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Changes in Research and Development of Major General Contractors in Japan in the last 10 years: The Building Construction Business Sector

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Abstract: Prominent general contractors (GCs) in Japan have historically maintained dedicated research and development (R&D) institutes that conduct comprehensive studies on structural engineering, construction techniques, and environmental management technologies. These research endeavors have evolved over time, reflecting the prevailing conditions and trends in the construction industry during each era. We examined changes in R&D activities over the past decade by analyzing R&D descriptions and statistical data contained in securities reports issued by 14 leading GCs using natural language processing. Our analysis revealed that over the course of the decade, R&D activities transformed significantly due to market dynamics and macro-environmental factors. For instance, during the 2000s, a surge in demand for high-rise condominium buildings led to an increased presence of related terminology in the 2009 fiscal year (FY) securities reports. However, this trend had declined by FY 2019. Notably, in FY 2019, there was an observable increase in R&D efforts concerning wood and cross-laminated timber applications. This can be attributed to the enforcement of laws and standardization measures that facilitated the proliferation of wood-based construction techniques in the 2010s. Throughout the 2010s, the primary concern of the Japanese construction industry was optimizing production processes to meet escalating domestic construction demands. A comparative analysis between 2009 and 2019 indicates a shift in focus, with fewer references to product innovation and a more pronounced emphasis on process innovation.

Key words: Research and Development (R&D), R&D Strategy, General Contractor, Natural Language Processing (NLP), Innovation

1. INTRODUCTION & BACKGROUND

In Japan, innovation has become increasingly important in recent years in response to challenges such as a decline in the working-age population, the creation of new industries, and rapid changes in the external environment. The construction industry, which has a long history and is considered a mature and conservative industry, is no exception, and sustainable development through innovation is needed.

However, research has shown that the construction industry has characteristics that inhibit innovation. For example, unlike the manufacturing industry, corporate activities are project-based, and there is a discontinuous structure in the creation and transfer of learning and knowledge within and between organizations, and the one-time nature of projects makes it difficult to adapt innovation to other cases [1] [2].

Thus, with general contractors (GCs), which are subject to constraints on innovation, it is important to increase knowledge systematically by continuously integrating the superior experience gained from each project into business processes, while simultaneously creating and sharing knowledge to support the project [3]. Therefore, with general contractors, the role of support departments, including research and development (R&D) and technical support, in the internal value chain is significant from the perspective of knowledge management. It is known that major Japanese general contractors are active in R&D because they have their own technical research institutes and their R&D investment is relatively large compared to that of other countries. R&D activities are not a direct surrogate for innovation, but they are part of the value creation function that is the source of innovation and should be give attention.

Drucker [4] points to the emergence of gaps and needs as well as changes in the external environment, such as demographic, industrial and market structures and perceptions, as factors that promote innovation. In Japan's construction industry, construction investment, which peaked in 1992 and has been declining since then, began to increase in 2011 due to reconstruction work following the Great East Japan Earthquake in2011 and the construction demand associated with preparations for the Tokyo Olympic Games in 2020. However, the construction industry, which had experienced a decline in the number of engineers and site workers, faced the new management challenge of improving productivity resulting from a labor shortage, which also brought about a paradigm shift in R&D strategies.

This study used text mining of annual securities reports to identify trends in the R&D content of major Japanese general contractors that have accelerated their R&D investments in recent years.

Focusing on the 14 Japanese general contractors with sales exceeding 300 billion yen and disclosing their annual reports from FY03/2009 to FY03/2019, the change in total sales (Figure 1) shows that sales bottomed out in 2011 and then increased continuously. Change in total value of R&D investment (Figure 2) shows that the investment amount tended to increase after 2015, although it remained at the same level until 2014, indicating that R&D activities increased. Change in the average ratio of R&D investment to sales (Figure 3) shows that the ratio of R&D investments to sales declined from 2011 to 2014 due to the upward trend in sales but increased after 2017. Although the ratio of R&D to sales was lower in the construction industry than in other industries, the average increases and decreases in R&D investments and the ratio of R&D to sales during this period increased by 63% and 37%, respectively (Figure 4). From 2009 to 2019, major general contractors aggressively accelerated their R&D investments, which was supported by their high sales performance.

