Column-leaning Displacement of Korean Traditional Wooden Architecture: 3D Scanning Data of Columns of Sungryeoljeon in Namhansanseong

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Abstract
Column leaning in Korean traditional wooden heritage structures has been emphasized in various reports since the first survey report in the 1950s, which established the importance of its measurement. Manual measurements have been carried out for a long time; however, recently, three-dimensional (3D) scanning has been used to obtain accurate data. Through periodic surveys of column leaning using 3D scanning, column displacement can be measured accurately.

This study aims to measure the column leaning in Sungryeoljeon at Namhansanseong, a World Heritage Site, using 3D scanning, and then determine its displacement through a periodic survey. Such displacement in column leaning may reveal the characteristics of wooden architecture.

The 12 columns of Sungryeoljeon are displaced in different directions. Generally, they lean toward the south and rotate clockwise. Column displacement does not occur so quickly in certain directions. Nonetheless, the aspects of column leaning that are already in progress need to be observed carefully.

Keywords: column-leaning displacement; 3D scanning; Korean traditional wooden architecture; Sungryeoljeon in Namhansanseong; periodic survey

1. Introduction
Lumber is the main building material for traditional Korean wooden architectural structures. Given the characteristics of wood, such structures change over time. This change refers to natural changes over the course of time, not human-made changes, such as the result of dismantlement or maintenance. 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 such changes also varies, from minute ones that are difficult to perceive to significant column leaning that affects the entire structure. Moreover, the exact cause of change tends to be difficult to pinpoint.

Since the first survey on wooden architectural heritage structures in the 1950s, researchers have continuously tracked changes in wooden components of traditional wooden architecture. The significance of changes in the wooden elements was, especially, highlighted in survey measurements. In addition, changes in several wooden elements (e.g., columns, beams, and cross beams) were studied. However, existing measurement methods, using tape measure, plumb line, and water levels, yield large survey errors that hamper the examination of minute changes in wooden materials. Moreover, such survey measurements are mostly conducted only during repair or restoration work. Periodic survey on wooden architecture is not being carried out. Therefore, the natural displacement of wooden materials that can be examined only by periodic survey could not be studied, and periodic records are unavailable.

Research concerning general 3D scanning has been widely conducted. But, researchers began surveying wooden architectural heritage structures and wooden elements using 3D scanning only recently. It can be said that there is almost no research that attempts to utilize the 3D scanner subject to traditional wooden architectural heritage structures of Korea.

The four studies conducted by Dai Whan An include research related to the recordings of 3D scan data and studies about the characteristics of 3D scan data. Moreover, research was conducted on the comparison of survey measurements of manual work and 3D scanned data.

The research by Dae Sung Park demonstrated the closest proximity to this research in which he
conducted repair works on three wooden architectural structures as a part of the research for regular inspection of wooden and stone architectural heritage structures and recorded the changes after conducting 3D scanning again 6 months later. Hence, he calculated the changes until the wooden materials stabilized after the repair in numerical values. But this paper deals with natural changes over the course of time.

Scan data have enabled a more accurate examination of changes in wooden materials. Unlike plumb lines or total stations, 3D scanners can obtain multiple points automatically and quickly. One particular advantage is that exact and convenient measurements of the location, shape, and size for all parts of an architectural shape can be collected.

3D scanning is not only precise but also convenient to use, and will enable periodic survey. Accordingly, the displacement of wooden buildings can be examined. In using periodically obtained 3D scan data, this study aims to identify changes in wooden materials by investigating the column-leaning of traditional wooden architecture. The findings may contribute to discussions on the characteristics of periodic changes in Korean traditional wooden architecture. This in-depth survey would also shed better light on Korean traditional wooden structures, including valuable insight into the stability review, preservation, and maintenance of these prized traditional heritage structures.

2. Characteristics of the 3D Scan and Research on Column-leaning

2.1 Characteristics of the 3D Scan

This chapter deals with the general and universal characteristics and utilization of 3D scan data and the merit of 3D scan data in the field of architectural heritage.

