number	Location	Point	X	Y	Z	XY length
No.1	Lower	P01	89.6030	101.6622	400.0959	
	Upper	P02	89.6389	101.6137	402.1053	
	Leaning		**0.0359**	**(0.0485)**	**2.0094**	**0.0604**
No.2	Lower	P01	89.5322	103.4094	400.1407	
	Upper	P02	89.5318	103.3854	402.6389	
	Leaning		**(0.0004)**	**(0.0240)**	**2.4982**	**0.0240**
No.3	Lower	P01	92.0862	101.6848	400.1310	
	Upper	P02	92.1298	101.6553	402.1378	
	Leaning		**0.0436**	**(0.0295)**	**2.0068**	**0.0527**
No.4	Lower	P01	92.1559	103.4010	400.1058	
	Upper	P02	92.1303	103.3993	402.5776	
	Leaning		**(0.0256)**	**(0.0016)**	**2.4718**	**0.0257**
No.5	Lower	P01	95.3320	101.6891	400.1409	
	Upper	P02	95.3253	101.6781	402.1395	
	Leaning		**(0.0067)**	**(0.0110)**	**1.9986**	**0.0129**
No.6	Lower	P01	95.1809	103.4125	400.1583	
	Upper	P02	95.2012	103.4148	402.5965	
	Leaning		**0.0203**	**0.0023**	**2.4382**	**0.0204**
No.7	Lower	P01	97.7769	101.6631	400.1297	
	Upper	P02	97.8267	101.6588	402.0582	
	Leaning		**0.0498**	**(0.0043)**	**1.9285**	**0.0500**
No.8	Lower	P01	97.8195	103.4255	400.1653	

	Upper	P02	97.8209	103.4002	402.7839	
	Leaning		**0.0014**	**(0.0253)**	**2.6186**	**0.0253**
No.9	Lower	P01	97.9029	107.4591	400.2443	
	Upper	P02	97.8115	107.4364	402.2786	
	Leaning		**(0.0914)**	**(0.0227)**	**2.0342**	**0.0941**
No.10	Lower	P01	95.0533	107.4814	400.2803	
	Upper	P02	94.9837	107.4528	402.2287	
	Leaning		**(0.0695)**	**(0.0285)**	**1.9483**	**0.0752**
No.11	Lower	P01	92.1975	107.4732	400.1918	
	Upper	P02	92.1233	107.4277	402.1894	
	Leaning		**(0.0742)**	**(0.0456)**	**1.9976**	**0.0871**
No.12	Lower	P01	89.3213	107.4630	400.0852	
	Upper	P02	89.2802	107.4403	402.1396	
	Leaning		**(0.0411)**	**(0.0227)**	**2.0544**	**0.0470**
* Direction: + for north-east and ( ) for south-west * Unit: m						

B. Size (Intensity) of column-leaning

There are twelve columns in Soongryeoljeon, and the size of the leaning is different for each column. Hence, we compared the sizes of leaning of each column. The smallest value was 0.0129 m and the largest value was 0.0941 m.

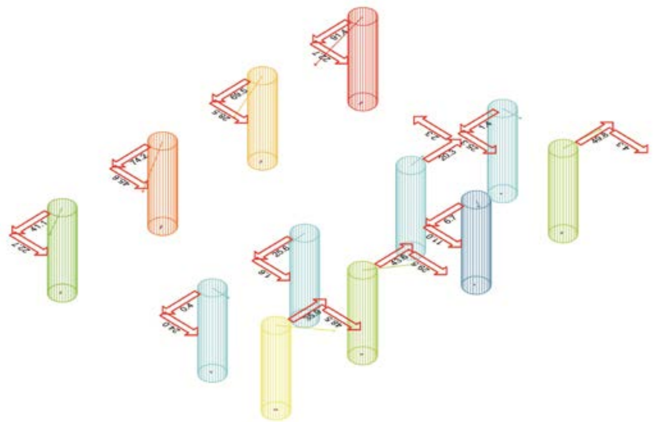

Fig 11. The size and direction of column leaning 1
<Sizes of vertical and horizontal displacements (Unit: mm)>

C. Direction of Column-leaning

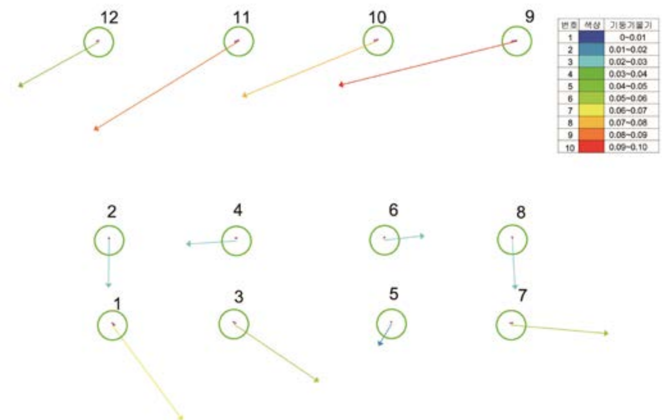

Fig 12. The direction of column-leaning 2(Unit: m)
<The sizes of vertical and horizontal displacements are proportional>

Each column leaned toward different directions. We compared the directions toward columns lean.

D. Analysis of the direction and intensity of column-leaning

Overall, the upper sections of external columns seem to be rotated counterclockwise. It was found that the entire Soonryeoljeon structure was rotated counterclockwise.

① Only the column 5 and column 8 among all external columns are leaning in opposite directions. The change, however, is relatively small.

② In terms of internal columns, the upper sections of the columns seem to widen. This is presumed to be a result of the rotation of the entire structure.

③ The intensity of leaning was the largest in the column 9 with 9.4 cm. Compared to the height of the column, it is leaning about 5%.

The rear column is leaning considerably; careful examinations are demanded.

E. Displacement measurement using 3D scanner

The substructures within the overall wooden architectural heritage structure are not permanent: over time, they are bound to be displaced and undergo change. Thus far, these induced changes have rarely been studied. Again, 3D scandata are precise measurements of each section of the structure; thus, reacquiring 3D scandata after a certain period of time would allow surveyors to compare two period-specific data sets and trace the changes in the shape of location of the structure.

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