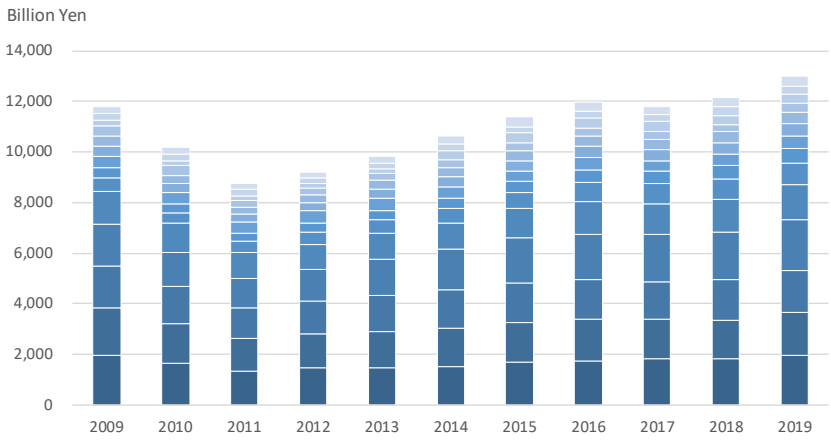


Figure 1. Transition of "Total Net Sales of 14 GCs"

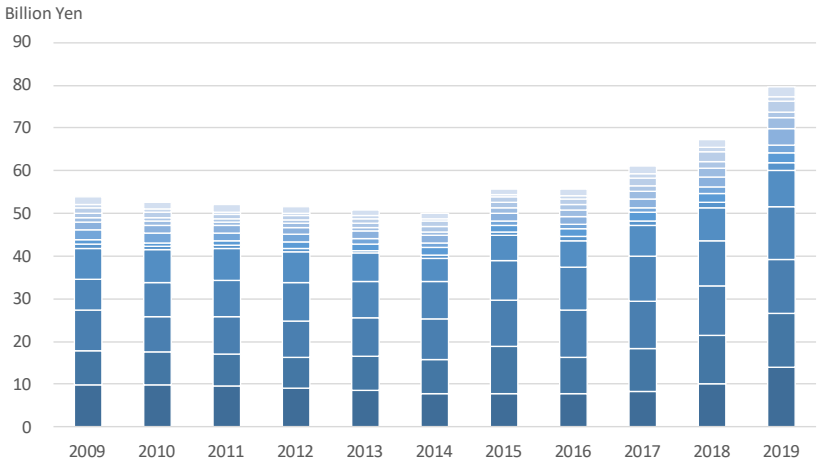


Figure 2. Transition of "Total R&D Investment of 14 GCs"

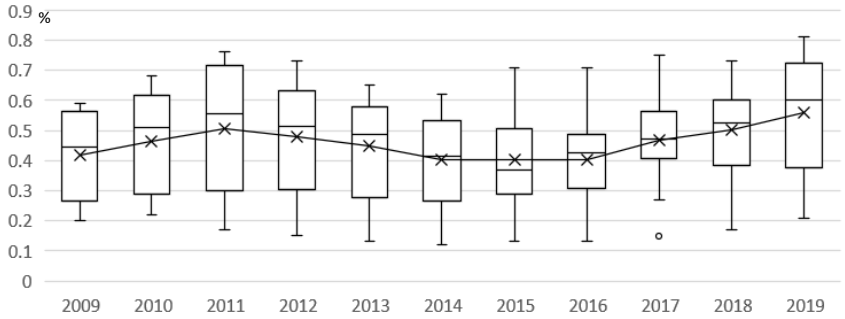


Figure 3. Transition of "Total R&D Investment / Total Net Sales of 14 GCs"

