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OFF-SITE/ON-SITE COMPOSITE CONSTRUCTION METHOD: AN UNCONSCIOUS LEAN CONSTRUCTION PRACTICE

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ABSTRACT

This paper provides a contemporary outlook on the concept, features, and achievements of the composite construction methods (fukugōka kōhō) developed in Japan between the 1970s and 1990s. The topic has not been widely publicised abroad, contrasting with prefabricated housing and construction robotics research conducted in the same period. However, the "compounding" approach can play a pivotal role in overcoming the present-day challenge of making digital construction technically possible and economically feasible. This research has employed two research methods. The first was a bibliographic survey of historical construction records and academic articles to grasp how fukugōka kōhō helped construction firms to deal with the pressing business and technological needs of that time. The second was focus group interviews with experienced engineers who came across the yielding effects of the compounding strategy and are now developing and implementing new elemental technologies integral to "smart construction systems" as part of R&D initiatives and productivity improvement management policies, which are tacitly lean. The awareness that try-out implementations of digital construction methods reassemble those past experiences put light on the possibility of resurging lean-ish hybrid production models to ensure competitiveness and reliability advantages in the transition period of technological maturation.

KEYWORDS

Fukugōka kōhō, prefabrication, off-site construction, work structuring, lean construction.

INTRODUCTION

The concept and technology of composite construction methods (*fukugōka kōhō*) emerged and flourished in Japan between the 1970s and 1990s. The fundamental idea was to combine conventional construction methods (*zairai kōhō*) and industrialised construction methods (*kōgyōka kōhō*) to improve the productivity of construction sites in the face of a chronic shortage of specialised construction workers (Nishida and Eguchi, 1989). Thus, it resulted from combining diverse construction technologies, promoting off-site production while maintaining the reliability of established on-site techniques in critical construction parts.

Previously existing composite structures (*gōsei kōzō*), by contrast with single-type counterparts, took the best of each material to respond to earthquake resistance requirements and high performance for realising skyscraper construction (AIJ, 1985). In turn, *fukugōka kōhō* combined the "off-site/on-site" production strategies with specific structural material settings.

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The *fukugōka kōhō* approach gained track when contractors perceived the technical and logistical difficulties of shifting directly to "purer" prefabrication (Takada, 1999).

Thus, *fukugōka kōhō* set realistic alternatives to tackle issues left unsolved by the desired but not all-rounded prefabrication schemes (Eguchi et al., 1988). For example, precast slabs did not eliminate local operations because the connection components remained as on-site manual work. Also, building pathologies, such as water, air, and sound leakage, compromised performance and durability. Thus, contractors preferred to continue employing conventional (by extension, more reliable) techniques in specific components and critical building interfaces.

Prototypical attempts of *fukugōka kōhō* focused on reinforced concrete (RC), steel frame reinforced concrete (SRC), and steel frame (S) structural systems. They usually strived to adopt as many precast concrete (PCa) elements as possible into the constituent parts of a conventional RC Rahmen structure (Ueno et al., 1989). The reasons for adopting it varied according to the requirements and conditions of each project. They included time shortening, reduction of personnel on-site, the downsizing or eventual elimination of temporary installations, reduction of material waste and energy consumption, quality improvement, and safety assurance (Konishi et al., 1996). The expected effects should fit the management targets of QCDSE (Quality, Cost, Delivery Time, Safety, and Environment).

Such strategy, resulting from selecting different construction methods in the same project, conveyed direct implications to structural design (type, properties, and composition of structural parts) and construction planning (construction zone division, erection sequence, assembly techniques, and temporary equipment allocation). The tentative plans employed high-variety low-volume parts to respond to design-construction conditions flexibly, simplifying work composition, nurturing multi-skilled workers, and enabling JIT (Kato et al., 1995).

Composite construction method plans resulted from disassembling, re-aligning, and integrating technologies concerned with construction work division, temporary equipment allocation, and labour assignment (Yashiro et al., 1993). The task of picking up features of existing methods considered the building use, construction site environmental conditions, gemba management policies, and the contract's ability to design technology interfaces between subsystems conceived independently (Takada, 1997). Contractors believed that accumulating improvements would lead to more robust and reliable structures in future projects.

