Lifting and transportation in high-rise building construction in Japan: the beginning of integrated lifting and transportation and recent developments

Tomoyuki Gondo*1, Reiji Miura* and Masato Kurosaka**

*Building Construction Management Laboratory, Department of Architecture, The University of Tokyo, Japan; **Department of Architecture, Tokyo Metropolitan University, Tokyo, Japan

ABSTRACT
Lifting and transportation (LT) directly affects construction costs and timetables for high-rise buildings. Recently in Japan, the occupation of professional lifting and transportation subcontractor (PLTS) was established, and the LT construction system has evolved into an integrated lifting and transportation (ILT) system. In the ILT system, PLTSs (rather than general contractors) manage the entirety of LT during construction. However, this change in LT systems since the beginning of high-rise building construction has not been investigated. For the improvement of LT management or productivity, this study aims to clarify the development process of LT and explore recent developments and problems in ILT in high-rise building construction via literature surveys, interviews, questionnaires, and surveys on construction sites. The findings are as follows: First, following an increase in workers’ wages in the 1990s, several PLTSs started working exclusively on LT, and during the 2000s, PLTSs began to manage all LT on construction sites. Second, most PLTS companies are small and have difficulty training workers, and the scope of LT work is not clear. Third, this paper clarifies the types of LT and several LT problems found on construction sites that are caused by a lack of communication between general contractors and PLTSs.

1. Introduction
1.1. Background
In Japan, the building height restriction of 31 m was eliminated in 1964, and the first building, more than 31 m tall, the Hotel New Otani (72 m), was built in the same year. The first building taller than 100 m, the Kasumigaseki Building (147 m), was built in 1968. Following these, numerous high-rise buildings have been built, and construction technology has developed to allow the building of higher and larger buildings within a shorter amount of time. However, a small number of research studies have focused on the technological development of high-rise building construction management in Japan. In particular, lifting and transportation (LT) is vital for construction of high-rise buildings, which require numerous materials, and directly affects the cost and time of construction. These materials are lifted vertically by lifts and transported horizontally on higher floors. When LT is not managed well, materials do not arrive on time, and workers must wait for them. In particular, the quantity and variety of materials used have increased with the construction of high-rise condominiums, which have been built mainly since 2000s because of deregulation in Japan. Moreover, the improvement of productivity on construction sites is an important and urgent issue in Japan because of the severe shortage of workers. However, few research studies have focused on LT.

The LT system has been continuously evolving, particularly for nonstructural materials such as M&E and interior finishing. During the 1960s and 1970s, general contractors planned and directly negotiated LT with their subcontractors. In contrast, after the late 1980s professional lifting and transporting subcontractors (PLTSs) were established and took over other subcontractors’ LT. Currently, one PLTS typically manages all LT of nonstructural materials at a construction site. In this paper, this new LT system is termed integrated lifting and transportation (ILT). These recent changes have not been examined, and there is no comprehensive description of the current LT process in Japan.

1.2. Purpose
The LT system in high-rise building construction directly affects cost and productivity and has changed significantly in recent years. However, little research has focused on LT, particularly on how, and by whom it is managed. For the improvement of LT management or whole productivity on construction sites, this research aims to clarify the LT development process in high-rise building construction in Japan from the 1960s to the 2000s and elucidate recent developments and challenges in LT, including PLTSs and ILT. In particular, this research focuses on the LT system on construction sites, including workers, managers, and contracts.
1.3. Review

There are limited research studies that have focused on the construction history of Japanese high-rise buildings. Kano (2009) described the brief history of construction technologies in Japan. Also, Yamazaki (2015) focused on hybrid structures such as reinforced concrete and steel. These studies focused on several high-rise buildings and made some reference to LT. From another perspective, the transition in machinery for LT was shown by Kurosaka et al. (2018) and CEMA (2010). They noted mechanization and increasing size and speed, among other attributes. However, they did not elucidate the LT construction system, including who does the work and how.

In addition, there have been several construction reports focused on LT, particularly with regard to the Kasumigaseki Building (Nikai and Tamura (1969), Nikai (1974)), and many engineers have referred to them. Gondo (2018) recently examined the features of the Kasumigaseki Building from the perspective of construction and explained the technological features of LT. Regarding other high-rise buildings, several construction reports have been published, some from the perspective of LT, as later described in chapter 3.

After the 1990s, mainly because of the shortage of workers, the Japanese construction industry focused on the productivity of construction, and several reports, or research studies focused on LT. Sawaguchi et al. (1996) documented several LT improvements at that time. In 1990, for example, several Japanese general contractors developed site automation technologies. Bock and Linner (2016) and Eguchi and Ichimura (1997) categorized these automation projects, and several projects attempted to automate or apply robotic technologies to LT, using Yoshida et al. (1997) or other research studies as examples. Regarding recent research studies for the improvement of LT, Jalali Yazdi, Maghrebi, and Bolouri Bazaz (2018) applied a mathematical model to LT simulation to optimize vertical transportation. Moreover, Park et al. (2013) applied a lifting demand-based zoning system. Research studies or trials from the 1990s applied new computer technology to construction.

