Journal of Civil Engineering and Management
ISSN 1392-3730 / eISSN 1822-3605
2021 Volume 27 Issue 3: 203–216
https://doi.org/10.3846/jcem.2021.14514

ANALYSIS OF CONSTRUCTION PRODUCTIVITY BASED ON CONSTRUCTION DURATION PER FLOOR AND PER GROSS AREA, WITH IDENTIFICATION OF INFLUENTIAL FACTORS

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Received 29 March 2020; accepted 9 February 2021

Abstract. This study analyzes construction productivity based on the construction duration per floor and per gross area over 20 years (1996–2015) and compares the results among the United States, United Kingdom, South Korea, and Japan, which have similar sizes of total construction investment and market risk. Although construction labor productivity is widely used to analyze and compare construction productivity among countries, it does not consider the changed construction duration caused by levels of investment and technology. Therefore, construction duration per floor and gross area was selected analyze and compare construction productivity in this paper. Regular and non-modular buildings with a total of five or more floors and a basement are collected during the analysis period (1996–2015). The total number of collected buildings is 800 and it includes buildings in the United States (194), the United Kingdom (186), South Korea (322) and Japan (98). Construction duration, increase rate and standard deviation are then compared between each country. Finally, factors that influence construction duration are derived and additionally considered to explain and adjust the trends and changes of construction productivity related to construction duration in the four countries. The productivity of the United States is the highest, but the difference between it and other countries decreases steadily because the increase rate of the construction duration in the United stated is larger than those of other countries. Then, the factors influencing the construction duration are derived as a learning effect by the number of ground floors and gross area, as well as the rate of constructed buildings with a first basement floor for efficient productivity management. The rate of the first basement floor influences both the construction duration per floor and per gross area. This study contributes to the field by explaining the productivity change based on the construction duration and proposing the key management point of the productivity by deriving the influence factors.

Keywords: construction duration, increase rate of construction duration, influence factors, learning effect by the number of floors and gross area, rate of the first basement floor.

Introduction

Construction productivity has a great influence on countries' productivity because the gross domestic product (GDP) makes up 13% of the global GDP of the construction industry (Banaitienė et al., 2015; Bughin et al., 2017). Productivity is a measure of the efficiency of outputs in terms of inputs, such as labor and capital (Vogl & Abdel-Wahab, 2015). For improving the productivity, a change in productivity could be analyzed from the past to the present because the reason for the change could be identified and an improved method could be proposed. This study analyzes the construction productivity over 20 years (1996–2015).

Most previous studies selected construction labor productivity as the index, then analyzed the productivity from the past to the present and compared this among different countries (Organisation for Economic Co-operation and Development [OECD], 2001; Harrison, 2007; Freeman, 2008; Abdel-Wahab & Vogl, 2011; Choy, 2011; Gregori & Pietroforte, 2015). However, the construction labor productivity does not reflect the project characteristics (Liao

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et al., 2011), construction and management capacity (El-Gohary & Aziz, 2014; Durdyev et al., 2018) or site conditions (El-Gohary & Aziz, 2014). For mitigation of the limitations, several previous studies analyzed productivity using the construction duration per floor and per gross area (Sacks & Barak, 2005; Won & Lee, 2008). However, the previous studies did not analyze and compare the productivity change from the past to the present using both these measurements. Construction labor productivity which is widely used to analyze and compare construction productivity does not consider the changes of construction duration caused by differences of investment and technology. Therefore, this study aims to analyze the productivity using the construction duration per floor and per gross area among countries with similar sizes of total construction investment and market risk. Furthermore, the influence factors are derived based on the analyzed construction durations for finding the reasons for the significant increase in construction duration. Although there are many parameters affecting construction duration (Chan, 1998; Chan & Kumaraswamy, 2002; Nguyen et al., 2013), parameters related to project scope and complexity was commonly used in previous studies rather than project environment and management attributes (Chan & Kumaraswamy, 2002). Parameters associated with project scope and complexity included gross floor area, the number of stories, building types, buildability of project design, and so on and they were used in this paper.

This study selects the Asia-Pacific, West European, and North American regions for productivity analysis, because the construction investments are the highest in these regions. Then, for comparison of the productivities (Table 1), the United States, the United Kingdom, South Korea, and Japan are selected among the regions based on the highest investment and lowest market risks in the Architecture, Engineering, and Construction (AEC) industry (IHS, 2013). The selected countries were underlined in Table 1.

This study is divided into three steps. First, the differences between this study and the previous studies are explained via literature review, and the methods of collecting and analyzing the data for the construction duration per floor and per gross area are explained. Then, the construction duration, increase rate, and standard deviation per floor and per gross area are analyzed and compared among the countries. The increase rate is selected because the influences of the exchange rate and the difference of the collected data from the various countries are low (Harrison, 2007); furthermore, the standard deviation is selected for a stability analysis of the productivity. Finally, the factors influencing productivity are derived based on the collection method of the case data, as the number of ground and basement floors and the gross area. Generally, if the number of ground floors and gross area increase, the construction duration can decrease because of the learning effect related to repetitive work. The construction duration of a basement floor is longer than that of a ground floor because of uncertain geological features, such as rock and underground water.

1. Literature review

Construction productivity is divided into total factor productivity (TFP), which is based on all input and output factors, and partial factor productivity, which is based on single or partial input and output factors (Fulford & Standing, 2014). Among previous studies related to TFP, Hu and Liu (2017) analyzed productivity based on both construction growth and carbon reduction to reflect the influence of carbon reduction on TFP. Zhi et al. (2003) analyzed the relationship between the construction industry's productivity and economic growth in Singapore using TFP. Total factor productivity is generally used for productivity measurement at the industry level (Zhi et al., 2003), but it is difficult to define and measure all input factors for output (Robles et al., 2014; BLS, 2016).

In previous studies of the labor-intensive construction industry, partial factor productivity through construction labor productivity was used more often to measure industry efficiency than total factor productivity (Rojas & Aramvareekul, 2003; Jarkas, 2010b; Robles et al., 2014). Construction labor productivity is generally used for measurement of industries' efficiency via relation analysis between the labor (input factor) and building components (output factor) (Vereen et al., 2016). Previous studies of construction labor productivity have analyzed specific construction types and work (Jarkas, 2010a; Han et al.,

Table 1. Construction investment and risk scores of top 10 countries (HIS, 2013)

No.	Country	Region	5-year risk score (1 = lowest risk)	Total construction investment (2013, billions of USD)
1	**United States**	**North America**	**6.54**	**888.8**
2	Canada	North America	8.86	207.3
3	**United Kingdom**	**Western Europe**	**11.02**	**301.1**
4	**South Korea**	**Asia Pacific**	**11.22**	**153.8**
5	**Japan**	**Asia Pacific**	**11.47**	**741.9**
6	Australia	Asia Pacific	11.77	216.5
7	Spain	Western Europe	12.64	209.3
8	France	Western Europe	13.16	304.2
9	Netherlands	Western Europe	13.19	87.7
10	Italy	Western Europe	13.57	195.5

2017; Forsythe & Sepasgozar, 2018), as well as the factors that influence labor productivity (Enshassi et al., 2007; Alinaitwe et al., 2007; Shoar & Banaitis, 2019).