The fact that *fukugōka kōhō* is not discussed under these terms today does not mean it has failed as a technology strategy or management concept. R&D projects were discontinued when the Japanese national economy stagnated after the "bubble economy" burst (Konishi et al., 1996). Then, many construction firms have resumed adopting conventional methods by default, while some suppliers have specialised in prefabrication for specific situations.

However, new technologies pledging to improve on-site operations have transformed the supply chain. Therefore, a revival of *fukugōka kōhō* is arguably an opportunity to promote innovative construction with productivity and personalisation advantages, satisfying both the customer and the production organisation. Digital platforms have significantly evolved, providing a comprehensive set of manufacturing, assembly, and inspection technologies unavailable by that time. The R&D initiatives, like those linked to the Construction RX Consortium, are a case in point (Construction RX Consortium, 2023). On the other hand, Lean Construction principles have been consolidated and can now offer an improved ground to establish better processes for both prefabrication and on-site digital construction schemes. Still, it seems that Japanese firms have handled them unconsciously or tacitly.

This research aimed to introduce the concept of *fukugōka kōhō* to the "outside world" with a refreshed outlook that helps identify drivers and potential barriers to future construction systems seeking to balance technical possibility and economic feasibility, taking advantage of the Japanese experience in developing and deploying composite construction methods.

RESEARCH SIGNIFICANCE

Japanese building construction is acknowledged for its quality and production efficiency. However, most studies disclosed outside Japan have focused on the housing sector, associated with the keywords "prefabrication", "unit construction method", and "modular construction". The seminal papers of Groàk (1993) and Gann (1996) diffused their impressions of missions to Japan to assess the development of prefabricated housing technologies in the 1990s. They did it from an "outsider perspective" through site visits, document analysis, and interviews.

The works of Yashiro (2014) and Matsumura et al. (2019), who interacted with those groups, are some of the few reports published in English conveying a "domestic view". The ZEMCH network, led by Noguchi (2016), has spread and popularised information about Japanese prefabrication, but they often recall the specific examples of the modular housing niche.

By contrast, the practices of Japanese General Contractors remain somewhat "mysterious" to the international community, given the limited number of sources about them. Foreigner researchers are aware of their technological strengths but know little about them. Bennett (1993) also visited Japan on technical missions and explored this niche. He emphasised the efficient production systems of the leading firms known as the "Big Five" (Kajima, Obayashi, Shimizu, Taisei, and Takenaka), praised for their massive research and development programs. Another notable yet rare case was the work of Bock (1989), who collected, organised, and diffused information in English about prefabrication and construction automation from housemakers to general contractors in rich detail due to the long-term nature of his stay in Japan.

Nevertheless, almost no research about composite construction methods has been published outside Japan. Evidence could be found in domestic papers and magazine reportages of that time. Although the peak of project implementation dates to the second half of the 1980s, the most relevant articles appeared in the early 1990s, based on the accumulated trial and error experience. The case of *fukugōka kōhō* was not limited to the Big Five. Semi-large and mid-sized firms also developed their authored versions and achieved positive results.

Current R&D programs promoting digital construction have set visions of not shifting directly to "purer robotisation" but establishing human-machine partnerships to reduce human labour. Arguably, lessons from the achievements and hardships of *fukugōka kōhō* could be used to set evidence-based R&D programs and support early-stage decision-making. Thus, there are reasons to revisit the *fukugōka kōhō* experience from a contemporary outlook.

RESEARCH PROCESS AND SOURCES OF EVIDENCE

The first part of this investigation identified the characteristics of *fukugōka kōhō* through a historical review to generate insights that could be revived today.

The bibliographic survey employed a triangulation strategy, uniting the academia and industry standpoints. The first source was the "*Sekō: kenchiku no gijutsu = Architectural product-engineering*" magazine series by *Shokokusha Publishing Co*. The second was the annual proceedings of the *Kenchiku Seisan Symposium* (Symposium on Building Construction and Management of Projects) sponsored by the Architectural Institute of Japan (AIJ). The third was a selection of miscellaneous papers from the AIJ database.