However, there are few research studies that show the actual state of LT or systems of LT at construction sites. As a rare example, Matsumoto (1997) analyzed LT results at four construction sites of high-rise office buildings, counting the number of lifts according to the type of construction (M&E, curtain wall, etc.). Dobashi, Unami and Yoshida (2001) noted the importance of the rationalization of LT, and in his research studies, he partially described the beginnings of PLTSs and ILT. However, his work mainly focused on the proposition of a new transportation system and not on PLTSs and ILT.

This paper refers to these previous research studies and, in addition, mainly focuses on the following two points. First, this paper examines the transition process of the construction system rather than that of the machinery or buildings themselves; for example, the changing process of who manages the entirety of LT at construction sites and how. Without this understanding of the construction system, it is difficult to improve productivity at construction sites, even if new machinery or automation technology is developed. For this purpose, this paper examines the popularization of PLTSs and ILT in Japan, developments that have not previously been examined.

Second, there are few research studies that investigate recent construction sites or using interviews or questionnaires regarding LT. The increase in PLTSs and ILT was a fundamental change in the construction of high-rise buildings in Japan. Thus, even if the survey was done on one construction site, this paper aims to clarify the characteristics or problems of construction using ILT via interviews with general contractors and PLTSs and the collection of quantitative data for LT.

This paper mainly focuses on the LT of nonstructural materials, such as M&E or interior finishing. These materials are generally lifted by temporary lift.

2. Methodology

The methodology of this paper consists of three parts. First, from a literature review, the authors investigated the evolution of LT for high-rise buildings in Japan from the 1960s to the 2000s. High-rise buildings were built beginning in the 1960s, and in the 2000s, ILT became popular. However, only a small number of reports regarding LT have been published, and it was difficult to collect quantitative data. Thus, the authors collected reports or records of specific buildings, mainly referring to “Architectural Product-Engineering” (published from 1966 to 2001, in Japanese), which contains construction reports for high-rise buildings. The authors selected 92 reports including content regarding LT from the journal. In addition, the authors referred to the company history of general contractors (Kajima Corporation, 2003; Obayashi Corporation, 1993; Shimizu Corporation, 2003; Taisei Corporation, 2003; Takenaka Corporation, 1989) and interviewed 10 engineers of general contractors.

Second, for grasping the PLTS profile and the current state of LT, the authors interviewed four PLTSs and distributed questionnaires to 47 PLTSs; 29 of which responded. The four interviewed PLTS companies are relatively larger than other PLTSs. At present, there are two PLTS associations in Japan: the East Japan Lifting Contractors Association, which consists mainly of PLTSs in eastern Japan, and the Association of Lifting Construction Companies, which consists mainly of PLTSs in western Japan. The authors distributed
questionnaires to all 47 companies listed in the two associations from December 2018 to January 2019. The authors collected 29 completed questionnaires from the Association of Lifting Construction Companies and nine from the Association of Lifting Construction Companies (Table 1).

Third, the authors investigated a construction site for a high-rise condominium building in Tokyo for 2 days in October and December 2018 and collected LT data for 13 days. This building had 41 stories and approximately 600 units (Table 2). On the survey date, approximately 70% of structural construction was finished, and interior finishing was conducted with structural construction. The pace of interior finishing was 6 days/floor. The authors captured the amount and content of LT. In addition, the authors interviewed general contractors and the leaders of the PLTS at the site.

3. Transition of the LT system in high-rise building construction in Japan

3.1. Early stage of high-rise buildings in Japan

Before the beginning of high-rise building construction in Japan, each subcontractor managed their LT using lifts set by general contractors. In many cases, these subcontractors did not create an LT plan before LT began. However, particularly at the beginning or end of daytime construction, many subcontractors tended to use lifts. Thus, in some cases, the lifts required a wait of 1 h or more. Therefore, during the construction of the Kasumigaseki Building, the first high-rise building taller than 100 m in Japan, the general contractor, Kajima Company, used a “central control system” for LT (Figure 1, left). In this central control system, there were several engineers from the general contractor who addressed LT. These engineers belonged to the LT division and collected the schedule of each subcontractor. Each subcontractor was required to designate LT staff, who submitted an LT plan to the LT division at least 1 week prior to the start of LT. The LT division coordinated these plans according to the capacity of the lifts and all of the subcontractors’ schedules. In some cases, the division denied the LT plan if it was not submitted on time or preferred the materials necessary for subcontractors whose schedule was delayed. In addition to an LT division or LT staff, there were workers who worked exclusively for LT, including control of lifts or sorting of materials. LT workers were selected by general workers (Nikai 1974).

After construction of the Kasumigaseki Building, the central control system was typically used for high-rise building construction until the 1980s, the bubble economy period in Japan (Tsuzura, Yukutake, and Sato 1990). From construction reports, it can be seen that there were several characteristic LT systems in other buildings. For example, in the construction of the Yokohama Tenri Kyokan (Architectural Product-Engineering, 1973), subcontractors submitted their list of materials 1 week ahead of time. Compared with the Kasumigaseki Building, the advantage of this system was that general contractors did not need to coordinate subcontractors’ LT requirements. Thus, general contractors could reduce the number of engineers who were in charge of LT.

