Agent-based Lift-car Group Operation Optimization Model in High-rise Building Construction

Minhyuk Jung[1], Moonseo Park[2], Hyun-soo Lee[3], Hosang Hyun[4]

Abstract: To hoist construction workers to their working space is directly related to the productivity of building construction since hoisting tasks are carried out during the working time. In order to reduce hoisting time in the condition that the number of construction lift-cars is limited, various types of the lift-cars group operation plans such as zoning and sky-lobby have been applied. However, previous researches on them cannot be compared in the performance due to their methodological limitation, discrete-event simulation methods, and cannot be find better solution to increase the performance. Therefore, this research proposed the simulation-based optimization model combining the agent-based simulation method to the scatter search optimization methods. Using the proposed model, this paper carried out the comparison analysis on the performance of typical operation plans and also optimize an operation plans by controlling the service range of lift-cars, the size and number of service zones. In this case study, it is verified that better alternatives than typical operation plans can be exists and it is possible to increase the productivity of building construction.

Keywords: Lift-car operation planning, Worker hoisting, Agent-based simulation, Scatter search Optimization

I. INTRODUCTION

Construction schedule and task execution stand on the basis of appropriate resource supply, and an abnormal management of them can cause the delay and additional cost in construction projects (Cho et al., 2013). In high-rise building constructions, resource hoisting takes an important role in resource supply since most of resources should be transported in a vertical way due to characteristic on building appearance (Moon. et al., 2014). Resources to be hoisted in building construction covers construction material, labor, and equipment. To hoist these resources are generally carried out in an intricate condition where constraints, e.g., limitation of hoisting equipment and space, interrupt their movement.

Above all, hoisting task of construction workers is relatively more constrained by time than that of other types of resources. For examples, construction material can be hoisted as far as they are delivered before construction activities do not start to be executed. On the other hand, the construction workers should be hoisted only in working time (Park. et al., 2013). Therefore, if worker hoisting takes too much time, it causes productivity loss since the working time becomes relatively insufficient. The lift-cars which are used for not only worker hosting but also construction materials hosting are usually limited in number. For worker hoisting to occupy the limited lift-cars for a long time can disturb other resource supply. For such reasons, construction worker hoisting is directly related to increase the activity productivity and even to material supply and it should be completed as soon as possible.

To mitigate time consumption of worker hoisting in a lift-car-limited condition, many researchers have focused on the lift-car group operation planning, e.g., zoning system (Park. et al., 2013) and sky-lobby system (Moon et al., 2014). Lift-car group operation planning is one of resource constrained project scheduling problems which assigns resources signifying lift-cars to tasks, transportation of worker to right place, in a way to minimize overall duration. The combination of resource allocation to tasks leads to a tremendous number of solution set, it is hard to find the optimal solution due to the non-linearity of this problem. In order to lessen the hosting time, the entire solution set of the resource problem should be searched under the same conditions and using the same methods. However, the solutions resulted from the previous research on the well-known lift-car group operation planning is a part of the entire solution set. Namely, there is a possibility to find better solutions by searching the rest of the solution set.

This research aims to propose simulation-based optimization model to find optimized lift-car group operation planning. Using the proposed model, the paper executes a simple case study which includes the comparison analysis on the performance among the well-known systems and optimization results.

II. PRELIMINARY STUDY

In this section, this paper gives some overviews on lift car group operation types and simulation methods which have been used in literatures on the lift-car hoisting time calculation.

A. Lift Car Group Operation Methods and Efficiency

As aforementioned above, the lift-car group operation plan is related to resource constrained scheduling problem. To avoid confusion when workers select a lift-car to board, the lift-car group operation planning limits the number of floor served by the lift-cars. By limiting the service floor of lift-cars, the maximum length of lift-car's travel path and the number of stop floors can be reduced, and these make a cycle time of lift-car's travel shorter whereas the risk is remained that inappropriate plan can cause the idle state of lift-car.