The point density is determined within a certain range by using a 3D scanner, and a laser is beamed to the target object to measure the laser reflected from the surface of a target object to obtain data regarding the location coordinate of a point on the surface of an object. Such data are called 3D scan data or point cloud where points gather to establish a 3D spatial coordinate on the form of a target object. These points do not have the size, but only location coordinates. The size of 3D scan data is determined depending on the number of points. The file of 3D scan data tends to be high-volume although it can vary according to the point density.

Typically, a dedicated program is used to check out the scan data obtained by the 3D scanner on the computer. A process of pasting several cuts of data obtained in the field based on this program and completing them as one data is performed. Subsequently, noise removal is conducted to eliminate unnecessary parts. Through this procedure, the data is formed as a complete point cloud. Then, a mapping task of overlapping 2D photo data with the 3D scan data is carried out to establish the 3D scan data that show the most similar colors to those of the original building.

So 3D scan data have more accuracy and no intentionality compared to the other methods of representation because of the density of point cloud. In addition, it utilizes 3D and digital data to a high degree.

Through the processes mentioned above, the data, including the 3D form and location information of architectural heritage, are obtained using the computer as shown in Figs. 5 to 11.

The following is a comparison between the advantages and disadvantages of 3D scanning, based on the characteristics mentioned above, and the prior manual surveying method.

1) 3D scanning is useful in tracking the pattern of change because it makes the entire scanned figuration into points. Whereas in the prior manual surveying method, the overall pattern of change was hard to determine because each point had to be confirmed one at a time individually. The prior manual surveying method is useful in that data can be obtained just for the specific desired positions.

2) The advantage of 3D scanning is that when needed, changes in other points can be confirmed as well because it investigates the entire figuration. With the prior manual surveying method, changes in areas other than the measured points cannot be determined.

3) Compared to the prior manual surveying method, 3D scanning is significantly more accurate. It is inevitable that the prior manual surveying method of manually taking measurements, such as using rulers and strings, has relatively higher errors.

4) The prior manual surveying method is in the form of 2D image. Whereas, the 3D scan data is a three-dimensional method displayed on the computer monitor, making itself closer to reality. Therefore, it can’t be helped that it is the more useful method in examining actual changes.

5) The 3D scan data cannot be used generally or smoothly due to the high price of equipment for scanning, difficulty in operating the programs, and the large size of data. Therefore, it has elements that make it difficult to use at the site of repair work. If the aim of field measurement is to quickly obtain results within a short amount of time on site such as repair work, then the prior manual survey method may be more efficient.

6) An investigation using 3D scanning takes the method of only obtaining data on site and later conducting the investigation on displacement and other aspects. The result may lead to misunderstandings about the architectural structures. However, the prior manual surveying method conducts most of the investigation work on site, which holds an advantage of being able to easily discover the errors in field measurements.

7) 3D scanning holds a disadvantage in that it cannot obtain data from places that are covered or where a laser cannot reach . The prior manual surveying method has an advantage in that it allows direct
measurement of places that are covered or where lasers cannot reach since it involves using visuals, hands, and rulers, etc. Both the investigation methods, prior manual surveying and 3D scanning have their own advantages and disadvantages. Therefore, they are both greatly used accordingly to serve different needs.

2.2 Research on Column Leaning

The columns may be tilted due to changes in the structure itself such as imbalance and subsidence of the cornerstones or external forces such as snow and rain. In addition whatever the reason is, it has been proved that the leaning of the columns of Korean traditional wooden architectural structures may change. However up until now, the goal of research has been to repair the columns that have been clearly identified to have already tilted. The research ceased once the results about the degree of tilt of the columns had been confirmed.

First, it was difficult to confirm the change in pattern since the prior manual surveying method was low in accuracy. Second, the changes in the columns were not calculated regularly. Therefore, the tendency to which direction the tilt was leaning towards was unable to be verified.

Since the direction of the tilt could not be identified, the cause for leaning of the columns could not be discovered. Therefore, it seems that if 3D scanning, which has much higher accuracy than the prior manual surveying method, is used to make regular investigations, the tendency of the leaning columns may be identified. Moreover it is expected that if such data accumulate for a long time, the cause for leaning of the columns, whether it is due to external forces, internal structural problems, or deterioration of the columns themselves, may be identified.