In addition to the central control system, in the Kasumigaseki Building, the general contractor developed an original container for a pallet system. In the Takihyo Marunouchi Building (1973, 86 m), a specialized container for lighting and sanitary ware was developed to reduce package waste (Architectural Product-Engineering 1974). In the Kobe Commerce, Industry, and Trade Center Building (1969, 110 m), there was limited space for lifts; the general contractor thus set up a temporary stage to receive materials that were lifted by a tower crane (Nikai 1974). Thus, during the 1960s and 1970s, in addition to

3.2. Transition of high-rise buildings in Japan

From 1990 onward, in the early stages of high-rise buildings, LT systems in construction sites were decentralized. Thus, the lifting and transportation system in high-rise buildings in Japan became flexible according to the construction site characteristics and the needs of the general contractor. General contractors thus tended to divide LT into several smaller tasks and manage LT in a central control system. For example, in the construction of the Pacific Century Place Tokyo (1993, 238 m), subcontractors who were responsible for exterior finishing LT planned their LT according to the general contractor’s schedule and sent the plan to the general contractor. A more detailed description of these LT systems is presented in Table 2.

Table 1. Outline of questionnaires.

| Association | East Japan Lifting Contractors Association | Association of Lifting Construction Companies |
|-------------|-------------------------------------------|---------------------------------------------|
| Establishment | Feb. 2017 | Feb. 2016 |
| Companies | 27 | 23 |
| Main field | Eastern Japan | Western Japan |
| Answers (distributions) | 9 (22) | 20 (25) |

Table 2. Outline of the construction site.

| Structure | Reinforced concrete (partially steel reinforced concrete) |
|-----------|------------------------------------------------------|
| Story | 41 stories and two stories underground |
| Building use | Housing (condominium) |
| Construction Duration | 47 months |
| Total floor area | Approximately 75,000 m² |
| Units | Approximately 600 |

Thus, during the 1960s and 1970s, in addition to

Figure 1. The changing process of the Lifting and transportation system in Japan (left: central control system of LT from the 1960s, center: beginning of the PLTS (professional lifting and transporting subcontractors) during the 1990s, right: LT from the 2000s).
the LT central control system, general contractors improved LT by other methods such as temporary packaging and temporary stages.

### 3.2. Computers and automation

In the Kasumigaseki Building, a large computer, SERAC, was mainly used for structural calculation and process planning. After the construction of the Kasumigaseki Building, computer usage gradually increased. The Asahi Tokai Building (1971, 110 m) was the first building in which a construction site had several computers, FACOM-R, which were used for the accumulation of LT results or revision of LT planning (Araki and Yamada 1971). However, the storage capacity of FACOM-R was only 1 kilobyte. Thus, its efficiency was limited. Gradually, the performance of computers improved, and their use spread at construction sites. For example, in the construction of the Umeda Center Building (1987, 125 m), five computers were located at the construction site and were used for LT, and the leaders of the subcontractors inputted their LT requirements via computer (Architectural Product-Engineering 1987). In the construction of the Shin Kobe Oriental City, there were approximately 600 hotel units. The general contractor developed a handy inputting device, and the workers recorded defects by barcode. The computer connected to the device outputted the order sheet for repairs (Architectural Product-Engineering 1989).

Beginning in the late 1980s, several Japanese general contractors began to develop site automation, which treats construction sites as factories. In these site automations, the construction area at the top was covered by a temporary wall and roof, and transportation devices such as hoists were sent to the roof. Thus, the construction site was safer, and the workers did not need to be concerned about rain or wind. As a typical example, the Automated Building Construction System (ABCS) was developed by the Obayashi Corporation. In the ABCS, an automated logistic system was equipped, and materials were transported by their barcode, lifted by an automated material lift, and horizontally transported by a hoist device (Shiokawa, Ohkawa, and Mori 1994).

### 3.3. Outsourcing of LT

Japan experienced a bubble economy from the late 1980s to the early 1990s. In the bubble era, general contractors faced difficulties related to a shortage of workers and increased wages. These problems motivated development of the aforementioned site automation. In addition, owners required higher or larger buildings, which meant an increase in construction materials.

Given this background, LT began to be outsourced to PLTSs. From interviews with general contractors and PLTSs, during the bubble era, some subcontractors (such as interior finishing subcontractors) started to order LT from PLTSs (Figure 1, center). Because the skilled workers of each subcontractor could focus on their own work, their wages were generally higher than those of the PLTS.

This usage of PLTSs spread in large housing construction sites consisting of a number of housing units, particularly construction sites requiring LT of a large quantity of plasterboards or light gage steel (LGS), among others. The subcontractors using these materials for construction started to order LT from PLTSs.

Two of the four interviewed PLTSs answered that the transportation workers of interior finishing subcontractors were the first PLTSs. Originally, these workers were hired only to carry materials to construction sites (e.g., carrying materials to the gates); however, several workers started to lift them to the upper floor and transport them to construction locations (e.g., the rooms of each housing unit). These early PLTSs only contracted as “one-time LT” with each subcontractor and came to the construction site only when they were called for LT tasks.