Table 1: Sources of the bibliographic survey

Source	Emphasis	Articles (no.)
Sekō: Kenchiku no Gijutsu (1966-2001)	Industry-centred	35
Kenchiku Seisan Symposium (1985-2021)	Industry-academia	10
AIJ miscellaneous papers (1989-1995)	Academia-centred	15

The second part attempted to understand the evolution of the characteristics of composite construction methods over time and the reason for their modifications through focus group interviews with veteran engineers. The target of this study was five prominent Japanese construction firms that developed and employed composite construction methods in the past. Three belong to the so-called "Big 5" group, and the other two are semi-large firms well-acknowledged for their technological achievements. The interactions were conducted entirely in Japanese between May and June 2022 and freely translated into this paper. The interviews were part of a broader study in which some questions focused on the *fukugōka kōhō* theme.

The participants belonged to various departments, including construction management, production technology, research and development, and design strategy. Their position varied from chief engineers to department managers and general managers. The average professional experience of the 14 participants was 30.75 years, with an average of 13.25 years on the gemba.

Table 2: Profile of the interviewees

Focus group	Interviewees: Position (Department)
Company A 2022.05.10	A1: Head manager (Building construction) A2: Head manager (Technical research institute) A3: Deputy manager (Operations support division)
Company B 2022.05.11	B1: Deputy director general (Building construction headquarters) B2: Manager, structure field (Production technology) B2: Manager, construction field (Production technology)
Company C 2022.05.12	C1: Head manager (Building construction) C2: Manager in charge (Building construction)
Company D 2022.05.27	D1: Head manager (Building technology) D2: Head manager (Building design strategy) D3: Chief structural engineer (Building design strategy) D4: Chief architect (Building design strategy)
Company E 2022.06.20	E1: Executive manager (Building construction headquarters) E2: Deputy general manager (Building construction headquarters)

FINDINGS OF THE HISTORICAL REVIEW

THE RISE OF FUKUGŌKA KŌHŌ

The Japanese construction sector has long faced a chronic labour shortage and declining productivity associated with an ageing workforce. Construction firms had struggled to find skilled tradespeople, mainly formwork carpenters and rod busters. At the same time, a plethora of new industrialised technologies was under development to meet ever-challenging project requirements, making construction methods more diverse and complex (Eguchi et al., 1988).

Despite the success of prefabrication among housemakers, production conditions were significantly different for order-made projects commissioned in mainstream construction. Traditional builders faced adversities associated with the uncertainty of the site environment and temporary supply organisations, making the production task more challenging. Still, general contractors were optimistic about off-site construction and positively invested in prefabrication technology development as part of rationalisation efforts (Takada, 1997).

However, precast concrete technology could not eliminate on-site operations because the joints still required local manual work (Konishi et al., 1996). Also, quality issues caused by flawed engineered interfaces disturbed users and urged hard-to-solve responses. Hence, *zairai kōhō*, considered more reliable, had to share the stage with prefabricated parts.

Ultimately, *fukugōka kōhō* served as an alternative to "pure prefabrication". It tackled issues left unsolved by the latter regarding productivity, quality, and its associated building performance, which were hard to perfect due to their production specificities. It enabled the realisation of superior structural performance and gemba productivity improvement by combining construction methods according to specific site conditions (Furusaka, 2009).

Figure 1 illustrates two examples of *fukugōka kōhō*. They shared the idea of utilising prefabricated components wherever possible and half-prefabricated parts wherever judged necessary to bind structural sections. However, the design details of those components and joints considered the specific production strategy of each firm and were often patented.