[1] Ph.D. Student, Department of Architecture, Seoul National University, Gwanak-gu, Seoul, Republic of Korea, archidea914@snu.ac.kr
[2] Professor, Department of Architecture, Seoul National University, Gwanak-gu, Seoul, Republic of Korea, mspark@snu.ac.kr (*Corresponding Author)
[3] Professor, Department of Architecture, Seoul National University, Gwanak-gu, Seoul, Republic of Korea, hyunslee@snu.ac.kr
[4] Ph.D. Student, Department of Architecture, Seoul National University, Gwanak-gu, Seoul, Republic of Korea, hhs518@naver.comr

Various types of lift-car group operation plan have been already applied to the actual building construction. The most well-known methods are the zoning and sky-lobby system, and many researchers have made an effort to evaluate these operation types and to find better solution. Park et al. (2013) proposed the optimization model of zoning system by modifying the number and size of zones. Moon et al. (2014) mentioned that sky-lobby system which installs sky-lobby floor to transfer to a local lift is usually applied in the case that the length of power supply cable of lift-car cannot cover the length of lift-car travel cycle. They propose a simulation model to evaluate the performance of sky-lobby system.

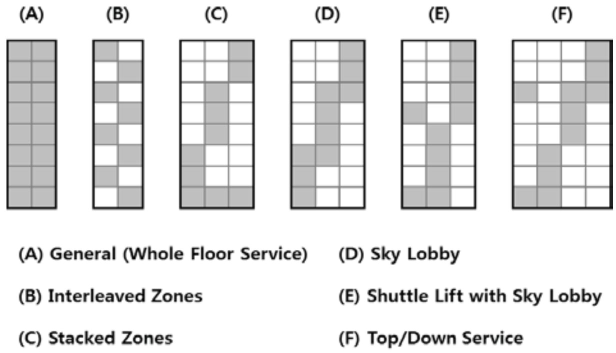

FIGURE 1
EXAMPLES OF LIFT-CAR GROUP OPERATION PLANS

Barney (2003) investigated a number of lift-car group operating plan types in operation and maintenance (O&M) phase of high-rise buildings, namely in elevators operation plan. In a building O&M phase, comparing to a construction phase, more various operating plan types are applied to building by combining two more different operating plans or creating new travel path with lift-car transferring. Even though they are devised by considering architectural features (e.g., building program, building shape) which are not related to construction, they demonstrates that more efficient operating plans can exists in transporting people in high-rise building.

B. Simulation Methods for Lift-car Model

Discrete event simulation (DES) method are mainly used for evaluating the efficiency of operating plans in the literatures (Ioannou & Martinez, 1996, Shin et al., 2011, Moon et al., 2014). However, DES have limitations to construct model for directly comparing the performance of various operating plan types under the same conditions and assumptions.

Firstly, DES is suitable to the performance evaluation of repetitive and pre-defined processes (Ioannou & Martinez, 1996). However, in order to find optimal process of lift-car operation in workers hoisting, that is the purpose of this paper, it is impracticable to make models of an innumerable number of processes. Secondly, in multi lift-car environment, the resource allocation in DES is based on fixed or simplified allocation rules, e.g., First-In-First-Out and First-In-Last-Out (Zhang & Li, 2004). These rules makes it impossible to optimize lift-car allocation as the real world does. Finally, Entity, which stand for workers, in DES which cannot make their own decision on how to act in a certain environment. In various combination of lift-car group operation plan, it is a possible case that the worker should determine a travel path in multiple options in order to arrive at their destination. However, the passive objects in DES method should assumes it as a probability which deviate from the process of the real-world.

While the DES methods focus on the process of system, agent-based simulation (ABS) method focuses on the behaviour of autonomous and intelligent agents which observes and acts upon an environment (Knotts et al., 2000). Since the ABS model doesn't define a specific process of agent's behaviour, various types of lift-car operating plan can be modelled by controlling them as an initial setting value. Also, the intelligent and autonomous agent can makes a decision on efficient resource allocation and own travel path in consideration of dynamic environment. For these reasons, this paper proposes model using the ABS method in simulation-based optimization model.

III. MODEL DEVELOPMENT

In this section, the paper give a detailed illustration on how the simulation-based optimization model is designed and how it can covers the aforementioned problems on the lift-car group operation. Firstly, basic concept of simulation-based optimization model is illustrated with its optimization algorithm, input and output variables, and objective function. This includes a parameterization way of various types of the lift-car group operation method, which is used to optimize as input values of the proposed model. Then, the description on simulation model is followed, which is an objective function in the entire model.