### 3.4. Beginning of ILT

Following the increase in one-time LTs at large construction sites, subcontractors hired their own PLTSs, and it became difficult for general contractors to maintain safety at construction sites. Therefore, from approximately 2000 onward, some general contractors started to directly subcontract to one PLTS to manage the entire LT of the construction site. These PLTSs started to plan LT for construction sites and manage LT for several subcontractors (Figure 1, right). This was the beginning of ILT in Japan.

This work was originally completed by general contractors. The ILT system has the advantage for general contractors of reducing the number of engineers needed to manage LT and facilitate safety at construction sites. For PLTSs or other subcontractors, it is easier to address sudden revisions to an LT plan according to weather or accidents because PLTSs are stationed at construction sites and know the entire LT plan. All four PLTSs interviewed said that ILT started at large and high-rise apartment and condominium building construction sites. Two PLTSs answered that ILT is generally used for buildings with more than 15 floors. Thus, at high-rise housing building construction sites, ILT is thought to have advantages. However, there are no rules for the application of ILT. The decision depends on the general contractors, though several general contractors answered that there are numerous large construction projects, and thus, one of the important roles of a general contractor is to find a PLTS during the early stage of construction.
4. Questionnaires and interviews

4.1. Outline of business

According to the 29 answered questionnaires, most PLTSs were established following the late 1980s. There was only one PLTS established in 1986; the others were established after 1990. Twenty-four PLTSs started their LT business during the establishment year. Their main businesses at establishment were interior finishing (nine PLTSs), M&E, floor, LGS, earthwork, and structural construction (one PLTS). Thus, nearly one-third of PLTSs started their business mainly from interior finishing.

All 29 PLTSs are doing LT business only in the Tokyo metropolitan region (prefectures from Tokyo, Kanagawa, Saitama, and Chiba) or the Kinki region (prefectures from Osaka, Kyoto, Hyogo, Wakayama, Shiga, and Nara). In interviews, general contractors answered that these PLTSs were working only in the Tokyo metropolitan or Kinki region. In other regions in Japan, high-rise buildings are rare, and thus, it is difficult for a business to obtain sufficient PLTS orders.

In Japan, there are 29 types of Construction Business Licenses. At their establishment, the most common licenses of a PLTS were scaffolding and excavation business (seven) and interior finishing business (seven) (Figure 2). Several PLTSs stated that the main reason for this is that the workers of scaffolding and excavation were completing LT work before the PLTS emerged as a one-Time LT. In addition, PLTSs generally carry the materials for interior finishing. Twelve PLTSs were established without a construction business license or answered unknown.

At present, all 29 types of construction business licenses have been obtained by at least one PLTS (Figure 3). In several cases, PLTSs obtained the construction business license related to the materials of their one-time LT work. For example, a PLTS mainly lifting ceilings or floors tends to obtain an interior finishing business license. At present, the construction business licenses for a scaffolding and excavation business (15 companies) and interior finishing business (15 companies) are the most common. At present, there are no construction business licenses specifically for LT. Thus, the two PLTS associations have advocated for the establishment of a new LT license.

The scale of LT companies is generally estimated by the maximum number of workers who can work for 1 day. This number contains not only regular employees whose insurance is paid by the PLTS but also part-time and temporary employees. The number of workers of 14 PLTSs is less than 50 (Figure 4). However, there are two companies that employ approximately 450 workers per day (one PLTS answered 460, and another answered 450).

For LT workers, 13 PLTSs have an education or training system. For example, several PLTSs have developed a guidebook including cautions according to the type of material, and another PLTS has held lectures. The two associations have each created original education or training systems.

4.2. LT Works and contract

LT work can be divided into one-time LT and ILT. The authors asked for the ratio of ILT sales out of the total LT business. The ratio of seven PLTSs was 0% (they only take one-time LT work), and only six PLTSs had a ratio greater than 50% (Figure 5).

In general, in a one-time LT contract, the PLTS makes a contract with each subcontractor, records the LT work, and claims a payment. General contractors are not involved in one-time LT.

In ILT, there are two types of contracts. In the first type, a general contractor makes a contract with the PLTS. In the second type, the subcontractor makes a contract with the PLTS. In both cases, the LT fee is paid by the subcontractor. However, in the former case, the general contractor deducts the LT fee from the subcontractor’s payment. Thus, in the former case,
the management cost of general contractors is necessary, and the payments by subcontractors increase. In the latter case, the PLTS first obtains permission from the general contractor to work at the construction site and then makes a contract with each subcontractor.

The payment contract for ILT is calculated by working day or lump sum. In a working day contract, the PLTS adds up the number of workers and working days and estimates the monthly payment. In a lump sum contract, the LT price of 1) each material, 2) each room or floor, and 3) the amount for LT (mainly lifting) are first determined. The PLTS requests payment each month according to these calculations. According to interviews with LT companies, lump sum contracts in the form of 1) or 2) are popular because subcontractors can easily determine if the amount for LT is appropriate or not. Approximately 20 years after the beginning of ILT, a consensus has developed regarding the standard price for LT.