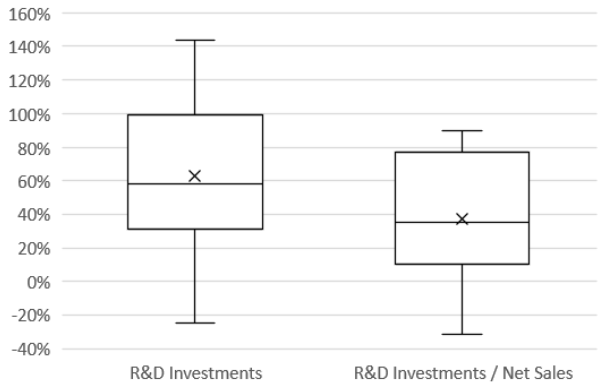


Figure 4. Rate of Change between FY03/2009 and FY03/2019

2. LITERATURE REVIEW

Manley et al. [5] conducted a large-scale survey of Australian construction firms to identify strategies that distinguish between high and low innovators. Fraser et al. [6] surveyed Japanese and Australian universities, construction companies, and manufacturing companies and found that Australian construction companies' R&D activities are likely to bring direct benefits to firms. The survey revealed that Australian construction firms perceived that their R&D activities should focus on construction process areas that could bring direct benefits to the company, whereas Japanese construction firms perceived that they should be deeply involved in R&D in all areas: foundations, construction processes, construction products, and social issues. Konno et al. [7] summarized the public works bidding system and R&D investment from the perspective of the Structure, Conduct, Performance model. The results suggest that firms that can participate in tenders that require technical proposals, such as the comprehensive evaluation bidding system, are more active in R&D investment, and that R&D investment leads to higher future profits.

Shide et al. [8] classified R&D activities into sales and self-use purposes and conducted a product architecture analysis as an alternative index to published patent information to clarify changes in the positioning of patent applications to general contractors.

Although the above studies exist, there is little literature that analyzes the changes in R&D strategies of major Japanese general contractors from a bird's eye view and clarifies the changes in R&D strategies in the 2010s, when a paradigm shift is thought to have occurred. This would provide useful knowledge regarding the impact of future changes in the external environment.

3. RESEARCH METHODOLOGY

In this study, we selected R&D activities in annual securities reports as the target of analysis to capture changes in R&D activities. News releases, academic papers, and patents can be cited as products of R&D activities, but these documents are not suitable for analysis to make comparisons between firms

or between fiscal years because they are easily affected by whether they are disclosed and the amount of text, depending on the company's policy and the discretion of the person in charge. In contrast, annual securities reports are considered suitable for analysis because they follow a certain format, are prepared in accordance with preparation guidelines, and require attention to facilitate comparisons among firms, as well as concise and clear descriptions.

As already noted, construction investment showed an upward trend after 2011; therefore, we analyzed how R&D activities changed around 2011. For this purpose, we used data points that were 10 years apart from FY03/2009 and FY03/2019.

First, items related to the building business segment were extracted according to the flow shown in Figure 5 for natural language data described in the R&D activities in the annual securities report. Descriptions of R&D activities as a whole and descriptions related to business areas, such as the environment and geotechnical fields, were included in the analysis if there were no descriptions that limited the business areas.

Next, the parts of speech of the words to be analyzed were selected, and compound words were set. In this study, nouns, adjectives, and adjectival verbs were selected as the parts of speech for analysis. When conducting a morphological analysis, it should be noted that the same word may be used in different contexts. For example, in the case of this study, the word “Seisan” (production) is sometimes used in the context of “Seisan-sei” (productivity) and sometimes in “Seisan- shisetsu” (production facilities),” and it is necessary to consider beforehand which words should not be confused for the purpose of the study. Therefore, six words were treated as compound words in consideration of the purpose of this study. Among the words classified as unknown words, 48 words such as “CLT（cross-laminated timber）,” “ICT (information and communication technology),” “IoT (internet of things),” and “BIM (building information modeling)” were added to the analysis, and frequently occurring words that were unnecessary for the purpose of this study, “consolidated,” “accounting,” “our company,” and “fiscal year” were excluded. The four words that were excluded were all used in the regular descriptions of securities reports.

After the above preprocessing, morphological analysis was performed.

