BUILDING OF A SAMPLE SCENARIO OF A BUILT-IN GUIDE TYPE ROBOT FOR EXTERNAL WALL MAINTENANCE WORK OF A SKYSCRAPER

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ABSTRACT: The construction of high-rise buildings is currently on the rise worldwide, and with 5 construction projects currently being promoted in Seoul to build higher than 100 stories, Korea is no exception. However, there are different considerations for the maintenance of such high-rise buildings, not to mention the construction process, than there are for other types of buildings. In addition, the conventional and most commonly used method of maintaining the external wall is to resort to a rope tied at the top of the building while the workers do their work. But if this process were to be applied to a high-rise building, the risk taken by the workers would increase, while work efficiency would decrease. For this reason, it is necessary to prepare a maintenance method in advance.

Accordingly, this research aims to draw up a cleaning sample scenario and derive design factors to be considered based on the assumed introduction of a maintenance robot. The research findings will provide fundamental data on the development of an external wall maintenance robot for the built-in guide type of high-rise buildings.

Keywords: *Built-in Guide Type Robot, A Skyscraper, External Wall Maintenance, A Sample Scenario*

1. INTRODUCTION

1.1 Research Background and Objective

The construction of high-rise buildings is on the rise worldwide, and with 5 projects currently being promoted in Seoul to build higher than 100 stories, Korea is no exception to this trend. As buildings higher than 60 stories have been frequently built in the past several years, the number of high-rise buildings has been rising sharply (Joseon Ilbo, 2009). However, there are different considerations required in the maintenance of such high-rise buildings, not to mention the construction process, than there are for other types of buildings.

For maintaining the external wall while workers do their work, the conventional and most commonly used method is to resort to a rope tied at the top of the building. Since the height of such buildings exceeds 200 m, which is the maximum range of the external wall cleaning, there are some difficulties doing this work. In addition, the conventional method of cleaning is to use the rope alone, which could lead to casualties due to a safety accident. A safer and more fundamental method of external wall cleaning should be prepared. One such measure that has been gaining support is the claim that cleaning work should be pursued through mechanization and automation.

This research aims to draw up a cleaning sample scenario and derive design factors to be considered based on the assumed introduction of a maintenance robot. The research findings will provide fundamental data on the development of an external wall maintenance robot for the Built-in Guide type of high-rise buildings.

1.2 Research Scope and Method

Cleaning methods for external walls can be broadly divided into four systems: Manual Work, Autonomous Driving System, Gondola System and Guide Rail System. While there has been high demand for both manual work and the Gondola System on mid- and high-rise buildings, the demand for the Guide Rail System is expected to be on the rise. This study is preliminary research for Built-in Guide type Robot development and rail design, and for this reason, the scope of this research is restricted to the analysis of related laws and the drawing-up of a sample scenario.

2. ANALYSIS OF RELATED TECHNOLOGY TRENDS

2.1 Current Status of External Wall Maintenance

External wall maintenance can be divided into two general types. One is either to discover and restore a damaged or deficient part, or to paint pictures or text on the wall. The other is cleaning work for a building affected by long-term sun exposure, which is considered important work in high-rise building maintenance.

Starting with Nihon Bisoh (Japan), many companies have studied a great deal about ways to commercialize the cleaning method using Gondola. In contrast, about 95 percent of external wall cleaning is expected to be done through manual work (see Fig. 1), while about 5 percent is done through a Gondola system. For this reason, sufficient preliminary studies have not been conducted in Korea.

Fig. 1 Case of external wall cleaning

The most commonly used method consists of five steps, which are shown in Fig. 2: 1) preparation of cleaning materials and tools; 2) installation of safety devices for the cleaning work; 3) making the posture for clean work and setting up cleaning tools; 4) implementation of cleaning work, and 5) disassembly of the rope and safety devices.

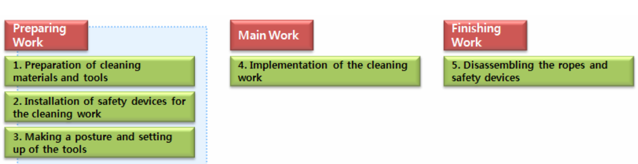
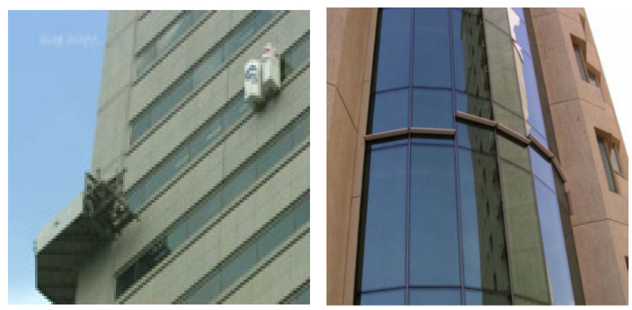