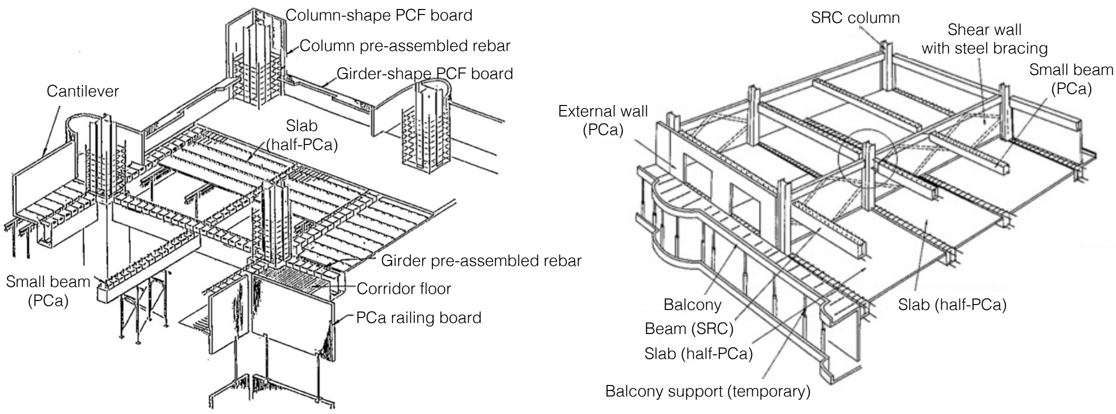

Figure 1: Examples of fukugōka kōhō (Adapted from: Sekō magazine, Aug 1986; Oct 1988)

The compounding approach enabled "leaner" sites to deliver buildings with similar outlooks, reducing wasteful local work subject to variability by systematically prefabricating components within reasonable boundaries, not pushing too much. Inspiration from the naval sector (i.e., Block Production System) and automotive sector (i.e., Just-in-Time) helped eliminate waste, overburden, and unevenness, the so-called *muda*, *muri*, and *mura* (Umehara et al., 1995).

By outsourcing tasks in the critical path, the project team could shorten the delivery time, reduce on-site personnel, and flexibly tighten connectors due to the modular design and the well-coordinated delivery of semi-finished parts, which were usually large and, in some cases, self-supporting. Consequently, the site necessitated fewer temporary construction equipment that obstructed the flow of people and hindered the execution of concurrent services.

DEFINITION AND TERMINOLOGY

Despite the absence of a resolute definition of *fukugōka kōhō*, the quote below hints on the concept development.

> "Fukugōka kōhō is a construction method that incorporates as many precast concrete (PCa) elements as possible into the skeleton constituent parts of a conventional structure (viz., generic cast-in-place concrete) aiming to improve the production efficiency on-site (Ueno et al., 1989)."

The terminology has changed as the management implications became clear. Records in the *Sekō* magazine revealed that the technology was first referred to as "*fukugōka kōhō*" in which the "*kō*" of "*kōhō*" was written with the ideogram "*takumi*" conveying a nuance of "engineering process (how to make it)". Afterwards, practitioners substituted that ideogram for "*kamai*", which is also read "*kō*" but suggests "structural composition (what is it made of)". Then, both ideograms were combined in a single word (*kōkōhō*) which implied that technologies were stacked together like a mosaic, integrating materials, equipment, workforce, and operations with the construction zone division and temporary work plans (Yashiro et al., 1993).

Regarding the specific names, it was common to attach a prefix (usually an acronym) that identified the core technology involved in each building system. Most companies labelled each variation by describing the specific material in use, functional cross-sections, connection types, and the target building typology to which it was conceived. Other companies would collectively address their inventions under an umbrella title, such as "*x-company-style fukugōka kōhō*".

PIONEERING SOLUTIONS

The planning of *fukugōka kōhō* resulted from the iteration of construction method selection and combination for rationalisation purposes. Construction firms first prioritised structural systems over other disciplines, considering it would bring impact benefits to urgent issues, such as cost. Despite the technical challenges, contractors believed that accumulating improvements over time would make these composite structures more robust and reliable (Eguchi et al., 1988).

Figure 2 illustrates the construction cycle of a project employing *fukugōka kōhō*, which directly impacted work structuring. The mix of precast and conventional work set specific takt times that were usually in between those estimated to *zairai kōhō* and full prefabrication.