A. Simulation-based Optimization Model

The purpose of the proposing model is to find an optimized solution which can control the lift-car group operating processes. To evaluate the performance of each solution that signify the process is related to resource allocation in stochastic and complex system. Therefore, simulation methods which is effective to evaluate complex system (Gosavi 2012) is applied for searching solutions as an objective function of optimization model, that is the simulation-based optimization approach.

As a main optimization method, scatter search (ScS) algorithm which is the population based non-linear problem solver like genetic algorithm (GA) is chosen. After decision parameters representing the lift-car group operating processes are randomly selected and improved by the ScS algorithm, Simulation model evaluates the process as many times as the number of the population of them.

Various types of Lift-car group operating plans are generalized and transformed as a numerical value in order to apply to simulation-based optimization model. Floors of

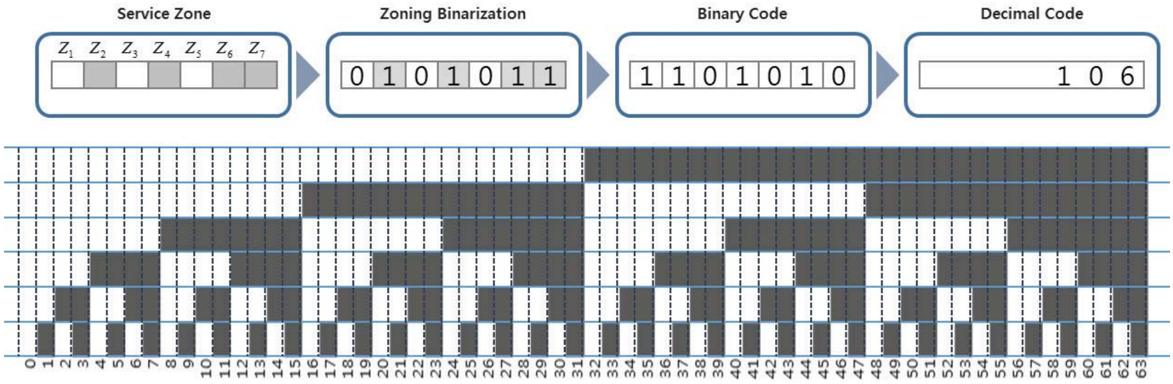

FIGURE 2
PARAMETERIZATION OF SERVICE RANGE OF LIFT-CARS FOR OPTIMIZATION ALGORITHM

building is divided into multiple zones that are comprised of connected floors, and the number and size of the zones are a part of the decision parameters. Lift-car group operation plans is related to which zone a lift-car the service zones of each lift-car should be transformed to numerical parameters. As shown in Figure X, service zones is expressed using binary code, that service zone is 1 and non-service zone is 0. However, in the case that the number of zone is changed, the digits contained by the binary code is changed, and it makes decision parameters to be also changed. Therefore, the proposed model makes the binary code to be decimalized as one decision parameter.

B. Agent-based lift-car Operation Simulation Model

As illustrated in Figure X, the lift-car simulation model which is designed in agent-based modeling method is comprised of four different types of agent groups, floor agent, lift agent, lift car group traffic controller (LCGTC), and worker agent. During simulation is processed, each agent by interacting with agents in the same or different groups. The roles and functions of each agent types are illustrated as follows.

1) Floor Agent: Floor agent represents a spatial environment, where workers agent are located in for carrying out their task and waiting lift cars as illustrated in Figure 4. Floor agents also play an important role in connection between workers agents and lift-car. Floor agents collects the information of worker agent's destination and lift-cars which worker agents expect to board, then manage them by sending the floor call to the LCGTC and Lift car agents until all worker agents take lift-cars they want. One floor agent is connected to at least one more LCGTC that control severallift-cars which have the same service range of floors.

2) Lift car Agent: Lift car agent simulates construction lift car as it is. The main functions of this agent type is to calculate a time delay during traveling between floors and to deliver construction workers to their destination. Before moving to floors, a lift-car agent generate a task list, which is a series of destinations where the lift-car agents have to