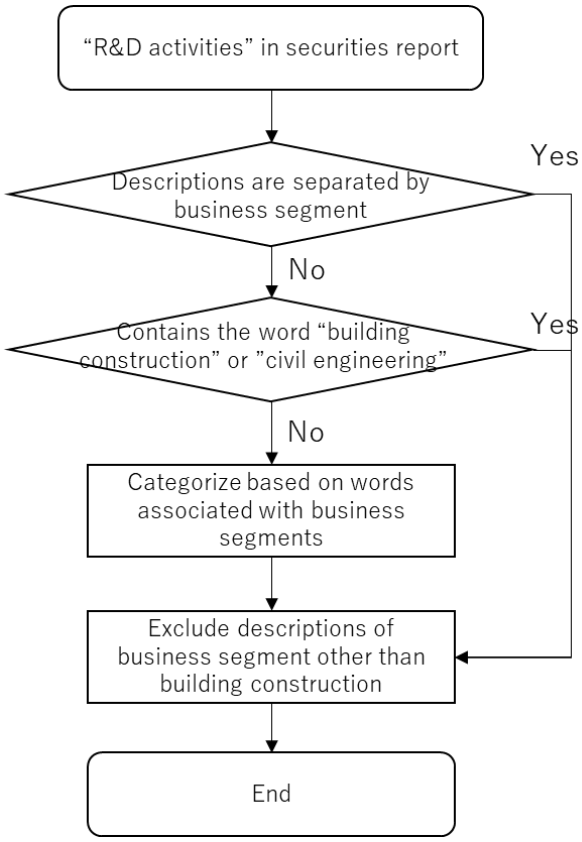


Figure 5. Flow of Data Extraction

4. RESULT

Table 1 shows the top 60 most frequently occurring words and their frequency of appearance, composition ratio (1), and ratio of change in composition ratio for FY03/2009 and FY03/2019 (2) as a result of morphological analysis.

$$Composition\ Ratio = \frac{Number\ of\ the\ Word}{Total\ Number\ of\ Words} \quad (1)$$

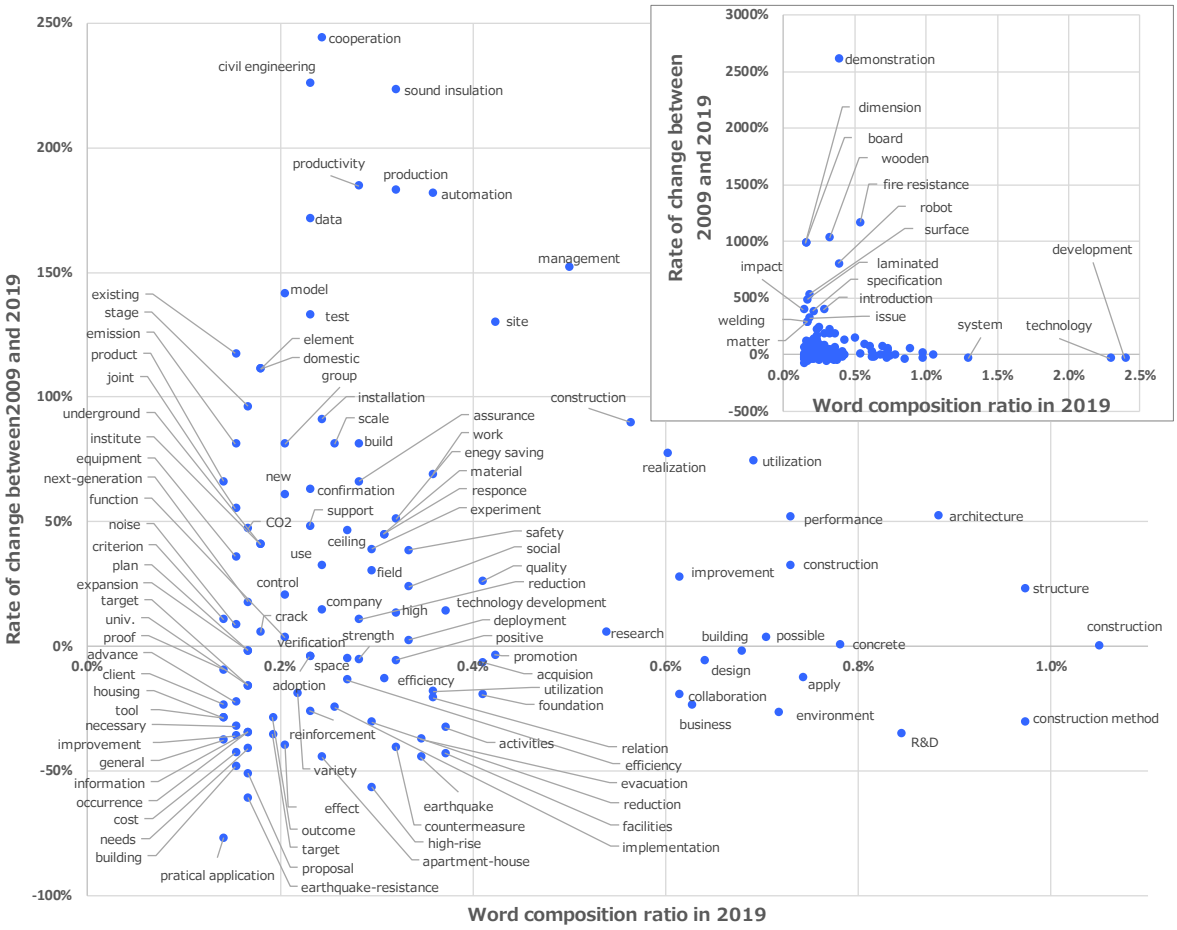
$$Rate\ of\ Change = \frac{Composition\ Ratio\ of\ the\ Word\ in\ 2019}{Composition\ Ratio\ of\ the\ Word\ in\ 2009} \quad (2)$$