Several PLTSs answered that the problem with these contracts is that the planning or management fees for ILT are not included. In previous times, these fees were included in the lump sum contract as a service. Another problem is that the lift operator is
expected to lift the workers of subcontractors in addition to materials, particularly at the beginning of daytime construction. Generally, however, a fee for lifting other subcontractors’ workers is not paid to the PLTS by general contractors or other subcontractors.

4.3. Jobs except for LT

Several PLTSs have taken various construction jobs related to LT when they work as one-time LTs. Based on questionnaires, 14 PLTSs have taken these jobs in addition to LT (N = 25), such as providing equipment for doors or furniture and assistance for other jobs such as interior finishing and cleaning. These jobs were mainly provided by the subcontractors who requested one-time LT.

Twenty-four PLTSs are performing other businesses besides LT (N = 29), such as renovation, security for construction sites, cleaning, dismantling, and transportation. The other five PLTSs only perform LT as their business.

5. Survey of the construction site

5.1. LT system

At the construction site that we surveyed, the composition of the LT team from a PLTS included one leader, two forklift operators, two operators of temporary lifts, and approximately six LT workers (the number changed on a daily basis). These 11 LT team members were employees of the PLTS. In addition, the PLTS had problems with a shortage of workers during the survey time. Thus, the PLTS called in two workers from their subcontracting company. In addition, for qualification tests, etc., the operators of the forklifts had to go to another location. In these cases, the LT leader operated the forklifts.

Figure 6 shows the logistic flow of materials at the site. At this site, there was no place to keep nonstructural materials because there was only a small marginal space that was used for structural materials, such as precast concrete posts and beams. There were two temporary lifts that had speeds of 96 m/min and a maximum load of 2 tons. The truck loading materials came from the right in Figure 6 to unload materials near the lifts, and LT workers or the forklift loaded them onto the lifts.

For ILT in large construction sites, including this construction site, small prefabricated rooms are built for the PLTS. These spaces are termed “LT centers.” At this construction site, the LT center was built near the lifts for ease of management and LT work. On higher floors, the rooms connected to the temporary lift were used as a temporary depot for nonstructural materials. The LT workers on higher floors received materials and kept them in this depot.

At this site, the PLTS and the general contractors made an ILT contract directly. The price of LT was determined by the amount of LT. There were three patterns of LT pricing: 1) vertical lifting, 2) vertical lifting and horizontal transportation, and 3) small LT. Small LT meant that subcontractors brought the materials to the lift themselves. The price of this lifting was lower than 1) or 2) because the PLTS only operated the lift. For example, the PLTS at this site did not contract with glass subcontractors via 1) or 2) because of the risk of breaking glass.

5.2. LT flow

(1) Preparation and LT planning before construction

LT flow at the construction site was as follows. After creating the contract, the PLTS estimated the LT amount and schedule from documents provided by the general contractor, including the plan of temporary work and the total work schedule. At the beginning of LT planning, facilities for LT, including lifts, were determined by the general contractors. From this information, the PLTS
determined the price of LT. Afterward, the PLTS held an explanatory meeting with the other subcontractors. At the meeting, the PLTS explained the rules and the price of LT, including the deadline to submit the LT plan and other details. According to the interviews, general contractors and LT companies said that these workflows before construction have become common at other construction sites for high-rise condominiums.

(2) Daily and weekly LT planning

By using ILT, the PLTS managed every material lifted by the lifts for every subcontractor. Thus, every subcontractor who wanted to lift materials had to apply for LT. The subcontractors submitted the application form for the next week’s LT on Wednesday. Then, the PLTS integrated every application form, made the LT plan for the following week, and sent it to the subcontractors on Friday. However, depending on the progress of the construction, the LT plan could be changed. Therefore, the PLTS needed to manage the LT plan according to the situation. In addition, in several cases, the PLTS accepted exceptional LT orders when the number or amount of materials became different from the LT plan or when the subcontractors asked for extraordinary LT on a particular day. LT leaders managed these sudden changes.

(3) LT Jobs

After materials arrived at the sites, they were inspected by the subcontractors, and the LT workers unloaded them from trucks. Before lifting to the upper floor, the materials were sorted according to floors or rooms by the PLTS because of the limited amount of materials that could be lifted at once. Then, the materials were lifted by temporary lifts and transported horizontally by LT workers.

5.3. Number of LTs

The standard time for interior finishing jobs at this construction site was 6 days per floor. We investigated LT records from 13 days, which were approximately two floors’ worth of construction for interior finishing jobs.

The total number of lifts was 1,114 (on average, 85.7 lifts/day). There were 33 different types of materials: six for M&E and 27 for other construction types (called architectural construction). These types were defined by the PLTS. Forty subcontractors used LT: eight subcontractors for M&E construction and the rest for other types of construction. Table 3 shows the number of 1) LT (to rooms), 2) lifting only, and 3) other types (a small amount of lifting achieved by subcontractors directly to the lift). In M&E LT, the ratio of 2) lifting only was 90.8%; in contrast, for architectural construction, the ratio was 62.7%. The leader of the PLTS said that recently, there had been a shortage of LT workers; thus, subcontractors contracted other workers only for horizontal transportation on the upper floor in addition to the PLTS. In particular, the M&E subcontractors were larger than other types of subcontractor. Thus, under the M&E subcontractors (first subcontractors), there were second, or third subcontractors who
were used only for horizontal transportation. Therefore, the ratio for lifting only was higher than for the other subcontractors.