Previous studies used the total work time as the input factor and gross production as the output factor for each country's construction industry (Allmon et al., 2000; Goodrum et al., 2002, 2009; Rojas & Aramvareekul, 2003; Nasir et al., 2014). Labor productivity is difficult to compare internationally because each country uses data based on different criteria. For international comparison, Vogl and Abdel-Wahab (2015) proposed the project level as the comparison criterion for each country's productivity. Chia et al. (2018) proposed a method of comparing the productivity of international construction labor using purchasing power parities (PPPs). PPPs is used to convert from each country's currency to common currency. Productivity is also influenced by factors such as project characteristics, construction and management capacity and site condition. However, the construction labor productivity does not sufficiently reflect on the technical competitiveness because the construction labor productivity is calculated by gross output, such as sales, and input, such as the number of employees and total work time. Especially, construction labor productivity could not reflect the characteristics of buildings, such as heights and large areas.

To mitigate the limitations of construction labor productivity, several previous studies have analyzed the productivity using the construction duration per floor and per gross area (Sacks & Barak, 2005; Won & Lee, 2008). Sacks and Barak (2005) used the construction duration per floor and per gross area for analysis of the implementation effect by three-dimensional (3D) modeling. Won and Lee (2008) used the construction duration per floor for the productivity analysis. The construction duration can reflect the factors more than the construction labor productivity can because the learning effect by increasing of the number of floors (Wideman, 1994; Chan & Kumaraswamy, 2002; Couto & Teixeira, 2005; L. D. Nguyen & H. T. Nguyen, 2013; Nguyen et al., 2013) and gross area (Chan & Kumaraswamy, 2002; Nguyen et al., 2013) of superstructures and substructures of buildings could be reflected in it. The construction duration per floor represents the productivity when the building is increased vertically, while the construction duration per gross area represents the productivity when the building size is increased horizontally. For improving the construction productivity, the past level of construction productivity and the differences with other countries should be analyzed as well as the current level. Furthermore, the influence factors on construction productivity should be derived. However, the previous studies did not analyze or compare the change of the productivity during the long period based on both the construction durations per floor and per gross area in various countries. This study analyzes the productivity among the United States, the United Kingdom, South Korea, and Japan using the construction duration per floor and gross area and derives the factors affecting the productivity to determine reasons for increased construction durations.

2. Research methods

This section explains how to collect required actual building data and measure and compare construction productivities related to construction duration in the AEC industries of South Korea, Japan, the United States, and the United Kingdom using the collected data. Construction duration per floor and 1,000 m^2 gross area of buildings were used as measurements in this paper. In order to explain trends and changes in the analyzed results, descriptive statistical information was provided and factors affecting construction duration were additionally considered.

2.1. Data collection

This paper utilized construction duration per floor and 1,000 m^2 gross floor area of buildings as indicators to measure and compare construction competitiveness of the four countries, from the perspective of project schedule. Construction duration per floor and 1,000 m^2 gross floor area of buildings was measured by dividing total construction duration to construct a building by the number of floors of the building and by 1,000 m^2 gross floor area of the building, respectively. Criteria to select appropriate buildings being analyzed were set to measure their construction duration per floor and compare the results under similar conditions including scopes and complexity of buildings projects. Although there were many parameters affecting construction duration, project scope and complexity was commonly used as main parameters in previous studies rather than project environment and management attributes (Chan & Kumaraswamy, 2002). The criteria selected in this paper are as follows:

- Collection period: Information on buildings completed from 1996 to 2015 is collected;
- Number of floors (Wideman, 1994; Chan & Kumaraswamy, 2002; Couto & Teixeira, 2005; L. D. Nguyen & H. T. Nguyen, 2013): Information on buildings with a total of more than five floors, including the ground and basement floors, is collected. Low-rise buildings with a total of less than five floors are excluded because the difference in gross area in the building characteristics is large. The influence of external construction factors, such as weather, is also large because the construction duration is short compared with that of high rise buildings;
- Basement floor (Nguyen et al., 2013): The construction duration of a basement floor is generally greater than that of a ground floor because additional works, such as earth work, foundation work, and piling are required. Thus, information on buildings that include at least one basement floor is collected. Won and Lee (2008) reported that there was a positive relationship between construction duration per floor of buildings and the basement floor rate of buildings located in South Korea and Japan;
- Building type (Chan, 1998; Chan & Kumaraswamy, 2002): Only information on regular buildings is col-

lected because the construction duration of an irregular building is generally greater than that of a regular building. Irregular buildings include leaning, twisted, narrow, and curved types, which are different from the quadrangle type.
– Non-modular buildings (Chan, 1998; Chan & Kumaraswamy, 2002): Modular buildings, such as apartment buildings, are excluded because the construction duration of modular buildings can be decreased by similarity and mass production.

Data on the number of floors, total gross floor areas, construction durations, countries, shapes, types, and completion years of building projects were collected from various websites, and published paper, book, and magazines. The total number of buildings collected to measure construction duration per floor in the four countries in this paper was 800, including 194 in the United States, 186 in the United Kingdom, 322 in South Korea, and 98 in Japan. For Japan, the data for the period of 2006–2015 were collected because the completion dates from 1996 to 2005 were not collected in this country. Among the collected data, when the difference in the data from median value is larger than three times the standard deviation, the data are excluded from the analysis because they are identified as outliers (Burke et al., 2018). The collected data are divided into four groups based on completion time for analysis. A group analysis is more suitable than an annual analysis because constructing a building generally takes more than one year. The first group is from 1996 to 2000, the second is from 2001 to 2006, the third is from 2006 to 2010, and the fourth is from 2011 to 2015.

2.2. Calculation method of the construction durations

The productivity is analyzed depending on the construction duration per floor and per gross area using similar methods used in previous studies (Sacks & Barak, 2005; Won & Lee, 2008), and this is compared among the United States, United Kingdom, South Korea, and Japan based on the average construction duration, increase rate, and standard deviation of the construction duration. The increase rate and standard deviation are commonly used to show changes and ranges in the results analyzed during 20 years. Based on collected case buildings, the construction duration per floor and per gross area are calculated by Eqns (1) and (2):

$$CDF_{i,j} = \sum_{k=1}^{K} \left(CD_{i,j,k} / NF_{i,j,k} \right) \times \frac{1}{NB_{i,j}}, \tag{1}$$

where $CDF_{i,j}$ is an average construction duration per floor in country i during period j; $CD_{i,j,k}$ is the construction duration of building k in country i during period j; $NB_{i,j}$ is the number of buildings in country i during the period j; $NF_{i,j,k}$ is the number of floors of building k in country i during period j.

$$CDFA_{i,j} = \sum_{k=1}^{K} \left((CD_{i,j,k} / TFA_{i,j,k}) \times 1{,}000 \right) \times \frac{1}{NB_{i,j}}, \tag{2}$$

where $CDFA_{i,j}$ is the average construction duration per gross area in country i during period j; $TFA_{i,j,k}$ is the gross area of building k in country i during period j.

Among the methods of data collection (Section 3.1), the data collection period and the attributes of regular and non-modular buildings are applied in the same way for all cases. However, the number of ground floors, gross area, and number of basement floors are applied differently by case, and these are related to the learning effect. The construction duration of the basement floor is generally longer than that of the ground floor. Thus, this study analyzes the learning effect relying on the number of ground and basement floors and the construction duration by the rate of the basement floor, and it derives the influence factors on productivity.