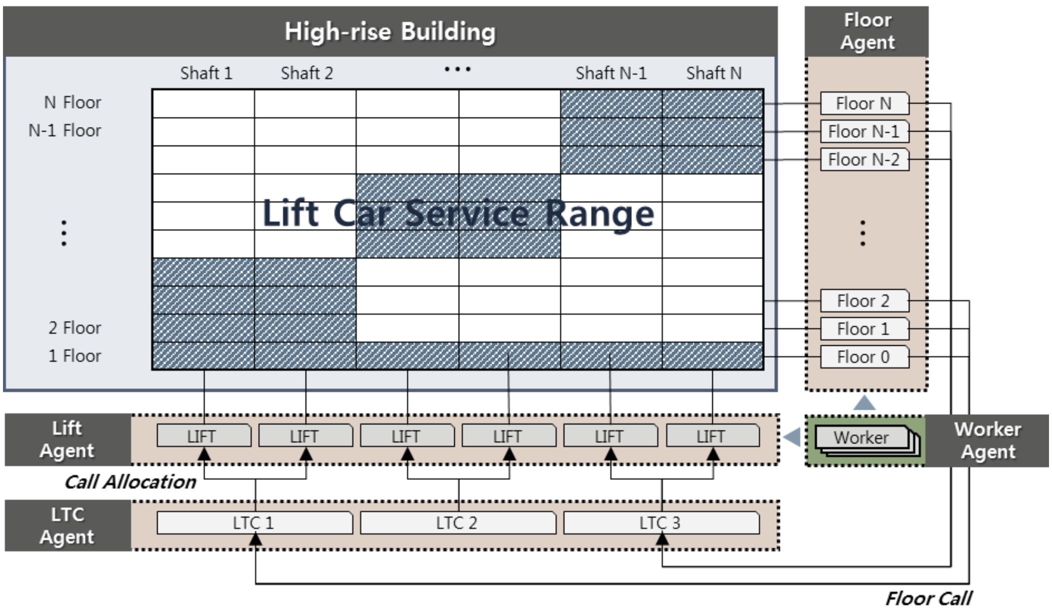

FIGURE 3
MODEL STRUCTURE OF AGENT-BASED LIFT-CAR OPERATION SIMULATION MODEL

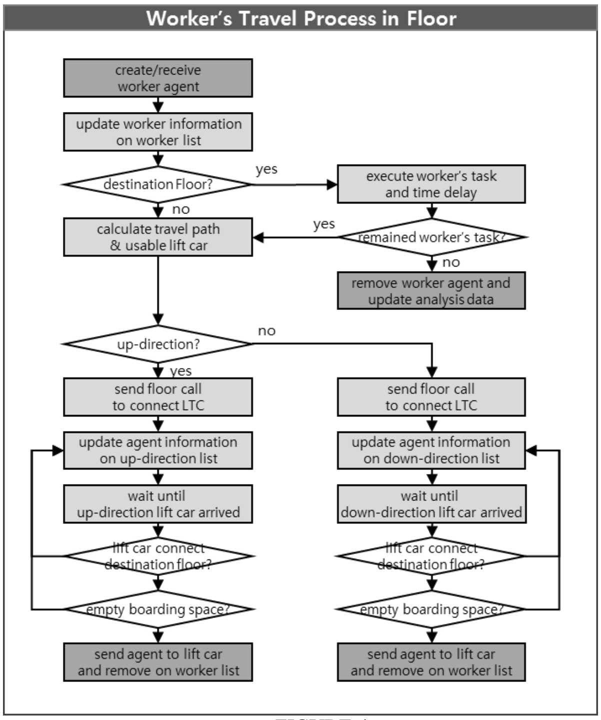

FIGURE 4
ALGORITHM OF WORKER AGENT BEHAVIORS IN FLOOR AGENT

go. These destination derives from the workers who belong to the lift-car agents, namely passengers of the lift car, and floor calls which are assigned by LCGTC and floor agents. When new passengers take the lift-car agent or when new floor call is assigned, the lift-car agent adds them to the task list, and determines the order in a way to minimize the lift-car's travel path. After determining the task list, the lift agent begins to move to its first destination, and connects to the floor signifying the destination, opens/closes the lift-car door, boards/alights the workers inside, and begins to move repetitively until the task list is empty as illustrated in Figure 5.

The time delays resulted from the lifting operation is decisive in the simulation result. However, its process is very flexible. For examples, during traveling, the lift-car agents may modify their task lists and the first ongoing destination by receiving a new floor call which has more priority than the others. The kinetic characteristics of lift-car travel is generally constrained by maximum speed and acceleration thus the traveling time can vary according to the current speed and remaining distance to move.