Table 1 shows that words such as “demonstration,” “CLT,” “automatic,” “sound insulation,” and “wooden” were out of scope in 2009, but began to appear in 2019, becoming a characteristic change to the top 60 words. On the other hand, “high-rise,” which was used 48 times in 2009, decreased to 23 times in 2019.

Table 1. Frequent Words and Rate of Change Between Two Points

	2009			2019			Rate of Change		2009			2019			Rate of Change
	Word	FoA	CR	Word	FoA	CR			Word	FoA	CR	Word	FoA	CR	
1	Development	249	3.5%	Development	187	2.4%	-32%	31	Apartment house	31	0.4%	Robot	30	0.4%	806%
2	Technology	238	3.4%	Technology	179	2.3%	-32%	32	Promotion	31	0.4%	Demonstration	30	0.4%	2618%
3	System	133	1.9%	System	101	1.3%	-31%	33	Utilization	31	0.4%	CLT	29	0.4%	new
4	Construction method	99	1.4%	Construction	82	1.0%	0%	34	Earthquake resistance	30	0.4%	Activities	29	0.4%	-33%
5	R&D	92	1.3%	Construction method	76	1.0%	-30%	35	Reduction	30	0.4%	Technology development	29	0.4%	14%
6	Construction	74	1.0%	Structure	76	1.0%	23%	36	Property	30	0.4%	Facilities	29	0.4%	-43%
7	Environment	69	1.0%	Architecture	69	0.9%	52%	37	RC	28	0.4%	Related	28	0.4%	-21%
8	Apply	60	0.8%	R&D	66	0.8%	-35%	38	Utilization	28	0.4%	Work	28	0.4%	69%
9	Business	58	0.8%	Concrete	61	0.8%	0%	39	Response	26	0.4%	Automatic	28	0.4%	182%
10	Structure	56	0.8%	Apply	58	0.7%	-12%	40	Efficiency	25	0.4%	Utilization	28	0.4%	-18%
11	Concrete	55	0.8%	Construction	57	0.7%	32%	41	Effect	24	0.3%	Earthquake	27	0.3%	-44%
12	Collaboration	54	0.8%	Performance	57	0.7%	52%	42	Realizsation	24	0.3%	Evaluation	27	0.3%	-37%
13	Building	49	0.7%	Environment	56	0.7%	-26%	43	Implementation	24	0.3%	Safety	26	0.3%	39%
14	Possible	48	0.7%	Possible	55	0.7%	4%	44	Positive	24	0.3%	Society	26	0.3%	24%
15	High rise	48	0.7%	Utilization	54	0.7%	75%	45	Proposal	24	0.3%	Deployment	26	0.3%	2%
16	Design	48	0.7%	Building	53	0.7%	-2%	46	Technology development	23	0.3%	High	25	0.3%	13%
17	Facilities	46	0.6%	Design	50	0.6%	-6%	47	Deployment	23	0.3%	Sound Insulatuon	25	0.3%	224%
18	Earthquake	44	0.6%	Business	49	0.6%	-23%	48	Soil	23	0.3%	Production	25	0.3%	183%
19	Practical application	43	0.6%	Collaboration	48	0.6%	-19%	49	Quality	23	0.3%	Positive	25	0.3%	-6%
20	Architecture	41	0.6%	Improvement	48	0.6%	28%	50	Energy	22	0.3%	Countermeasure	25	0.3%	-40%
21	Activities	39	0.6%	Realizsation	47	0.6%	77%	51	Treatment	22	0.3%	Wooden	25	0.3%	1032%
22	Construction	39	0.6%	Construction	44	0.6%	90%	52	Reinforcement	22	0.3%	Energy saving	25	0.3%	51%
23	Evaluation	39	0.6%	Research	42	0.5%	6%	53	Building	21	0.3%	Efficiency	24	0.3%	-13%
24	Countermeasure	38	0.5%	Fire resistance	42	0.5%	1168%	54	Strength	21	0.3%	Materials	24	0.3%	45%
25	Foundation	36	0.5%	Management	39	0.5%	152%	55	Construction	21	0.3%	Response	24	0.3%	45%
26	Research	36	0.5%	Site	33	0.4%	130%	56	Target	21	0.3%	High rise	23	0.3%	-57%
27	Improvement	34	0.5%	Promotion	33	0.4%	-4%	57	Needs	20	0.3%	Experiment	23	0.3%	39%
28	Performance	34	0.5%	Foundation	32	0.4%	-19%	58	Space	20	0.3%	Reduction	23	0.3%	-31%
29	Related	32	0.5%	Acquisition	32	0.4%	-6%	59	Plan	20	0.3%	Field	23	0.3%	30%
30	Acquisition	31	0.4%	Quality	32	0.4%	26%	60	High	20	0.3%	Secure	22	0.3%	66%