3. Construction duration per floor

3.1. Productivity analysis

The construction duration and increase rate per floor and standard deviation are analyzed using Eqn (1) (Table 2). In the results, the construction duration in the United States is the shortest (37.2 days), but the increase rate of the construction duration is the highest (41.8%). The construction duration of the United Kingdom is longer than that of the United States, but the difference from the United States is steadily decreasing because the increase rate is low (0.2%). The construction durations of South Korea (59 days) and Japan (59.9 days) are both longer than those of the United States and United Kingdom, but the increase rate of South Korea is high (38.4%), while that of Japan is negative (–12.5%). The stability levels of the construction productivity of the United Kingdom and Japan are high because the standard deviation of the United Kingdom (4.8 days) and Japan (4 days) are smaller than those of South Korea (9 days) and the United States (7.8 days). The increase rate of the construction duration of the United Kingdom and Japan are commonly low. While the productivities of the United States and South Korea have decreased, the productivity of Japan has increased and the productivity of the United Kingdom has changed little. For the United States and South Korea, the predictability of the construction duration per floor could be difficult because the stability of the productivity is low. In order to find reasons to make differences of construction duration per floors among the four countries during around 20 years, learning effects related to the number of floors of superstructures and substructures of buildings was additionally considered in the next section. Besides the learning effects of increasing gross areas, other factors can affect construction duration of buildings projects, such as advanced construction equipment and methods. However, they were not considered as an adjustment method in this paper.

Table 2. Construction duration per floor (1996–2015; unit: day)

Period	United States	United Kingdom	South Korea	Japan
1996–2000	34.0	49.1	47.2	
2001–2005	39.5	53.9	53.6	
2006–2010	27.0	40.7	69.8	63.9
2011–2015	48.2	49.2	65.3	55.9
Average duration	37.2	48.2	59.0	59.9
Standard deviation	7.8	4.8	9.0	4.0
Average increase rate	21.1%	2.1%	12.5%	–12.5%
Increase rate from the 1^{st} to last group	41.8%	0.2%	38.4%	–12.5%

3.2. Influence factors

For the learning effect, the construction duration per floor is analyzed according to an increasing number of floors (Figure 1). The collected data are divided into five groups (1–10, 11–20, 21–30, 31–40, and 41+ floors). A learning effect is present for all four countries, but the construction duration per floor steadily decreases with more floors. That is, the learning effect is the largest for floors 1–10. The learning effect is evident in buildings with more than 30 floors defined as high-rise buildings in South Korea (MOLIT, 2016), but the effect is not large. Thus, if only the construction duration per floor is used for the productivity analysis, the productivity can be high when the number of ground floors is low and the construction duration is short.

As a learning effect depends on the number of basement floors, the collected data are divided into first, second, third, fourth, and fifth basement floors (Figure 2). The construction durations of the four countries are long for the first basement floor, while they decrease according to an increasing number of basement floors. However, the construction duration is increased temporarily for the fourth (United States and South Korea), third (United Kingdom), and fifth (Japan) basement floors. Especially, in the case of the United States, the construction durations of the fourth and fifth basement floors are greater than those for the second and third basement floors. The construction of a basement floor is influenced by uncontrollable factors, like characteristics of rock and geology, and these could be why the learning effect is unusual even when the number of basement floors increase. As a result, the relationship between the construction duration and number of basement floors is relatively low compare to the number of ground floors.

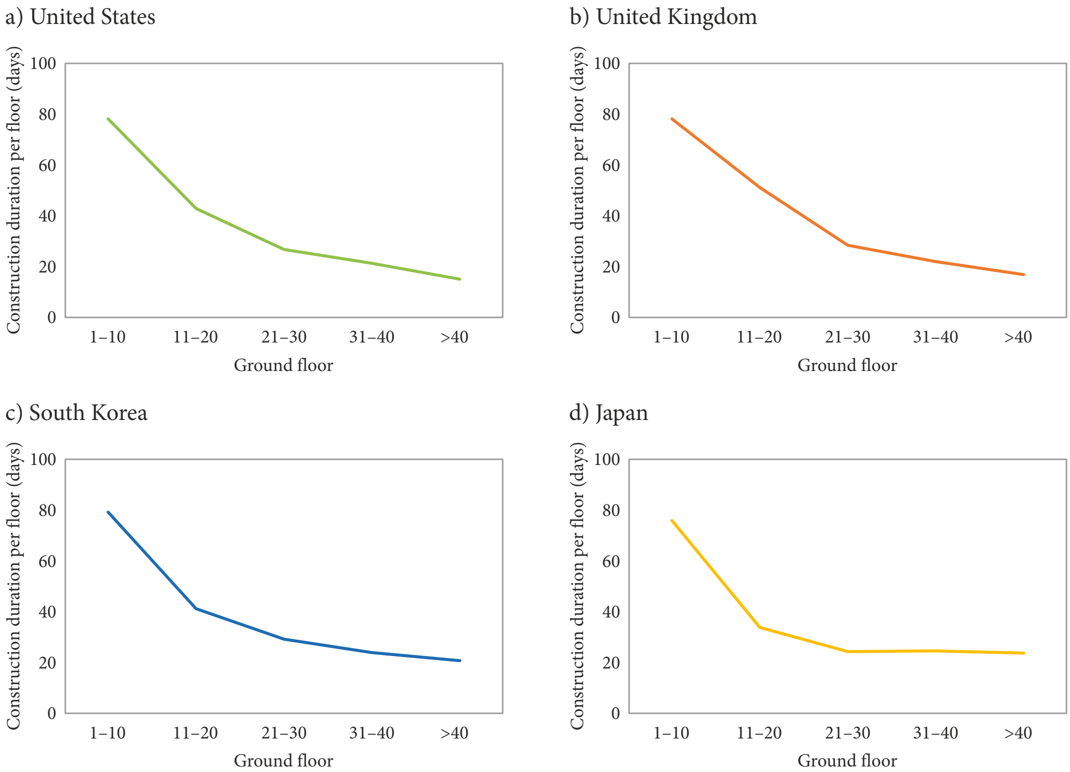

Figure 1. Construction duration per floor according to the number of ground floors