Therefore, due to this reason, the research focused on identifying the tendency of leaning columns through 3D scanning and the methods to do so. If such data are gathered, they can be used as foundational information in identifying the cause of the slanting of columns. Furthermore, it is believed that this kind of method may be applied to not only columns but other wooden parts as well to efficiently maintain cultural assets.

3. Research Subjects

The study examines column leaning in Sungryeoljeon, a building at the Namhansanseong UNESCO World Heritage Site. Sungryeoljeon was selected after its preservation and maintenance became an important issue after Namhansanseong was designated in 2014.

Located in Namhansanseong's northeastern section (Figs.1. and 2.), Soongryeoljeon is a shrine built in the 16th year of King Injo of Chosun (1638) dedicated to King Onjo of Baekje (reign: 18 BC–28 AD). The ancestral tablet of Yiseo (1580–1637), the director in charge of the shrine's construction, is also kept here. Thus, Soongryeoljeon is deemed especially significant among the buildings of Namhansanseong.

4. Research Methods

4.1 Equipment and Software

1) Scanner: Faro Focus 3D, a long-range scanner using phase-shift methods, was used.

2) Scan data tool: Faro Scene Ver 5.0 was used for data post-processing to increase scanner conformity. (Figs.5. to 8.).

3) Drawing Tool: AutoCAD 2008, a graphic design program, was used to prepare the drawings.

4.2 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 to scan Soongryeoljeon. Hence, the reference points were set in areas observable from the various long-range scanner positions (Figs. 9. and 10.).

2) Scanning: Scan the reference points and Soongryeoljeon using the scanner. Place the scanner inside and near the structure to obtain scan data.

3) Data post-processing: Register the scan data in the post-processing program; align and merge the data into one combined data set.

4) Review the combined data and eliminate unnecessary and irrelevant ones.

5) Prepare a snap shot of the regulated data: In the post-processing program, manipulate the view of the

<table>
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<th>Table 1. Reference Points</th>
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<tr>
<td>TBM2</td>
</tr>
<tr>
<td>TBM3</td>
</tr>
</tbody>
</table>

Fig. 5. Layout of Sungryeoljeon (3D Scan Data)

Fig. 6. Front View (3D Scan Data)

Fig. 7. Side View (3D Scan Data)

Fig. 8. Cut View (3D Scan Data)

Fig. 9. Measurement Reference Points (P number is not column number)

Fig. 10. Snapshot of the Lower Sections of the Columns

Fig. 11. Snapshot of the Upper Sections of the Columns
scan data 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 snapshot of the lower and upper planes of the columns (Figs.10. and 11.). The snapshots must include the reference points. The snap shots are shown with grids in 1 m intervals to show the sizes.

6) Inserting the snapshots into graphic software: Insert the snapshots of the upper and lower sections of the columns into the AutoCAD. Resize the snapshots to scale with reference to the grids shown; then the two snapshots will be in the same scale. Align the reference points of the two snapshots to 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.12.).

8) Measuring column leaning: The line connecting the upper and lower cross section lines represents the column leaning. The direction of the line represents column leaning direction (Fig.13.).

9) Repeat survey: Periodically repeat measuring column leaning using the same methods. Make the reference point identical to the grid size of the snapshot, and maintain the reference points. Three surveys were conducted to measure changes in one year at four-month intervals:
   - First survey: May 24, 2013
   - Second survey: August 28, 2013
   - Third survey: December 7, 2013

10) Displacement survey: Measure the changes in the upper column according to the time flow. Check the changes in the upper columns. Compare the difference between the first and second survey data, second and third survey data.

4.3 Special Notes

1) Using the snapshots: When the architectural heritage structure is 3D scanned, too many sets of 3D scan data are obtained; the volume of file becomes too big. This makes it difficult to insert them directly into a graphic program to prepare drawings. Thus, 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 the drawings. Figs.9. to 11. are the snapshots of scan data, which completes the post-processing step by the scan data tool, Faro Scene Ver 5.0.