Fig. 2 Conventional external wall cleaning method

2.2 The Current Status of Maintenance Using a Built-in Guide Type Robot

A variety of Built-in Guide types of vertically- or horizontally-moving robots have been developed and applied in foreign countries. First, the representative horizontally-moving robot that applies the Built-in Guide was developed by Nihon Bisoh and has been applied to multiple high-rise buildings, including Yokohama Landmark Tower. Second, there is a vertically-moving robot that applies a Built-in Guide that is the iku system developed by iku company, whose wiper moves vertically along the belt installed inside of the mullion to clean the curtain wall (See Fig. 3).

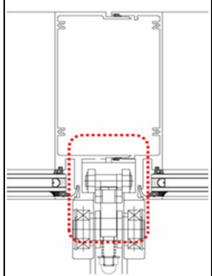


a) Horizontally Moving Robot
b) Vertically Moving Robot

Fig. 3 Overseas Cases of Built-in Guide Type Robots

While there are no buildings in Korea that apply the Built-in Guide, a quasi-Gondola System like the Gondola Rail System is applied on the 63 Building and the Posco Center, to move vertically (See Table 1). The utilization of Gondola Rail Systems in Korea currently appears to be very low due to its error taking place in construction and insufficient deformation management.

Table 1: Gondola Rail System Used for 63 Building

63 Building		Characteristics
Profile		-Direct exposure to the air of Guide Rail -Increase in waterproof and airproof function thanks to internal triple seal gasket -Relatively advantageous in terms of securing space thanks to all-in-one Guide Rail and Aluminum Frame -Difficult to provide insulation and prevent dew condensation due to the use of a non-insulated bar

3. ANALYSIS OF RELATED LAWS FOR HIGH-RISE BUILDINGS AND MAINTENANCE

3.1 Review on Related Laws for Maintenance

The main types of building maintenance can be broadly defined as improvement (change of a building to have a better condition), repair (restoration of the damaged part to restore the original function), and reinforcement (improvement of the damaged structure to be better than its original condition). Related laws include 'Act on Construction,' 'Enforcement Decree of the Framework Act on Construction,' 'Enforcement Decree of the Framework Act on The Construction Industry,' 'Special Act on the Safety Control of Public Structures,' and 'Enforcement Decree of the Special Framework Act on the Safety Control of Public Structures.' (See Table 2)

There are laws related to the maintenance of buildings, but no detailed cycles of repair and mending are specified in these laws. The external cleaning work of a building is determined by the user or manager, taking the building's image and the sunlight's efficiency into consideration. It is done twice a year (spring, fall) or once every two years based on need. This can be utilized as the fundamental data for the preparation of future standards of repair and mending.

Table 2 Comparison between Related Laws on Maintenance

Division	Content
Building Construction Ordinance, Article 35	It is specified that an owner or manager of a building shall manage and maintain the structure, land, and construction facilities in a manner appropriate for the specifications.
Enforcement Decree of the Framework Act on Construction, Article 23	It is described that an owner or manager of a building will manage and maintain the building by having a regular inspection once a year in order to conform to Clause 1 of Article 35
Enforcement Decree of the Framework Act on the Construction Industry	Facility maintenance management is defined as the work carried out to inspect and maintain the building, as well as to improve, repair and reinforce the building in order to maintain its function and increase convenience and safety for users
Special Act on the Safety Control of Public Structures, Article 4	It is specified that the main management agent must plan and implement the safety of the building.
Enforcement Decree of Special Framework Act on the Safety Control of Public Structures, Article 5	It is described that the main management agent establishes and implements a safety and maintenance plan in accordance with Article 4. For an apartment building, this can be planned by the main agent.

3.2 Review of Related Laws on High-rise Buildings

According to the Enforcement Decree of the Framework Act on Construction, a high-rise building is defined as one with 50 stories or more, or standing 200 m in height or higher. In addition, the U.S. specifies a high-rise building as having 50 stories or higher or 200 m in height or higher, Japan as 60 m, and China as 100 m in height or higher. The standard for high-rise buildings in foreign countries will vary depending on conditions.

4. DRAWING-UP OF A MAINTENANCE SCENARIO FOR A BUILT-IN GUIDE TYPE ROBOT

This chapter discusses the selection of samples and draws up a scenario as preliminary research on the development of a Built-in-Guide type Robot required for high-rise building maintenance.