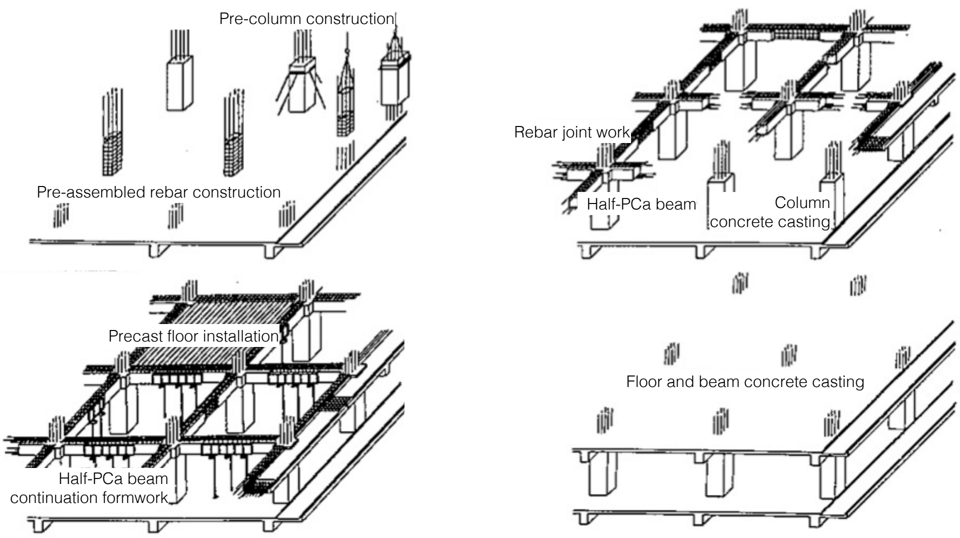

Figure 2: Construction cycle with fukugōka kōhō (Adapted from: Sekō magazine, Jan 1991)

A survey by Konishi et al. (1996) with several companies identified the most recurrent merits among 51 composite construction method variations. A breakdown of these factors revealed that the leading one was time shortening (43), followed by labour-saving (*shōryokuka*) (38), quality improvement (29), personnel reduction (*shōjinka*) (28), proficiency effect (*shūjuku kōka*) (27), cost reduction (26), and material-saving (24). Other benefits reported included the independence of weather conditions, the possibility of constructing higher buildings, larger spans, lighter structures, and improved earthquake resistance, to name a few.

A major consequence of *fukugōka kōhō* was the simplification of temporary construction (*kasetsu kōji*). The reduction of storage, transport, and safety installations implied cost savings and clear space for the remaining work on-site. For instance, precast horizontal boards avoided vertical supports and allowed the quick start of subsequent tasks. Parallel work optimised equipment utilisation (*kadōritsu*) and promoted site tidiness (viz., 5S workplace organisation).

A study by Ueno et al. (1989) compared two projects of similar scope and scale (3-story residential building) in which one employed *zairai kōhō* and the other *fukugōka kōhō*. Regarding resource utilisation, the project with *fukugōka kōhō* saved about 30% of man/hour in the structural frame construction and about 30~50% in the formwork, rebar, and concrete casting operations. The cycle process was shortened from 12 to 8 days, and the total construction time was compressed from 15 to 12 months.

INTERVIEW RESPONSE-BASED CONSIDERATIONS

DRIVERS AND BARRIERS IN ADOPTING FUKUGŌKA KŌHŌ

The historical survey revealed that the **main drivers** for adopting composite construction methods in the so-called first-generation *fukugōka kōhō* (1970-1990) were:

- Productivity (or QCDSE in the broadest sense).
- Structural performance (or overall building performance).
- Flexibility of construction process and operations.
- Product individualisation and customisation capabilities.
- Enhanced component supply and on-site logistics.

The interviewees were asked about the main reasons for adopting composite construction methods today in light of the current industry situation. The motivation has not significantly changed, as the most frequent responses were pursuing "*cost reduction*" through the willingness to increase productivity compared to conventional construction methods.

> "It is [mostly] about money. The selection of construction methods considers the customer's requirements. Roughly speaking, decision-making strives to balance cost and construction time. [That is because] there are cases where they are willing to pay a bit more for faster construction (Mr A1)".

The secondary factor was the "*flexibility*" of the construction process and operations. The argument was supplying the advantages that an element technology is good in a composite structural system that better fits the project overall. The other factors were pointed out as "manageable". Although not necessarily easy to solve, the engineers "don't overthink them". Regarding *structural performance*, the interviewees reported that improved material properties (viz., high-strength concrete) have made combining too many different materials unnecessary to extract their advantages (e.g., employing RC where SRC used to be required), making the construction process simpler and more efficient. By all means, the application was contingent on compliance with technology evaluations and obtaining permission from the local authorities.

> "I think structure performance was not a reason to adopt *fukugōka kōhō* because the selection of a construction method must ensure '*dōyūi tanpo*', that is, the new candidate must ensure equal advantage or performance superiority compared to established methods (Mr B2)".