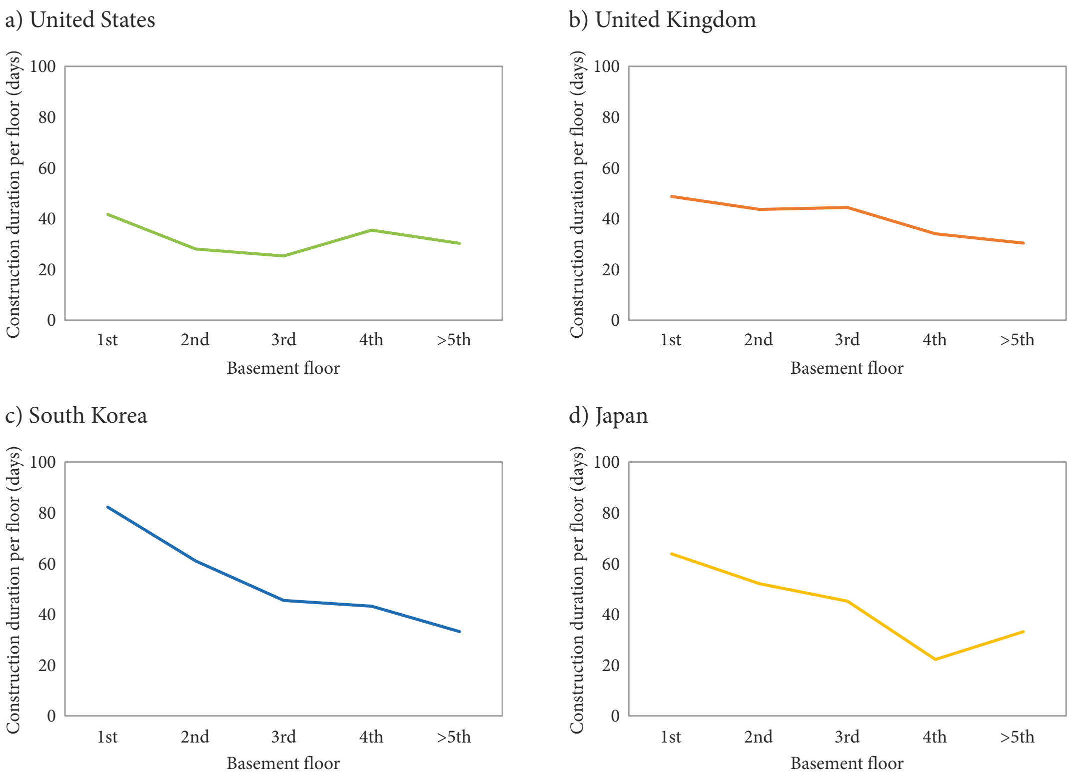

Figure 2. Construction duration per floor according to the number of basement floors

The rate of the first basement floor compared with the total number of basement floors is calculated, and a relationship between the rate of the first basement floor and construction duration is analyzed because the construction duration of the first basement floor is the longest among the basement floors. The rate of the first basement floor for Japan is the highest (54.9%), followed by the United Kingdom (44.8%), United States (30.9%), and South Korea (20.0%; Table 3). When the rate of the first basement floor and average construction duration are compared (Table 2), the average construction duration for Japan is the longest (59.9 days), and the rate of the first basement floor is also the greatest. However, the average construction duration of South Korea (59.0 days), the United Kingdom (48.2 days), and the United States (37.2 days), as well as the rate of the first basement floor, are different. The relationship between the rate of the first basement floor and the average construction duration per floor is found to be low.

The relationship between the rate of the first basement floor (Table 3) and the increase of the construction duration (Table 2) are also compared. The increase rate is used for analysis of national competitiveness because this is less influenced by the condition of each country (Harrison, 2007). The first basement rate in the United States steadily increased and then decreased after 2006–2010, then increased again. This trend is similar to that of the construction duration. The first basement rate of the other three countries also changed in tandem with the construction duration. The first basement rate in the United Kingdom steadily decreased and then increased from 2011 to 2015. The trend of the first basement rate was similar to the trend of the construction duration, except for 2001–2005, when the construction duration per floor increased slightly. The first basement rate for South Korea was also similar to the construction duration trend, except for 2011–2015, when the construction duration decreased slightly but the first basement rate increased slightly. However, the difference was not large, because the increase rate was low (0.6%). Although the collected data are limited to 2006–2015 for Japan, the trends of the first basement rate and construction duration were similar. Namely, the change of the first basement floor rate reflected the construction duration change. The construction duration of first basement floors is relatively long because of the learning effect according to the number of floors. Furthermore, the number of floors of superstructure is likely to increase if the number of floors of substructure is increased. If the construction duration decreases compared with a high rate, the productivity can be considered as increasing.

Finally, the first basement rates depending on the number of ground floors were compared (Figure 3), and then the effect of the result on the construction duration per floor was compared (Figure 1). Although the construction duration of the United States decreased, the rate of the first basement floor increased for 11–20 and 31–40 floors. The construction duration of the United Kingdom decreased for 21–30 floors, but the rate of the first basement floor increased. The construction duration of South Korea increased for 31–40 floors, but the rate of the first basement floor increased. The construction duration and rate of the first basement floor of Japan were similar, unlike those in other countries, but the amounts of increase and decrease were different. Namely, the first basement

Table 3. Rates of the first basement floors in the four countries by period

Period	United States	United Kingdom	South Korea	Japan
1996–2000	28.6%	50.0%	11.3%	
2001–2005	39.5%	48.4%	20.0%	
2006–2010	20.9%	35.1%	24.0%	64.7%
2011–2015	34.5%	45.7%	24.6%	45.0%
Average rate	30.9%	44.8%	20.0%	54.9%

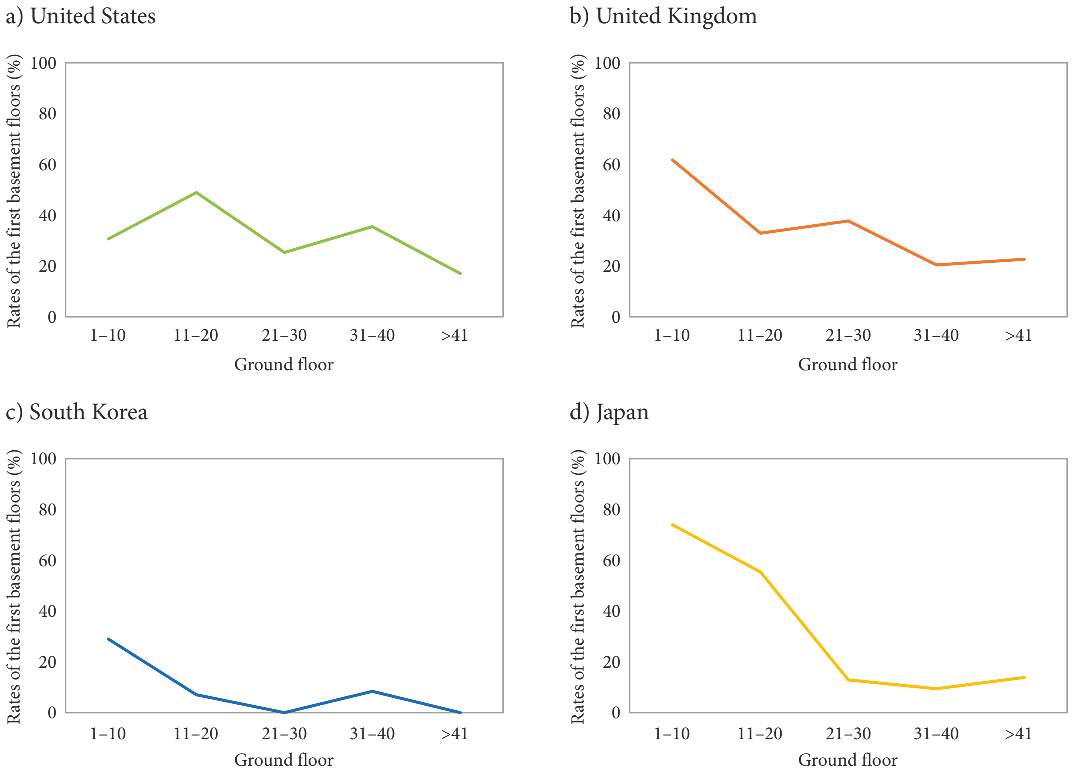

Figure 3. Rate of the first basement floors according to the number of ground floors

rate affected the increase rate of the construction duration per floor, but the relationship between the rate of the first basement floor and the learning effect with an increasing number of floors on the ground is relatively low.