2) Represent column leaning in 2D on AutoCAD: Drawings are prepared in 2D even with 3D scan data because existing survey drawings are done in 2D.

5. Results and Analysis

5.1 Column Leaning: First Survey

The first survey is of column leaning including multiple artificial changes along with long-term natural changes. The first survey is the standard for the periodic survey, and thus has value in that its meaning must be found separately from the additional surveys continued in the study. Therefore, it is considered as an independent chapter.

Each of the 12 columns in Soongryeoljeon had a different leaning measurement. The values were compared: the slightest leaning was by 12.9 mm and the most pronounced was 94.1 mm. Each column also leaned toward different directions, which were compared as well. Overall, the upper sections of the external columns seemed to rotate counterclockwise. Indeed, the entire Soongryeoljeon structure rotated counterclockwise. Only columns 3 and 8 leaned in opposite directions. The change, however, was relatively small. As for the internal columns, the upper sections of the columns seemed to widen. This is presumed to be a result of the rotation of the entire structure. The intensity of the leaning was found to be the highest in column 12 with 9.4 cm. Compared with the height of the column, it was leaning by about 5%.

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Fig.12. Size and Direction of Column Leaning by the First Survey (Sizes of Vertical and Horizontal Displacements in mm)

Fig.13. Direction of Column--leaning by First Survey (Unit: mm); Sizes of Vertical and Horizontal Displacements are Proportional

5.2 Change in Individual Column Leaning

The second and third surveys were conducted in the same way as the first. These two surveys determined the natural changes in wooden materials through time. Changes in column leaning are determined by subtracting the first measurement from the second one.
Changes in the x- and y-axes are examined, and the overall changed distance is determined by calculating the changes in the x- and y-axes. The trend of changes shows whether the leaning examined in previous surveys and the shift of the leaning toward another direction has decreased or increased.

Table 2. Individual Column Leaning (Unit: mm)

<table>
<thead>
<tr>
<th>Col. No.</th>
<th>1st Survey (X)</th>
<th>1st Survey (Y)</th>
<th>2nd Survey (X)</th>
<th>2nd Survey (Y)</th>
<th>3rd Survey (X)</th>
<th>3rd Survey (Y)</th>
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<td>52.7</td>
<td>42.3</td>
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<td>3</td>
<td>6.7</td>
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<td>12.9</td>
<td>(0.6)</td>
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<td>(6.8)</td>
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<td>17.5</td>
<td>(4.5)</td>
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<td>6</td>
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<td>25.9</td>
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<td>94.1</td>
<td>(96.6)</td>
<td>42.8</td>
<td>105.7</td>
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* Direction: + for north-east and ( ) for south-west
* X: leaning in the X-axis direction
* Y: leaning in the Y-axis direction
* XY: distance of column leaning

5.2.1 Column Leaning Change by the Second Survey

In the first row, columns 1, 2, and 3 showed a decrease in leaning for both x- and y-axes. Column 4 showed a slight increase toward the x-axis and a decrease toward the y-axis. Therefore, change occurred in the opposite direction of the original leaning direction overall, which shows that column leaning tended to return to the original leaning.

In the second row, column 5 showed a decrease in leaning toward the direction of progress, but column 6 further leaned toward the direction of progress. Columns 7 and 8 leaned toward the x-axis, but showed a decrease toward the y-axis. In other words, columns in the second row leaned toward different directions.

In the third row, columns 9 to 12 were leaning more toward the direction they had already been leaning. All except column 11 showed relatively much leaning toward the y-axis. In particular, column 12 was leaning by at least 20 mm, showing the most significant change.

The back columns in the third row seemed to be gradually leaning southwest, and affecting the leaning of the other columns. Thus, columns in the first and second rows generally leaned north, conflicting with the direction toward which the columns in the third row leaned, thereby supporting the building's stability.

5.2.2 Column Leaning Change by the Third Survey

Columns in the first row leaned toward different directions showing different aspects from the direction measured in the second survey. Column 1 showed increased leaning toward the x-axis and decrease toward the y-axis. Column 2 showed decreased leaning toward the x-axis but increase toward the y-axis. This trend is distinctive in that it is showing change in the opposite direction from column 1. Column 3 showed increased leaning toward both the x- and y-axes unlike in the second survey. Column 4 showed decreased column leaning in general.