※FoA: Frequency of appearance ※CR: Composition Ratio ※The same word appears, but it was translated into English based on the type of Japanese word.



※The same word appears, but it was translated into English based on the type of Japanese word.

Figure 6. Relationship Between Word Composition Ratio in 2019 and Rate of Change Between Two points

Table 2. List of words appeared only in 2019

New word	2019	
	FoA	CR
CLT (cross-laminated timber)	29	0.4%
BIM (building information modeling)	19	0.2%
Control	17	0.2%
AI (artificial intelligence)	16	0.2%
PC (precast concrete)	16	0.2%
Net zero energy building	16	0.2%
Measure	15	0.2%
ICT (information and communication technology)	14	0.2%
Laboratory	14	0.2%
Remote	14	0.2%
IoT (internet of things)	13	0.2%
Operation	13	0.2%
Inspection	13	0.2%
Modeling	13	0.2%
AR (augmented reality)	11	0.1%

※FoA: Frequency of appearance

※CR: Composition Ratio

Next, Figure 6 plots the percentage change in the composition of words in 2019 on the horizontal axis and that between 2009 and 2019 on the vertical axis. Owing to space limitations, words with a horizontal axis of 1.2% or more and a vertical axis of 250% or more are shown in a separate figure in Figure 6. The words plotted in the upper-right corner are those that appeared more frequently in 2019 and whose composition ratio increased from 2009. Words that did not appear in 2009 but did appear in 2019 are not shown in the figure and are, therefore, shown separately in Table 2.

First, we examined the words listed in Figure 6 that showed a large percentage of positive change in the composition ratio and the characteristics of the words listed in Table 2. Words related to wood construction ("fire resistance," "wooden," "CLT"), words related to building processes ("robot," "PC (precast concrete)," "measure," "inspection," "production," "construction," "management," "site," etc.), and words related to information processing and advanced technology ("BIM," "AI (artificial intelligence)," "ICT," "IoT," "AR (augmented reality)," "data," "model," "automation ," etc.) were common.

From the above, it can be concluded that in FY03/2019, compared with FY03/2009, R&D activities related to building processes advanced. At the same time, the development of information processing and advanced technology led to an active search for applications in the building process. In addition, wood-related technologies, which had not received much attention in the past as R&D targets for general contractors, have attracted attention, and it is thought that they began to appear as R&D results around 2019.

The term "civil engineering" was also extracted as a term with an increasing trend. This is largely because of the increased number of business segments in annual reports. Four out of 18 cases in FY03/2019 were described as concrete technologies or management technologies that are commonly used in both construction and civil engineering, or as architectural technologies that are also applied to the civil engineering field.