4.1 Selection of Samples

Sang-dong Lee (2002) analyzed the distribution and design trend of high-rise buildings based on all the buildings constructed up until the 20th century. For this research, the samples to which the Built-in Guide type Robot is applied were selected based on the classification criteria in terms of mass design, plane and façade. (See Fig. 4)

The high-rise buildings completed in Korea are as follows, and are analyzed to generally have beam-type mass design, rectangle or rectangle-like plane, and horizontal window. By conducting a comparative analysis on the various types of buildings already completed, we tried to prepare the grounds for selecting samples and the research direction. However, since the Built-in-Guide type Robot can be applied to a new building, additional verification should be made for any buildings to be completed to ensure faithful representation.

	Mass Design (For the middle part)	Plane	Elevation
Daehan Life (63) Builidng	Cylindrical	Rectangular	Lattice
International Trade Center	Vertical Step-type	Rectangular	Lattice
Tower Palace I	Column-type	Rectangular	Horizontal
Mok dong Hyperion	Column-type	Amorphous	Horizontal
Tower Palace III	Column-type	Amorphous	Horizontal
the# Centum Star	Column-type	Rectangular	Lattice
Dongtan Meta Polis	Column-type	Amorphous	Horizontal
Songdo the# First World	Column-type	Rectangular	Lattice
Hakildong Exllu	Column-type	Rectangular	Horizontal
Iaan Taehwagang Exordium	Column-type	Amorphous	Lattice

Fig. 4 Current Status of High-rise buildings in Korea (as of 2010)

Wu-yeong Lim (2008) categorized high-rise buildings in terms of structural system and finishing materials because the façade design of a high-rise building is closely related with the technological factors, though external elements consisting of the façade have been diversified thanks to technological advancements and the development of materials since modern times. Wu-yeong Lim (2008) divided high-rise buildings into four patterns. Of the four patterns, the pattern consisting of 'SRC Structure + Composite Panel + Curtain Wall System' was expected to be adopted continuously in order to overcome the structural restrictions of a high-rise building. As a result, taking all of the analyses into account, Tower Palace is most appropriate as a sample for the development of the Built-in Guide type Robot, since Tower Palace has a full curtain wall with beam-type, rectangle and horizontal window.

4.2 Drawing-up of a Sample Scenario

A cleaning sample scenario was drawn up for the sample building that applies the built-in Guide type Robot. The sample scenario consists of three parts: preparation, main work and finishing. Detailed processes can be categorized into unloading and moving of the cleaning robot, attachment and installation, setup and preliminary operation, operation, and detachment and moving.

With this sample scenario, it is possible to derive the elemental technologies necessary for developing the Built-in Guide type Robot and the Guide Rail.

4.2.1 Preconditions

The primary objective of the Built-in Guide type Robot is to keep the facade of the building clean. However, the preconditions are that the functionality, the primary objective of the curtain wall, airproofing and waterproofing, as well as façade design and economy of design/construction, should be secured.

The initial speed of operation and time are set at 1.25 m/min and 1 hr per operation, respectively. (However, the maximum battery capacity is 2 hrs.) It is assumed that the ownership of the robot is held not by the building owner, but by a specialized cleaning company. Such an operation speed is set at the minimum based on the data on Cox Gomyl, which performed the cleaning work of Burj Dubai. It is assumed that since the equipment is rented from a specialized cleaning company, bringing the robot in and out as well as attaching and detaching it to/from the rail needs to be included in the working process.

An additional battery and a water container are attached to the robot. If a glitch or an error occurs, the ways of returning the robot and carrying out repairs should be discussed. There are two different ways of returning the robot and carrying out repairs: one is using Gondola, and the other is using a worker by securing another access path.

4.2.2 Composition of the Sample Scenario

Taking the preconditions into account, the possible paths that the Built-in Guide type Robot could take can be divided into horizontal and vertical. It is judged that when a horizontal window is incorporated into the building, or when security is an important factor for the building, such as for a hotel or design room, a horizontally moving path is appropriate. A vertically moving path is appropriate for most buildings other than the examples above.

1) Horizontally moving robot

The horizontally moving robot, as shown in Fig. 5, performs its cleaning work on one side of one story. If the work finishes, the robot goes to the next story by using the docking station. Docking stations are installed at the four corners of the building, and help the robot to move vertically using Gondola. At the docking station, the robot's battery and water container can be changed. Since the docking stations must be installed at the corner, the number of docking stations may vary depending on the plane shape and size of the building. An operator is required for each docking station to provide assistance.