From the perspective of the construction duration per floor, the construction productivity of the United States was the highest among the four countries, but its increase rate was the lowest. Impacts of learning effect and the rate of the first basement floor on construction duration per floor were additionally analyzed to find the reasons to make these differences of the four countries. As the results, the influence of the learning effect on construction duration per floor was relatively larger than that of the rate of the first basement floor.

4. Construction duration per gross area

4.1. Productivity analysis

The construction duration and increase rate per 1,000 m^2 of gross area and standard deviation are analyzed using Eqn (2) (Table 4). This study selects the analysis criterion as 1,000 m^2 of gross area for easy calculation because the construction duration of 2,000 m^2 of gross area is only increased twice compared with 1,000 m^2. The construction duration of the United States is the shortest (16.8 days), while that of South Korea is the longest (38.5 days); and these results are the same as the construction duration per floor. However, the duration for Japan (28.0 days) is shorter than that for the United Kingdom (36.1 days), and this result is different. The construction duration of the United States is largely increased compared with other countries (59.0%), like the construction duration per floor. The construction duration of the United Kingdom increased slightly (5.3%), and this result was similar to construction duration per floor in that the increased width is also small (0.2%). The construction duration of South Korea decreased (–19.3%) and this is different from the construction duration per floor result, which showed an increase (38.4%). The construction duration of Japan decreased (–9.1%), like the analyzed construction duration per floor. Moreover, the standard deviations of the United Kingdom (2.8 days) and Japan (1.9) were low, and thus, the stability levels of productivity were higher than those in the United States (3.4) and South Korea (3.6).

Table 4. Construction duration 1,000 m^2 gross area (1996–2015; Unit: day)

Period	United States	United Kingdom	South Korea	Japan
1996–2000	13.5	37.2	42.8	
2001–2005	15.5	35.7	36.7	
2006–2010	16.9	32.5	40.0	29.3
2011–2015	21.5	39.1	34.6	26.7
Average duration	16.8	36.1	38.5	28.0
Standard deviation	3.4	2.8	3.6	1.9
Average increase rate	17.0%	2.5%	–6.3%	–9.1%
Increase rate from the 1st to final group	59.0%	5.3%	–19.3%	–9.1%

To summarize, for the construction duration per gross area, the productivity of the United States and Japan were high, but the increase rates of the United States and United Kingdom were low. Thus, the difference between the United States and Japan has steadily decreased. The productivity stability levels of the United Kingdom and Japan were high and the predictability of the construction duration per gross area was also higher than that in the other countries.

4.2. Influence factors

For analyzing the learning effect based on gross area, the construction duration is analyzed according to increasing of each 30,000 m^2 of gross area (Figure 4). The learning effect shows a similar pattern for all four countries, and the result is similar to the construction duration per floor (Figure 2). The decreased width of construction duration is also large for a gross area below 30,000 m^2 and the width decreases steadily with an increasing gross area. Thus, the productivity is high when the gross area is small and the construction duration is short if the construction duration per gross area is only used as an analysis criterion for productivity.

The effect of the number of ground floors on the construction duration is analyzed (Figure 5) because the gross area is generally increased by an increase in the number of floors. The construction duration per gross area shows a decreasing trend with the learning effect according to the increase in the number of ground floors, but the learning effect is smaller than the construction duration per floor is. For example, the construction durations of the United States, United Kingdom, and Japan are increased for 21–30 floors, while the construction duration of South Korea is increased for above 41 floors. Especially, the construction

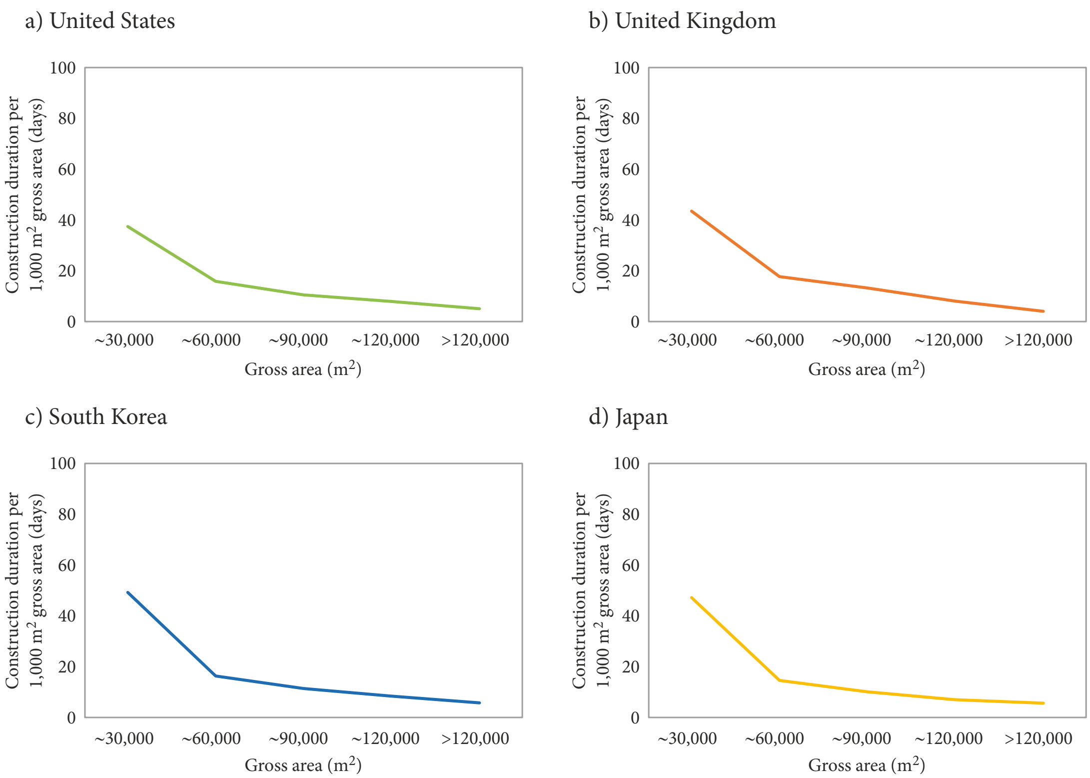

Figure 4. Construction duration per gross area according to the gross area

duration of Japan for 21–30 floors exhibits a greater increase than that for 11–20 floors, and the construction duration of South Korea for above 41 floors exhibits a greater increase than those for 11–20, 21–30, and 31–40 floors. Thus, the relationship between the change of construction duration per gross area and the number of ground floors is relatively lower than that of the construction duration per floor.