Columns in the first row were characterized by different trends in leaning direction unlike the equal leaning decrease measured in the second survey. Columns in the second row all showed changes in northward leaning. Only column 6 leaned northeast; the rest leaned northwest. Columns in the third row also showed changes in northward leaning. Only column 11 leaned northeast close to the horizontal angle; the rest moved northwest. As such, the columns generally showed leaning change toward the north.

Table 3. Change in Individual Column Leaning (Unit: mm)

<table>
<thead>
<tr>
<th>Col. No.</th>
<th>Second-First (X direction)</th>
<th>Second-First (Y direction)</th>
<th>Total</th>
<th>Third-Second (X direction)</th>
<th>Third-Second (Y direction)</th>
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<td>(4.7)</td>
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<td>6.9</td>
</tr>
</tbody>
</table>

*Second-First: Subtraction of the first measurement from the second one; Change in distance between the first and second survey
*Third-Second: Subtraction of the second measurement from the third; Change in distance between the second and third survey
*X direction: Distance moved toward the x-axis
*Y direction: Distance moved toward the y-axis
*Total: Total distance moved, combining both x- and y-axes
*Displacement Trend: Decrease and increase of leaning, shift toward another direction
6. Conclusion

This study aims to conduct a periodic survey of the column leaning of Sungryeoljeon, an important Korean traditional wooden architecture located in the UNESCO World Heritage site, Namhansanseong, and then determine the aspects of change. Each material in Korean traditional wooden architecture has a significant characteristic of naturally changing over time. Such delicate differences cannot be determined easily using conventional measurement survey methods, and, thus, this study used 3D scanning, which offers high accuracy and is frequently used.

The measurement results for individual column leaning changes in Sungryeoljeon are as follows.

1) Columns generally lean toward the south, which is their original leaning direction. In particular, columns in the third row, which are in the back, showed excessive column leaning. Moreover, columns tend to rotate clockwise gradually. This indicates that the entire upper part, including the roof, is rotating clockwise.

2) The columns may stop leaning or lean in the reverse direction. This may be caused by various factors, such as when affected by surrounding columns, the weight of the roof, seasonal factors like temperature or humidity, or frame materials. This study could not determine the exact cause. The cause may be identified by additionally conducting multiple years of study or comparing with other buildings.

3) The most significant column leaning is already in progress by approximately 100 mm toward the direction where it had been leaning.

4) A column showed more than 20 mm of change for approximately 6 months, which is the period for the three surveys. However, in general, the columns do not show rapid change in leaning toward a certain direction.

The following aspects can be identified if, based on the above results, surveys on column leaning are continuously conducted on a long-term basis.

1) It is possible to determine the aspects of change in wooden materials according to the change of time using 3D scan data for wooden buildings, which could not be easily measured by conventional survey methods. Consequently, the causes for change in wooden materials can be determined.

2) It is possible to determine the differences between artificial and natural changes in wooden architecture. The cause of changes and differences before and after artificial changes, such as repair, can also be determined. This information can be used in selecting the appropriate repair methods for wooden structures.

3) By periodically surveying the wooden materials of wooden architecture, the results can be used as basic data for the long-term management of wooden structures.

The substructures within the overall wooden architectural heritage structure are not permanent because over time they are bound to be displaced and undergo changes. Thus, these induced changes have rarely been studied. Again, 3D scan data are precise measurements of each section of the structure; thus, reacquiring 3D scan data after a certain period would allow surveyors to compare period-specific data sets and trace the changes in the structure. This study has value as the initial research attempting periodic surveys on Korean traditional wooden architecture. Data on the aspects of change obtained by periodic surveys on Korean traditional wooden architecture have significant value and thus must be examined.

Acknowledgements

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Notes

1) Reference 3), 4), 5), 6)
2) Reference 5)
4) The mechanical error range of long-range 3D scanner is ±2 mm.
5) Guide Map of Namhansanseong
6) Basic Plan on Comprehensive Improvement of Namhansanseong, 2012

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