The other function of the Lift-car agents is to manage the workers agent in the lift-car agents as described in Figure 5(b). When the lift-car agents arrived at new floor, they informs worker agents of the current floor, so as to each worker agent determine they should leave or not.

3) Lift-car Group Traffic Controller Agent: LCGTC agents allocate floor call from floor agents in consideration of lift car's tasks and locations. When floor calls are generated, LCGTC control them to prohibit from being created unreasonable and wasteful task during lift car operation, so that the simulation model is able to calculate accurately time consumption. For example, if there are two more lift-cars whose service range is same, LCGTC assign floor call to the lift-car which is expected to be arrived at the floor in the shortest time. Also LCGTC manage the allocations by repeating to assign and cancel them because lift-car's movement and the situation of floor calls is dynamically flexible.

LCGTC connects to the lift car agents who serve the same range of floors. Namely, the number of LTC means the number of service range combined as an operation method.

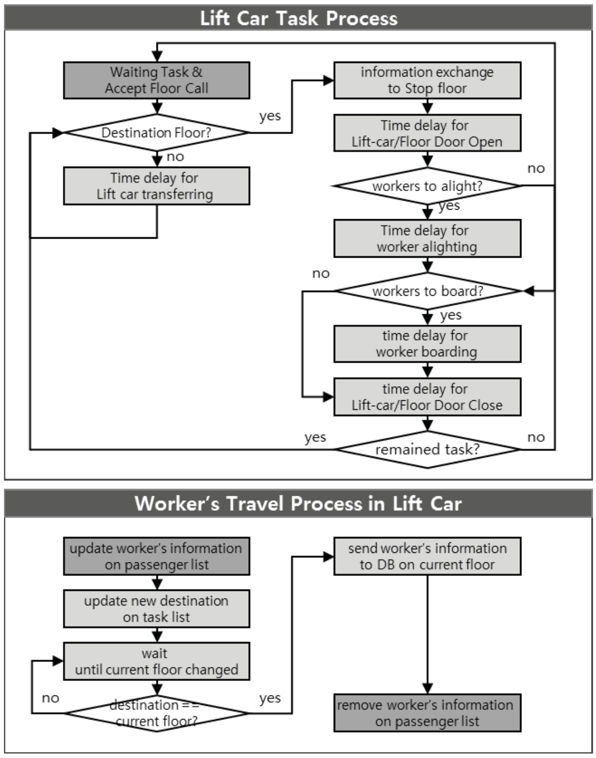

FIGURE 5
ALGORITHMS OF LIFT CAR OPERATION AND WORKER AGENT BEHAVIOR

4) Worker Agent: The worker agents have an information on the schedule and location in which they should work. The main function of those agents is to find optimized travel path to arrive at their destination floor in the shortest time. In the cast that there are serval travel paths, the agents autonomously should evaluate alternatives and make a decision on that to take which a lift-car will bring them most quickly. However, it is not a simple task since there can be an enormous number of alternatives when the number of floors and lift-car is a lot.

Thus, using the branch and bound algorithm which is one of the most well-known optimization method for finding travel path.

IV. CASE STUDY

In order to evaluate various types of lift-car group operation plans and find optimal solution among them, a case study is carried out with the proposed model. The case of building construction is virtually set as a 50-story

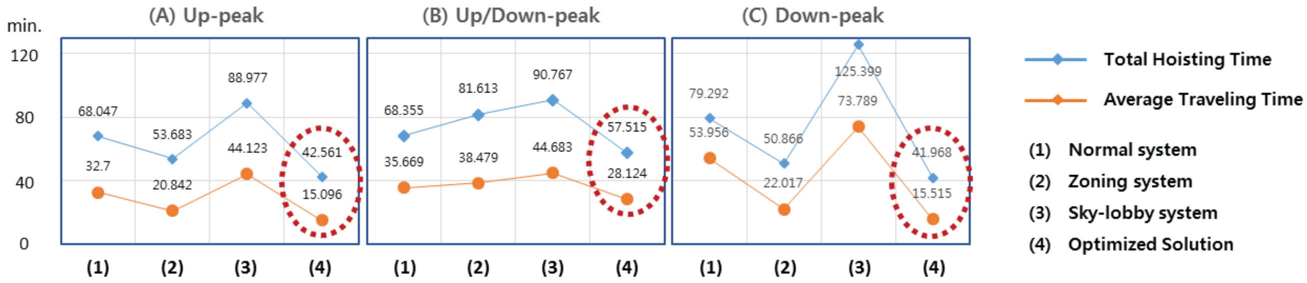

FIGURE 6
AVERAGE TIME OF WORKER AGENTS TRAVELING AND TOTAL WORKER HOSTING TIME

building construction site where 500 workers have task schedule and six lift-cars are installed in the site. Destination floor of worker agents is assumed to be uniformly distributed.