The construction duration depending on the number of basement floors is analyzed (Figure 6). When the

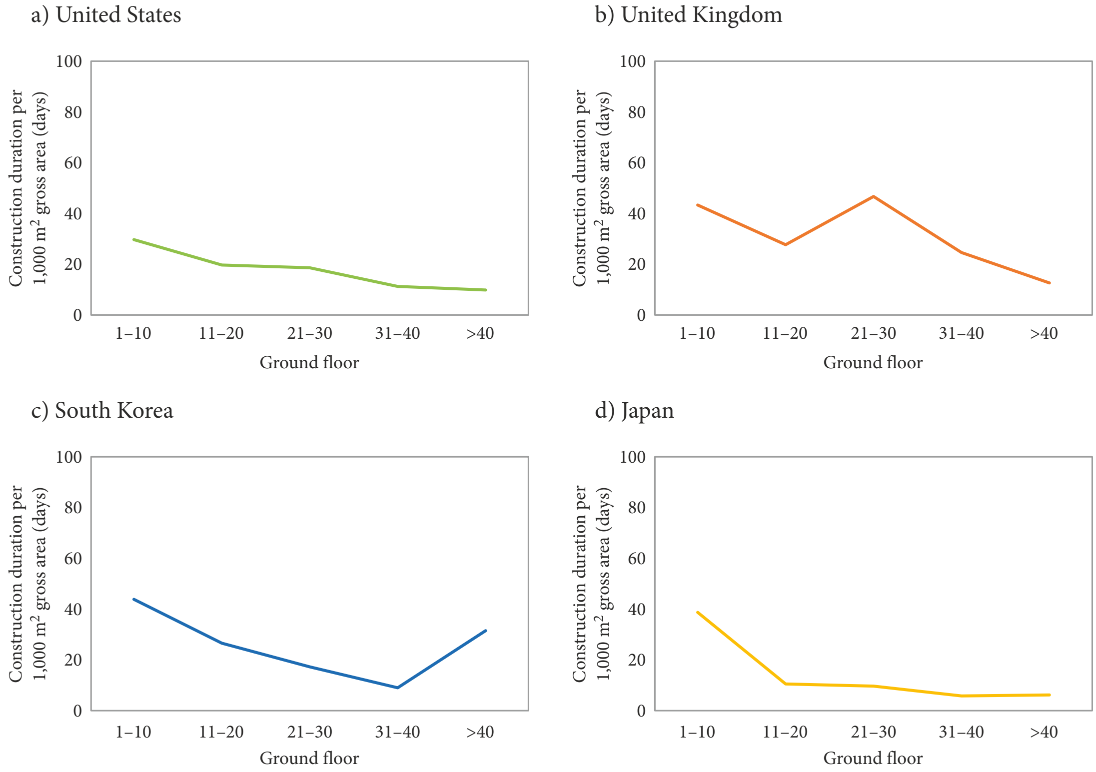

Figure 5. Construction duration per 1,000 m^2 gross area according to the number of ground floors

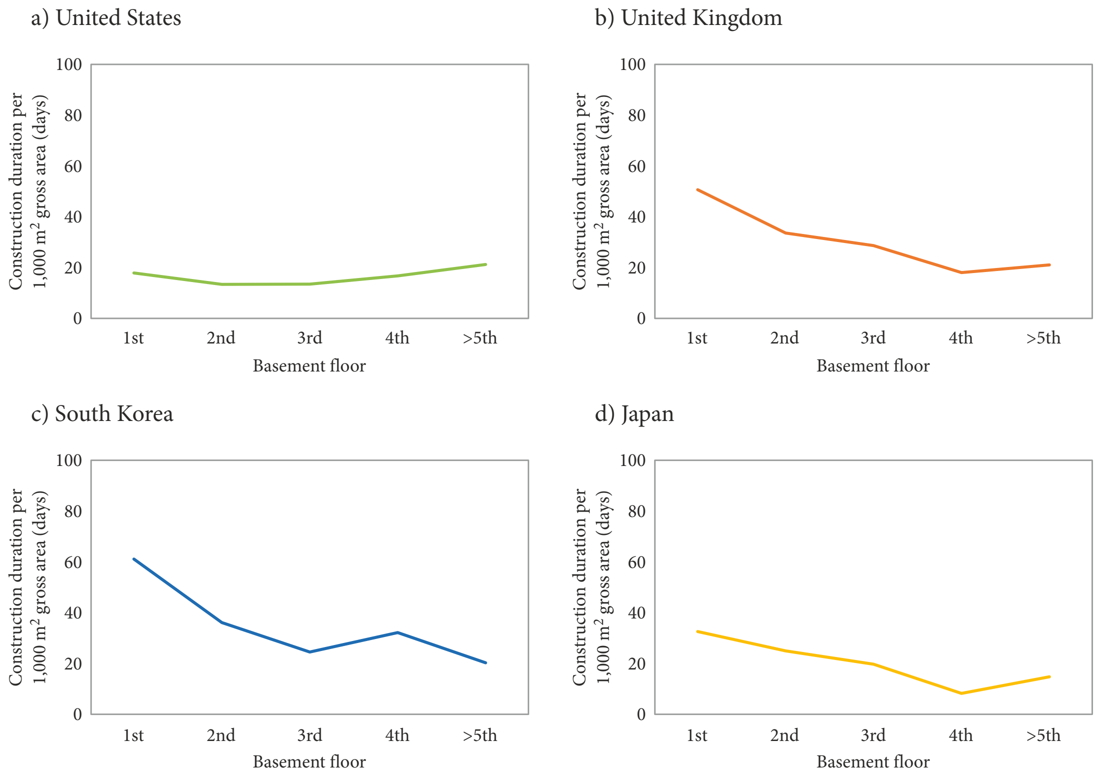

Figure 6. Construction duration per 1,000 m^2 gross area according to the number of basement floors

number of basement floors is increased, the construction duration is also increased except in the United States. This result is similar to that of the construction duration per floor. For the United States, unusually, the construction duration increased steadily with the increasing number of basement floors, although the result was largely influenced by several cases because the collected past cases decreased with an increasing number of floors. For the United States, South Korea and Japan, the trends of the construction duration per gross area and per floor are similar according to the increasing number of basement floors, but in some cases, the construction duration is increased more than in former phase for the third (United Kingdom), fourth (South Korea), and fifth (Japan) basement floors. The relationship between the construction duration and number of basement floors is also low, and this is similar to the construction duration per floor.

The relationship between the rate of the first basement floor and the construction duration is analyzed. When the rate of the first basement floor (Table 3) and average construction duration are compared (Table 4), the average construction durations of South Korea (38.5 days), Japan (28.0 days), and the United States (16.8 days) and the rate of the first basement floor are different. For the United Kingdom, the construction duration (36.1 days) and rate of the first basement floor are the same as the second highest. Thus, the relationship between the rate of the first basement floor and average construction duration per gross area is low.

The relationship between the rate of the first basement floor (Table 3) and the increase rate of the construction duration (Table 4) is analyzed. The first basement rate of the United States repeatedly increased and decreased, but the construction duration increased slightly. For the United Kingdom and Japan, the first basement rate and increase rate are represented as similar trends. The difference is not large for the United States, United Kingdom, or Japan, but it is large for South Korea. The first basement rate of South Korea increased significantly in 2001–2005 and increased slightly after 2001–2005, but the increase rate decreased during 2001–2005, and then there were repeated increases and decreases after 2001–2005. Consequently, a relationship between the rate of the first basement floor and the increase rate of the construction duration was evident, but this was weaker than that of the construction duration per floor.

Finally, the rates of the first basement floor depending on the gross area are compared and the effect of the result (Figure 3) on the construction duration per gross area was analyzed (Figure 4). When the gross area increased to 90,000 m^2, the rate of the first basement floor of the countries decreased except for Japan. The rates of the first basement floor of the United States and South Korea decreased to 90,000 m^2 in gross area, and then they increased. The rate of the first basement floor of the United Kingdom decreased to 120,000 m^2 in gross area and then increased. In contrast, the construction duration of all the countries is decreased steadily. For Japan, the trend of the rate of the first basement floor and the construction duration decreased similarly, unlike those in the other countries. Thus, the rate of the first basement floor had no influence on the learning effect with increasing gross area except for Japan, where the effect was relatively significant compared with those of the other countries. However, the rate of the first basement floor affected the increase rate of the construction duration per gross area.