Table 4 shows the number of LTs according to the material. The lifting of the top three materials, LGS, plasterboards, and floorboards, accounted for 46.3%. These relatively heavy materials were sorted after being unloaded from trucks. Thus, the number of LTs increased. Similar to the subcontractors, there were materials in which the ratio of 2) lifting only was high, such as for ALC, LGS, floorboards, and kitchen units. This depended on whether the subcontractors called their own workers for horizontal transportation on the upper floor.

5.4. Problems at the construction site

At the construction sites, there were four main problems related to LT work. First, it required considerable time to sort materials that were delivered to the construction sites by package, particularly air ducts and similar items. These packages were too large to bring in the lifts. However, it was difficult to package materials according to the size of the lift before delivery to the construction sites. This was because these packages were too small for trucks, which would decrease transportation efficiency.

The second problem was the bumps at the construction site. For example, there was a bump of approximately 15 cm in front of the lift. Furthermore, in the house units, there were several stepped slabs for the bathroom, toilet, etc. These bumps or steps obstructed the use of a cart, and in the rooms, LT workers had to carry them without carts (Figure 8).

Third, several other subcontractors’ jobs obstructed LT work. For example, during the concrete casting of the upper floor, the pump car, and concrete mixer truck blocked off access to one of the lifts. Thus, LT jobs were performed by only one lift (Figure 9).

Fourth, the productivity of LT is dependent on the skill of the LT leader. For example, this leader managed exceptional LT and controlled the forklift when the driver was absent. It is necessary to train or educate LT leaders and workers. The four PLTSs interviewed said that it requires approximately 3 years for LT leaders to acquire the necessary skills.

6. Discussion

6.1. Development process

In Japan, the LT system for high-rise buildings has developed based on the management of general contractors. At the beginning of high-rise construction in the 1960s through the 1990s, general contractors made LT plans and discussed them with subcontractors. From the late 1980s, several PLTSs were established because of the high cost of subcontractors or the increase in the amount of materials needed for large apartments and condominium buildings. Finally, starting in the 2000s at large construction sites for high-rise condominiums in urban areas, several PLTSs played a role that typically had been played by general contractors. Recently, ILT has become popular in high-rise building construction in urban areas, and prices for LT have become somewhat standardized. These developments in LT show a decrease in direct management by general contractors and an increase in the responsibility of PLTSs. Japanese general contractors are thus freed from complicated negotiation with many subcontractors and have decreased their management fees for LT. The most important result is the changing process of the LT management system in Japan from the beginning of high-rise building construction to the present, which has not been pointed out in previous research focusing on the machinery of LT (Kurosaka et al. (2018), CEMA (2010)) nor in previous research on LT systems (Dobashi, Uenami, and Yoshida (2001), Matsumoto (1997)), which focuses only on a certain point in time.

Table 3. Amount of lifting in M&E construction and architectural construction.

| Construction  | Types of material | Number of subcontractors | Total | 1) Lifting & transportation | 2) Lifting | 3) Others |
|---------------|-------------------|--------------------------|-------|-----------------------------|-----------|----------|
| M&E           | 6                 | 8                        | 195   | (100%)                      | 16        | 177      | 2        |
| Architectural | 27                | 32                       | 919   | (100%)                      | 340       | 576      | 3        |
| Total         | 33                | 40                       | 1114  | (100%)                      | 356       | 753      | 5        |

Table 4. Amount of lifting (materials).

| Rank | Materials    | Amount of lifting (kg) | Ratio (%) | 1) Lifting & transportation | 2) Lifting | 3) Others |
|------|--------------|------------------------|-----------|-----------------------------|-----------|----------|
| 1    | LGS          | 216                    | 19.4      | 128                         | 88        | 0        |
| 2    | Plasterboard | 185                    | 16.6      | 73                          | 112       | 0        |
| 3    | Floorboard   | 115                    | 10.3      | 2                            | 112       | 1        |
| 4    | Piping       | 93                     | 8.3       | 1                            | 91        | 1        |
| 5    | Kitchen      | 69                     | 6.2       | 1                            | 68        | 0        |
| 6    | Openings     | 57                     | 5.1       | 21                           | 36        | 0        |
| 7    | Furniture    | 43                     | 3.9       | 37                           | 6         | 0        |
| 8    | Finishing    | 42                     | 3.8       | 36                           | 6         | 0        |
| 9    | ALC          | 36                     | 3.2       | 1                            | 35        | 0        |
| 10   | Bath unit    | 35                     | 3.1       | 0                            | 35        | 0        |
6.2. Problems with productivity

The other contribution of this research is to clarify the problems of LT at recent construction sites according to the changes in LT management. Until the 1990s, improvements in LT had been achieved by general contractors using machinery or automation. General contractors have the responsibility for the overall management of construction, including LT. However, they have recently decreased their involvement in LT. On the basis of our research, we observed several new problems at the construction site.