Traffic patterns of worker agent vary depending on a period of time, e.g., morning rush hour (Up-peak), lunch break time (Up/down-peak) and evening rush hour (down-peak), and the difference can influence the results of lift-car operation, three independent experiments which differently initialize the worker agents' starting and arriving point are designed. The model measures average of travel time of each worker agents and total worker hosting time, the optimization is performed in a way to minimize total worker hosting time. Also the performance of the well-known operation plans, entire floor, zoning, sky-lobby system is compared to that of the optimization results.

As shown in Figure 6, the zoning system presents generally more outstanding performance than the other typical operation systems expecting the experiment in the up/down-peak traffic conditions. The optimized solution from the propose model shows better than the others in all experiments. And this result shows that there is the possibility on better solutions which are not considered before.

IV. CONCLUSION

In hoisting resource-constrained conditions, to hoist construction workers to their working space is directly related to the productivity of building construction since hoisting tasks are carried out during the working time. In order to reduce hoisting time in the condition that the number of construction lift-cars is limited, various types of the lift-cars group operation plans is applied in building constructions.

However, previous researches on them cannot be compared in the performance due to their methodological limitation, discrete-event simulation methods, and cannot be find better solution to increase the performance. Therefore, this research proposed the simulation-based optimization model combining the agent-based simulation method to the scatter search optimization methods.

Using the proposed model, this paper carried out the comparison analysis on the performance of typical operation plans and also optimize an operation plans by controlling the service range of lift-cars, the size and number of service zones. In this case study, it is verified that better alternatives than typical operation plans can be exists and it is possible to increase the productivity of building construction.

When construction managers devise a lift-car group operation plans, the applicability, how the optimized plans are easily understandable without any confusion of users, is one of the important issue. The further study will be focused on analysis of common patterns which show better performances so as to increase utilization of the proposed model in building construction.

IV. CONCLUSION

This research was supported by a grant (14RERP-B082884-01) from Housing Environment Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

REFERENCES

[1] G. C. Barney, L. Al-Sharif, *Elevator traffic handbook: theory and practice*. Routledge, 2003.
[2] C. Cho, Y. Lee, M. Cho, S. Kwon, Y. Shin, J. Lee, "An optimal algorithm of the multi-lifting operating simulation for super-tall building construction", Automation in Construction, 35, pp. 595-607. 2013.
[3] A. Gosavi, *Simulation-based optimization: parametric optimization techniques and reinforcement learning* (Vol. 55). Springer, 2014
[4] S. Hwang, "Planning temporary hoists for building construction", 2009 Construction Research Congress, ASCE, Seattle (April), pp. 1300-1307, 2009
[5] P. G. Ioannou, J. C. Martinez, "Scalable Simulation Models for Construction Operations", Proceedings of 28th Conference on Winter Simulation, IEEE Comp. Soc., December 8-11, 1996, Coronado, CA, USA, pp. 1329-1336, 1996.
[6] M. Park, S. Ha, H. Lee, Y. Choi, H. Kim, S. Han, "Lifting demand-based zoning for minimizing worker vertical transportation time in high-rise building construction", Automation in Construction, 32, pp. 88-95, 2013
[7] Y. Shin, H. Cho, K. I. Kang, "Simulation model incorporating genetic algorithms for optimal temporary hoist planning in high-rise building construction", *Automation in Construction*, *20*(5), pp. 550-558, 2011.
[8] H. Zhang, H. Li, "Simulation-based optimization for dynamic resource allocation". *Automation in Construction*, *13*(3), pp. 409-420, 2004.
[9] J. Moon, M. park, H. Lee, M. Jung, "Analysis for Construction Lift Planning with Transfer Operation for Super High-rise Buildings", Korean Journal of Construction Engineering and Management, 6(15), pp. 053-062, 2014.