Analyzed results of construction duration per gross area were similar to those of construction duration per floor. The United State was ahead of Japan, South Korea, and the United Kingdom, from the perspective of construction duration per gross area. However, the increase rate of the United States was the lowest among the four countries. Similar to the factors influencing to construction duration per floor, the influence of the learning effect on construction duration per 1,000 m^2 gross area was larger than that of the rate of the first basement floor.

5. Discussion

This discussion section explains a method to adjust the analyzed differences between construction duration per floor and gross area and which factors should be considered to improve the construction productivity. First, the construction duration per floor and per gross area is increased steadily in this study although the construction technology is advanced and skilled manpower is increased (Table 5). It is difficult to construct basement floors of buildings in congested cities. For example, a ground subsidence and civil complaint are likely to occur because the distance between buildings is close in the downtown construction. The construction duration for basement floors is generally longer than that for floors of superstructures. Furthermore, the complexity of the first basement floor is increased because all mechanical, electrical, and plumbing (MEP) of buildings gathers in the first basement floor. Thus, for improving the construction productivity, the technology development and training of professional manpower for the basement floor construction are essentially required.

Second, construction productivity can be analyzed differently depending on the construction duration per floor and per gross area. If the construction durations are different, it is difficult to find the reasons for the changed productivity and analyze consistent productivity. Previous studies did not adjust the difference between per floor and per gross area results. This section explained how to adjust and explain the analyzed difference using the influence factors. The learning effect by increasing the ground floor and gross area and the rate of the first basement floor are derived as factors influencing the construction duration like previous studies (Wideman, 1994; Chan & Kumaraswamy, 2002; Couto & Teixeira, 2005; L. D. Nguyen & H. T. Nguyen, 2013; Nguyen et al., 2013). However, there were rare previous studies to investigate and compare impacts of the learning effects and the rates of the first basement of buildings on construction duration. As the results, the

Table 5. Comparison between per floor and per gross area results

(a) Construction duration (days)

Year	United States		United Kingdom		South Korea		Japan	
	Floor	Area	Floor	Area	Floor	Area	Floor	Area
1996–2000	34.0 (1)	13.5 (1)	**49.1 (3)**	**37.2 (2)**	**47.2(2)**	**42.8(3)**		
2001–2005	39.5 (1)	15.5(1)	**53.9 (3)**	**35.7 (2)**	**53.6 (2)**	**36.7 (3)**		
2006–2010	27.0 (1)	16.9 (1)	**40.7 (2)**	**32.5 (3)**	69.8 (4)	40.0 (4)	**63.9 (3)**	**29.3 (2)**
2011–2015	48.2 (1)	21.5 (1)	**49.2 (2)**	**39.1 (4)**	**65.3 (4)**	**34.6 (3)**	**55.9 (3)**	**26.7 (2)**
Average	37.2 (1)	16.8 (1)	**48.2 (2)**	**36.1 (3)**	**59.0 (3)**	**38.5 (4)**	**59.9 (4)**	**28.0 (2)**

(b) Increase rate of construction duration (%)

Year	United States		United Kingdom		South Korea		Japan	
	Floor	Area	Floor	Area	Floor	Area	Floor	Area
2001–2005	16.3 (3)	14.5 (3)	**9.8 (1)**	**–4.1 (2)**	**13.5 (2)**	**–4.2 (1)**		
2006–2010	**–31.8 (1)**	**9.3 (3)**	**–24.6 (2)**	**–8.9 (1)**	**30.4 (3)**	**9.0 (2)**		
2011–2015	78.8 (4)	27.0 (4)	21.0 (3)	20.5 (3)	**–6.4 (2)**	**–3.6 (1)**	**–12.5 (1)**	**–9.1 (2)**
Average	21.1	17.0	2.1	2.5	12.5	–6.3	–12.5	–9.1

Notes: "Floor" is the construction duration per floor and "Area" is the construction duration per gross area; "( )" is the rank of productivity.

influence of the learning effect is greater than the rate of the first basement floor, but the rate of the first basement floor is an influence factor on both the construction duration both per floor and per gross area. L. D. Nguyen and H. T. Nguyen (2013) and Couto and Teixeira (2005) claimed learning rates of 83.5% (formwork installation and rebar fabrication/installation of a 20-story building) and 85% in high-rise building projects in Portugal, respectively. Thus, the rate of the first basement floor is used for logically analyzing and elaborating on trends and changes of construction duration per floor and 1,000 m^2 gross area in this paper.

The ranks of the construction duration per floor and per gross area are analyzed among the countries (a in Table 5). In most cases, the rank of the productivity is different between the construction duration per floor and per gross area except for the period of 2006–2010 in the United States and South Korea. For the increase rate of the construction duration, the ranks are analyzed (b of Table 5). The rank of the increase rate is also different by country in most cases. Thus, it could be difficult to find the reason for the productivity change in the construction duration and increased rate of the construction duration because of the difference.

For finding a reason to explain changes of construction productivity related to construction duration, impacts of the rate of the first basement floor on the construction duration per floor and per gross area was analyzed by country (a in Table 6). In the results, the difference among the ranks of the construction duration per floor and per gross area could be explained. In most cases, the ranks of the productivity were almost similar compared with before the adjustment. For the increase rate of the construction durations, adjusted construction duration per floor and 1,000 m^2 gross area by the rates of the first basement floor was analyzed (b in Table 6). The ranks of the adjusted construction duration per floor and per 1,000 m^2 gross area were relatively consistent in most cases rather than those of the existing construction durations. As exceptions, the rank of the United States (7.4 days) was the first and that of South Korea (8.5) was the second for the adjusted construction duration per gross area during the period 2011 to 2015. This is different from those of the adjusted construction duration per floor, where the United State (16.6) ranked the second and South Korea (16.1) ranked the first during the same period. However, the difference between the United States and South Korea was small at 0.5 days for the adjusted construction duration per floor.

Although the rate of the first basement floor could not correct the rank of the productivity in all cases, the difference was close, and thus, construction productivity related to construction duration could be adjusted by the rate of the first basement floor. The result of 0.5, which is the difference between South Korea and United States for the adjusted construction duration per floor, was calculated by multiplying the rate of the first basement floor and existing construction duration per floor. The difference was more reduced than that of the existing construction duration per floor between the United State and South Korea during the period 2011 to 2015 (17.1 days = 65.3 – 48.2; a in Table 6) was, where the rate of the first basement floor was not multiplied.