First, the pumping car obstructed the lift. This problem occurred because the general contractor was not directly involved with LT. In addition, general contractors tend to complete structural construction prior to interior finishing and M&E. There are two possible solutions. The general contractor can either rejoin LT planning or obtain feedback from the PLTS regarding LT planning and temporary planning. Because ILT began after the 2000s, at present, managers of general contractors know how to manage LT. However, the number of managers of general contractors who do not have experience in LT will increase. Several previous studies have been

Figure 7. Bump in front of lift No. 2.

Figure 8. Transportation to the room on the upper floor.
undertaken from the viewpoint of general contractors or researchers. However, the results of this research show that it is important for general contractors to obtain feedback from the PLTS.

Second, the productivity of LT depends on the ability of the PLTS leader. In the case of an exceptional LT, the leader decides which materials should be lifted, considering the whole schedule of the subcontractors. However, there are no standard qualifications for LT workers. Additionally, there is currently a shortage of LT workers. To solve these problems, there should be manuals or systems to train exceptional LT leaders, or the LT association, or company should train them. Moreover, the scope of LT work is unclear. The license or work beyond LT is diverse, and in many cases, the PLTS is not responsible for the management of LT or lifting of the subcontractors’ workers, which is seen as a service. In addition, PLTSs are often asked to do other jobs. In these situations, it is difficult to provide educational materials or courses. It is necessary to make the scope of work clear at the beginning. When PLTSs help with other projects, their responsibilities can become vague. This study is an important contribution because it is the first study that is based on data from questionnaires, interviews, and construction site surveys on PLTSs.

Finally, in LT jobs, a huge amount of material is lifted and transported. Thus, as written in previous research, starting in the 1970s, there were several tests to apply computer technology to LT. From the late 1980s to the early 1990s, there were typical site automation trials. However, particularly for high-rise condominiums, which use a significant quantity and variety of materials and whose designers or residents require a lot of design revision, it is difficult to rationalize using only computer technology, such as in Yoshida et al. (1997) or Jalali Yazdi, Maghrebi, and Bolouri Bazaz (2018). Therefore, in addition to addressing these trials, it is important to revise design and construction flow and include deadlines for such revisions. For these improvements, general contractors, or designers should get feedback from PLTSs.

Though the importance of LT has been pointed out by several previous studies, this research specifies the actual problems at recent construction sites and thus constitutes a first step toward the improvement of productivity.

7. Conclusion

This study showed three main findings as follows:

1. In Japan, after the 1960s, the construction system related to LT changed. In particular, exclusive LT subcontractors (PLTSs) appeared during the bubble era; from the 2000s, they expanded their work scope to include LT management, which had been the work of general contractors. Thus, ILT became common in high-rise building construction in megacity areas such as Tokyo and Osaka. This process decreases the involvement of general contractors with LT.
2. From the questionnaires of two PLTS associations in Japan, we showed the company profile...
and current status for PLTSs. Such a comprehensive survey of PLTSs had not been performed before. We found that at present, most PLTSs are relatively small companies that use fewer than 50 LT workers per day and mainly undertake one-time LT work. Also, the scope of their work is not clear. This makes it difficult to educate or train LT workers or improve the productivity of construction sites by applying new technologies.

(3) From this intensive survey of one construction site of a high-rise condominium, we clearly determined the amount and types of materials lifted and the problems that occurred to decrease productivity. In particular, to improve LT, it is important to involve general contractors or to obtain feedback from the PLTSs. The survey was performed at only one construction site; however, there are no prior research studies that have focused on LT from the viewpoint of the PLTS or ILT. In addition, from interviews with general contractors and PLTSs, the systems, and problems seen at this construction site were found to be typical to a certain extent.

(4) Subjects for further study are as follows: 1) to collect further data for LT at construction sites. Particularly, additional work is required for building types other than condominiums. For example, high-rise office buildings have larger floors than condominiums, thus potentially making it easier to improve LT productivity. 2) The ideal relationship between general contractors and PLTSs or the improvement of the working environment of PLTSs, particularly to clarify the scope of work and develop a training or qualification system for LT workers. Such research is fundamental to improving the situation at construction sites and can refer to other subcontractors’ work or contracts. 3) The possibility of applying new IT technologies to LT, considering the problems highlighted in this study. For example, such research should consider that in most cases, LT is managed by small PLTSs, and thus, new technologies should be available for these small companies.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**Funding**

This work was supported by the JSPS KAKENHI under Grant 18K13890.

**ORCID**

Tomoyuki Gondo http://orcid.org/0000-0002-6125-865X

**References**

Araki, M., and K. Yamada. 1971. "Mini-computer System in Construction Site." *Technical Research Report of the Shimizu Institute of Technology*. Vol. 18, 189–196. Tokyo: Shimizu Institute of Technology. (in Japanese).

Architectural Product-Engineering. 1973. 6. No.92, 28-65. Shokokusha (in Japanese).

Architectural Product-Engineering. 1987. 12. No.267, 69-78, Shokokusha (in Japanese).

Architectural Product-Engineering. 1989. 5. No. 283, 73-90, Shokokusha (in Japanese).