On the other hand, the terms related to housing complexes ("high-rise" and "apartment-house") and "environment" plotted at the bottom of the list were found to have decreased significantly in FY03/2019, although these appeared at the top of the list in FY03/2009, indicating that they were a R&D trend, but we confirmed a significant decrease in FY03/2019.

In addition, "proposal" was used 24 times in FY03/2009, while it decreased to 13 times in FY03/2019. In addition, although not a major change, "client" and "needs" as related terms also showed a decreasing trend. This finding suggests that R&D activities may have been less oriented toward client firms' needs from 2009 to 2019. Another decreasing trend observed during this period was "cost" as a term expressing the direction of R&D.

5. FINDINGS & DISCUSSION

The analysis thus far has revealed that the content of R&D activities of major Japanese general contractors has changed over time. These changes in R&D activity may be influenced by changes in the external environment.

For example, although many terms related to condominiums were mentioned in 2009, the number decreased in 2019. This can be attributed to a rapid increase in the supply of super high-rise condominiums after 2000 because of the relaxation of the floor area ratio and shading regulations in 1997, when the Building Standards Law was revised to promote urban residential living and the floor area ratio calculation method for condominiums was relaxed. However, as housing demand decreased in the 2010s following the economic downturn caused by the Lehman Shock in 2008, the position of condominiums as targets of R&D activities by general contractors is thought to have declined.

In addition, the "Law Concerning the Promotion of the Use of Wood in Public Buildings," which was promulgated and enforced in 2010 to conserve national land and stimulate demand for domestic timber, JAS (Japanese Agricultural Standards) standardization in 2013, and the Building Standard Law notification related to cross-laminated timber (CLT), which was promulgated and enforced in 2016, are thought to have accelerated R&D related to CLT among general contractors.

In addition to the influence of policy, there was also a change in the R&D strategy from client needs to an emphasis on production processes due to a change in the supply-demand balance. Shide et al. [8] suggest that major Japanese general contractors promoted R&D that meets the needs of client firms based on the number of patent applications related to condominiums and semiconductor factories from the 1980s to the 2000s. On the other hand, the period analyzed in this study suggests that in the decade leading up to 2019, the focus of R&D of major general contractors shifted its center of gravity from the

function of building to the process of building construction. In 2009, the companies were in the midst of a severely competitive environment due to declining construction investment; the main objective of their R&D activities was to focus on technologies that they could propose to their clients and differentiate themselves. In 2019, while such a competitive environment eased, productivity improvement became the order of the day, and as a result, the importance of technologies used in building construction processes increased. The need to improve productivity may have led to a relative decrease in R&D activities, which in turn led to proposals for clients. It is also suggested that R&D activities that contribute to cost competitiveness may have decreased from 2009 to 2019 because the competitive environment eased.

Taken together, these results suggest that the R&D strategies of major Japanese general contractors may have shifted their center of gravity from product innovation to process innovation from 2009 to 2019. While there are some universal themes in the R&D activities of general contractors, such as concrete strength, many of these activities reflect the influence of macro, market, and competitive environments.

6. LIMITATIONS

This study has several limitations. First, the analysis in this study was derived from descriptions in annual securities reports, and it does not capture actual R&D activities that are not described in annual securities reports. It is possible that the number of R&D activities may have changed in response to the increase in R&D expenditures of the surveyed firms between 2009 and 2019, the years covered by the analysis. However, because there are limitations to what can be described in annual securities reports, this study is limited to a relative comparison between the two periods.

Second, because annual securities reports are disclosed to shareholders, there is a possibility of bias due to the intentional selection of the report contents. However, there is a limit to observing corporate activities from outside, and considering feasibility, the analysis using publicly available information adopted in this study is a reasonable method to some extent.

7. CONCLUSION

In this study, we analyzed and discussed the R&D activities of major general contractors by text mining their annual reports for FY03/2009 and FY03/2019, when the external environment changed. As a result of the analysis, we were able to quantitatively observe that the R&D activities of general contractors, which seemingly have not changed significantly in the construction industry, a mature industry with a long history, have been changing under the influence of macro, market, and competitive environments. In addition, from the perspective of R&D strategy, it was suggested that during this period, the strategy changed from one that emphasized product innovation to one that emphasized process innovation.

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