The trend of the adjusted increase rate by the rate of the first basement floor are analyzed by each country (Figure 7). In most cases in the four countries, the change of the increase rate of the construction duration per floor was larger than that of the construction duration per gross area, and the change trends were similar. For example, the increase rates of the United States and United Kingdom decreased in 2006–2010 and then increased, while the construction duration of South Korea increased in 2006–2010 and then decreased. Thus, the adjusted productivity of the United States and United Kingdom increased and that of South Korea decreased in 2006–2010. Since there were rare previous studies to analyze and compare trends of construction productivity related to construction duration using a data set of actual completed buildings, it was difficult to validate the analyzed results based on the relevant studies. Increase and decrease trends in the United Station, the United Kingdom, and South Korea during around 20 years (1995 to 2015) in this paper were similar to those of construction labor productivity analyzed in previous studies (Bughin et al., 2017). Bughin et al. (2017) concluded that increase rates of relative construction labor productivity in the United States and United Kingdom during the period 2005 to 2015 were 0.9% and 0.2% higher, respectively, than those during the period 1995 to 2005, unlike South Korea. The increase rate of Japan was

Table 6. Comparison based on the rate of the first basement floor between construction duration per floor and per gross area

(a) Adjusted construction duration by the rate of the first basement floor (days)

Year	United States		United Kingdom		South Korea		Japan	
	Floor	Area	Floor	Area	Floor	Area	Floor	Area
1996–2000	**9.7 (2)**	**3.9 (1)**	**24.6 (3)**	**18.6 (3)**	5.3 (1)	4.8 (2)		
2001–2005	**15.6 (2)**	**6.1 (1)**	26.1 (3)	17.3 (3)	**10.7 (1)**	**7.3 (2)**		
2006–2010	5.6 (1)	3.5 (1)	**14.3 (2)**	**11.4 (3)**	**16.8 (3)**	**9.6 (2)**	41.3 (4)	19.0 (4)
2011–2015	**16.6 (2)**	**7.4 (1)**	**22.5 (3)**	**17.9 (4)**	16.1 (1)	8.5 (2)	**25.2 (4)**	**12.0 (3)**
Average	11.5 (1)	5.2 (1)	**21.6 (4)**	**16.2 (4)**	11.8 (2)	7.7 (2)	**32.9 (4)**	**15.4 (3)**

(b) Adjusted increase rate of construction duration by the rate of the first basement floor (%)

Year	United States		United Kingdom		South Korea		Japan	
	Floor	Area	Floor	Area	Floor	Area	Floor	Area
2001–2005	6.4 (3)	5.7 (3)	4.7 (2)	–2.0 (2)	2.7 (1)	–2.8 (1)		
2006–2010	–6.6 (2)	1.9 (2)	–8.6 (1)	–3.1 (1)	7.3 (3)	2.2 (3)		
2011–2015	**27.2 (4)**	**9.3 (3)**	**9.6 (3)**	**9.4 (4)**	–1.6(2)	–3.3 (2)	–5.6 (1)	–4.1 (1)
Average	6.5 (4)	5.3 (4)	**0.9 (2)**	**1.1 (3)**	**2.5 (3)**	**–1.3 (2)**	–5.6 (1)	–4.1 (1)

Notes: "Floor" is the construction duration per floor and "Area" is the construction duration per gross area; "( )" is the rank of productivity.

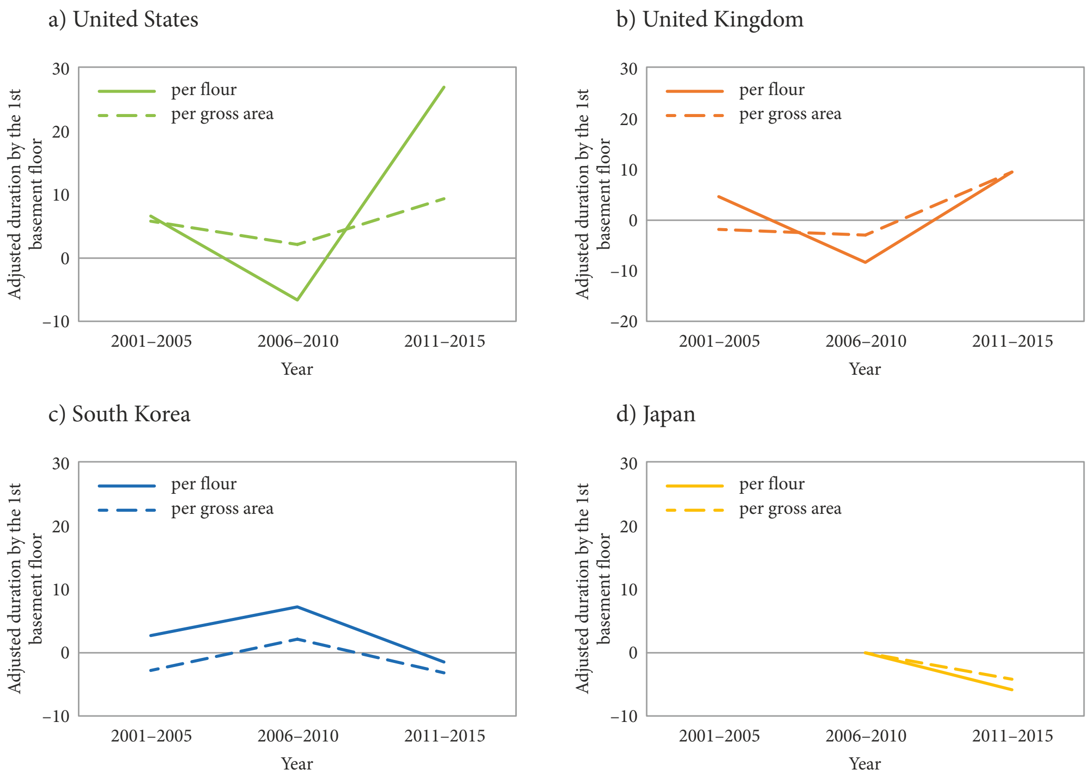

Figure 7. Comparison the adjusted construction duration by the rate of the first basement floor between per floor and per gross area

only analyzed from 2011 to 2015 because the related data could be collected starting from 2006. As the results, the adjusted construction duration per floor and 1,000 m^2 gross area of buildings in Japan decreased in 2011–2015.

Conclusions

This study analyzed the construction productivity change associated with construction duration over 20 years (1996–2015) and compared the productivity the countries with similar sizes of construction investment and market risks. In order to analyze the construction productivity, construction duration per floor and 1,000 m^2 gross area in buildings were used in this study. We collected data of 800 buildings with similar project scope and complexity in the four countries, the United States, the United Kingdom, South Korea, and Japan. The number of superstructure and substructure floors, building types and shapes were considered to collect data. In order to find the reasons for the increased or decreased construction duration per floor and gross area, which were analyzed in this paper, the influencing factors were derived.

As the results, for the construction duration per floor and per gross area, the construction productivity of the United States was the highest over the 20-year period (1996–2015), but the difference from other countries (the United Kingdom, South Korea, and Japan) decreased steadily because the increase rate of the construction productivity is low. The productivity stability of the United Kingdom and Japan is high because the range of fluctuation is small. Although there are many factors affecting construction duration, this paper focused on the two influencing factors, which were the learning effect by increasing the number of ground floors and gross area and by the rate of the first basement floor. As the results, the influence of the learning effect is larger than that of the rate of the first basement floor, but the rate of the first basement floor commonly influences the construction duration per floor and per gross area in the four countries.

Although the data provided by different countries is different, a main contribution is to analyze the productivity of the countries over a long period using the construction duration per floor and per gross area. Based on the result, the factors influencing the construction duration were derived. The results of this study can be utilized for explaining the difference depending on the construction duration per floor and per gross area. This is because it could be difficult to find the exact reasons for the changed productivity by analyzing the inconsistent productivity. Among various parameters affecting construction duration, this paper focused only on the limited number of the parameters, such as learning effect and the rate of basement floor, to explain changes in trends related to construction duration per floor or gross area of buildings in the four countries. Consequently, the trends of construction duration per floor and 1,000 m^2 gross area in the four countries during around 20 years could be partially interpreted. Therefore, in the future, more influence factors to interpret change in the trends will be derived to explain the changed trends of construction productivity, from the perspective of construction duration.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2019R1F1A1058568).

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