Architectural Product-Engineering. 1974. 7. No.105, 23-40, Shokokusha (in Japanese).

Bock, T., and T. Linner. 2016. “Volume 4: Site Automation.” In *Automated/Robotic On-Site Factories, Cambridge Handbooks on Construction Robotics*. Cambridge University Press. doi:10.1017/CBO9781139872027.

CEMA (The Japan Construction Equipment Manufacturers Association). 2010. The 20years History of CEMA. Tokyo: CEMA. (in Japanese).

Dobashi, T., T. Uenami, and T. Yoshida. 2001. “Development of the Management Method in the Physical Distribution of Construction materials–A Simulation Method in Physical Distribution.” In *Proceedings of the Seventeenth Symposium on Building Construction and Management of Projects*, 207–212. Tokyo: Architectural Institute of Japan. (in Japanese).

Eguchi, T., and A. Ichimura. 1997. “Comparison of Conveying Systems in Several Automated Building Construction Systems.” In *11th Construction Robot Symposium*, 63–69. Tokyo: Architectural Institute of Japan. (in Japanese).

Gondo, T. 2018. *Building System Kasumigaseki Building*, 250–287. Tokyo: Mitsui Fudosan. (in Japanese).

Jalali Yazdi, A., M. Maghrebi, and J. Bolouri Bazaz. 2018. “Mathematical Model to Optimaly Solve the Lift Planning Problem in High-rise Construction Projects.” *Automation in Construction* 92: 120–132. doi:10.1016/j.autcon.2018.03.029.

Kajima Corporation. 2003. *The History of Kajima Corporation 1970–2000*. Tokyo: Kajima Corporation. (in Japanese).

Kano, N. 2009. “Seko-shi.” [Construction History] In *BCS Prize-winning Works 1960–2009*, 148–171. Tokyo: Shinkenchikusha. (in Japanese).

Kurosaka, M., R. Miura, Y. Matsumoto, and T. Gondo. 2018. "Transition of Construction of the Skyscraper in Japan-Productivity in the Lifting and Transportation.” In *Proceedings of the Thirty-Fourth Symposium on Building Construction and Management of Projects*, 141–146. Tokyo: Architectural Institute of Japan. (in Japanese).

Matsumoto, T. 1997. “A Study of the Method of Planning to the Vertical Transportation of Building Materials for Highrise Building Construction.” *AIU Journal of Technology and Design* 5: 27–30. Architectural Institute of Japan. (in Japanese). doi:10.3130/aijt.3.27.

Nikai, S. 1974. Vol.4 Construction. Series of Skyscrapers. Tokyo: Research Institute of Kajima. (in Japanese).

Nikai, S., and Y. Tamura. 1969. "New Construction Management system–Report on Kasumigaseki Building 2." *Architectural Product-Engineering* 6: 79–87. Shokokusha (in Japanese).

Obayashi Corporation. 1993. *The 100 Years History of Obayashi Corporation*. Tokyo: Obayashi Corporation. (in Japanese).

Park, M., S. Ha, H. Lee, Y. Choi, H. Kim, and S. Han. 2013. “Lifting Demand-based Zoning for Minimizing Worker Vertical Transportation Time in High-rise Building Vertical Transportation System.” *Automation in Construction* 25: 15–28. doi:10.1016/j.autcon.2012.10.019.
Construction." Automation in Construction 32: 88–95. doi:10.1016/j.autcon.2013.01.010.
Sawaguchi, M. 1996. Special Issue: Rationalization of Transportation and Construction Management. Vol. 3. Tokyo: Kenchiku Gijutsu. (in Japanese).
Shimizu Corporation. 2003. The 200 Years History of Shimizu Corporation. Tokyo: Shimizu Corporation. (in Japanese).
Shiokawa, T., T. Ohkawa, and T. Mori. 1994. “Development of an Automated Building Construction System.” Report of Obayashi Corporation Technical Research Institute, No.49, 1–6. Tokyo: Obayashi Corporation Technical Research Institute.
Taisei Corporation. 2003. The 140 Years History of Taisei Corporation. Tokyo: Taisei Corporation. (in Japanese).
Takenaka Corporation. 1989. The 90 Years History of Takenaka Corporation. Tokyo: Takenaka Corporation. (in Japanese).
Tsuzura, T., K. Yukutake, and Y. Sato. 1990. “Development of a Computer-aided Vertical Transportation System for High-rise Construction.” In Proceedings of the Sixteenth Symposium on Building Construction and Management of Projects, 91–96. Tokyo: Architectural Institute of Japan. (in Japanese).
Yamazaki, Y. 2015. “Evolution of Construction and Management Technologies in Super Highrise Buildings with Hybrid Building Structures.” In Architectural Production Seminar, 1–8. Tokyo: Architectural Institute of Japan. (in Japanese).
Yoshida, N., T. Kanagawa, Y. Tani, and Y. Oda. 1997. “Development of an Automatic-oriented Sheltered Building Construction System.” In Proceedings of the Fourteenth International Symposium on Automation and Robotics in Construction, 129–138. Pittsburgh (USA): IAARC.