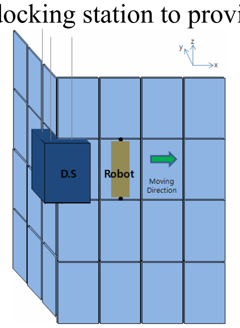


Fig. 5 Horizontally Moving Built-in Guide Type Robot

A detailed diagram of the vertically moving robot is shown in Fig. 6. First, preparation includes unloading and moving the robot for the cleaning work, and testing the robot after attaching it to the rail. Second, the main work includes the work of cleaning the façade (spraying water and detergent and cleaning and squeezing) by moving horizontally and moving to the next story after finishing one. Third, finishing includes moving the robot for the finishing work (cleansing and drainage), detaching it from the rail, and storing it for future use.

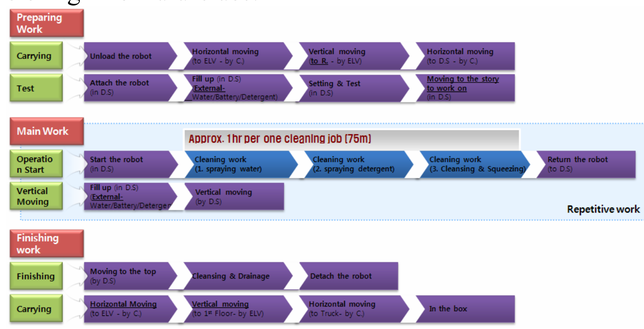


Fig. 6 A Sample Cleaning Scenario for the Building Façade

The vertically moving robot is very appropriate for buildings that require management by story. However, the operator on the Gondola is exposed outside of the building, which poses a safety problem. Structural reinforcement for the façade of the building is needed so that the weight and cost of the curtain wall will greatly increase.

2) Vertically moving robot

The vertically moving robot is, as shown in Fig. 7, vertically moving along a column at one side of the building.

When the cleaning work for one column is finished, the robot goes to the next column. The vertical movement is done at the top of the building. The docking station installed at the top of the building helps the robot move horizontally, at which point the battery and water container can be changed by the operator. When the building is large or the working speed needs to be raised, a couple of robots can be used at the same time. One operator working in a safe space can operate the robots, which is advantageous.

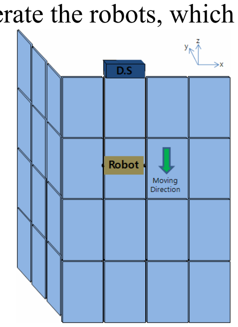


Fig. 7 Vertically Moving Built-in Guide Type Robot

The sample scenario for the vertically moving robot is similar to that of the horizontally moving robot. But one big difference lies in the robot's stop, which occurs, one at the top and again at the bottom. The vertically moving robot, once the problem of the weight added to the façade is solved, can be used for almost any type of building. As a result, the vertically moving robot is believed to be the most appropriate.

5. CONCLUSION

Recently, the number of high-rise buildings has been on the rise, which has meant that maintenance cost has increased by two and three times, along with the increase in the construction cost. It is suggested that the use of an auto cleaning robot could increase the productivity and safety of cleaning work, which is mostly done outside of a building. In particular, the Guide Rail on a high-rise building could be useful in this capacity, as it has the advantage of not being significantly influenced by factors of the external environment, including wind pressure. For this reason, this research is preliminary research into a cleaning automation/mechanization for a high-rise building, and aims to analyze the related laws and draw up a sample scenario.

Through a literature review, we have gained an understanding of the current status of domestic and overseas maintenance and finishing materials, and have researched and reviewed the detailed standards by analyzing the related Korean laws. Through this research, it was found that while there are laws regulating maintenance, there are no specific standards for repair and mending cycles. It is thus urgently necessary to prepare and present detailed standards and guidelines for high-rise building maintenance, at a legal and systemic level.

In addition, this research selected a sample building for developing a Built-in Guide type Robot and rail design, and drew up a sample cleaning scenario.

A beam-type and rectangular full curtain wall, like Tower Palace I, was selected as the sample building to draw up the sample scenario. The sample scenario was drawn up for two types of robots, horizontally moving and vertically moving. Based on the scenario, the applicability of the Built-in Guide type Robot and Guide Rail design that can cope with diverse structures and environments in the future was also estimated. It is expected that the research findings will serve as fundamental data for the development of a robot that can automatically perform the work of façade cleaning.

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