In the past, the construction method combinations were necessary for erecting a building with particular architectural features (i.e., high-rise, large spans, earthquake resistance). Now, many venturous designs are possible with fewer structural type combinations which means a trend toward simplification. Structures of either "single-type method" or "composite method" must satisfy the design's performance specifications and adhere to technical requirements.

Construction records of the historical survey revealed that the **main barriers** to deploying the first-generation *fukugōka kōhō* (1970-1990) were:

- The need for adaptation and rework due to the complexity of the design.
- Lack of skilled labour.
- Technology interface issues.
- Regulatory permissions (i.e., technical standards, town planning etc.).
- Reliability of parts and component supply.

The discussion about the barriers called out the kernel of the composite construction method idea. Some interviewees highlighted that *fukugōka kōhō* variations were devised to overcome the pitfalls of previous construction methods, so it was hard to point out their barriers.

> "Generally speaking, *zairai kōhō* is the reference construction method to be employed. Occasionally, we face a problem such as 'the construction period is too short' so the adoption of *fukugōka kōhō* is worthwhile. Regarding the barriers, I would say that solving the decomposition and continuity between construction methods is challenging (i.e., *technology interface issues*) (Mr A1)".

Furthermore, *fukugōka kōhō* can simultaneously raise advantages and disadvantages on the same factor. For instance, 'cost-saving' was considered the main reason for adopting. However, the extra cost of adapting the technology to peculiar project conditions (rework of designing a piece devised for a different construction method) can be a barrier at the same time.

> "In principle, *fukugōka kōhō* takes only the good parts of each element method, so adding a few PCa in *zairai kōhō* structures would be good. However, off-site production implies the need for transportation, which implies extra costs (Mr C2)".

Some of the obstacles of *fukugōka kōhō* are similar to those of *kōgyōka kōhō* (prefabrication) since the latter is integral to it. The external and internal logistics are a case in point.

> "A significant factor is the yard condition. Whether there is a yard or not, whether a crane can be placed or not, whether the trucks can come in or not (Mr B3)".

Because *fukugōka kōhō* was new to most players, project teams struggled to understand the underlying process and streamline actions leading to tangible gains. The information flow and decision-making chain could fall short of clarity when adopting novel arrangements.

> "If we adopt a generic (default) construction method, there is a generic flow to proceed. However, *fukugōka kōhō* does not follow the generic flow. So, we must imagine and elaborate it (from scratch) by ourselves (Mr A3)".

Moreover, the new combination must meet the quality and performance threshold; otherwise, it will be rejected as a candidate system for that project.

> "If it clears the quality threshold, we will check the cost merit. After that, we assess the impact in construction time. […] We want to select a combination that takes this balance. We often ask ourselves: 'How far should we prefabricate?' (Mr D1)".

The need for adaptations in the construction plan and the rework of interface design undermined a more extensive application. Thus, design-bid-build projects in which the design comes from an external office were also more challenging to deal with than design and build commissions for a single firm (large Japanese general contractors hold full-scale design teams).

TECHNOLOGY ADVANCEMENT AND CHANGES IN ITS IMPORTANCE PERCEPTION

Regarding the **conceptual and physical changes** over the decades, it was unanimous that progress in building materials promoted significant transformations in structural design. These changes modified the strategies for the appointment of corresponding construction methods.

> "In the 1980s, PCa was widely discussed. However, at that time, there was no high-strength concrete as we have today, so it would have been impossible to build high-rise buildings only with PCa (Mr A1)".

An example was the substitution of SRC by PCa frames for high-rise building structures, thanks to the evolution of concrete technologies, reducing gemba operation complexity.

> "About 40 years ago, SRC was the only choice for high-rise residential buildings because of its superior performance. However, SRC is expensive and makes the construction period longer. From the 1980s, [high strength] PCa became an option. Nowadays, there are almost no new buildings with SRC (Mr B1)".

Fukugōka kōhō aggregated PCa parts into conventional RC skeletons for rationalising the erection process. It also combined RC columns and S beams to extract their superior structural properties, creating many design variation possibilities to satisfy customer needs.

> "In the 2000s, we often used a construction method of RC columns and S beams. It was a way of having the best of each material. The older mentality was 'If I use an S beam, then I should use an S (or SRC) column too'. However, the development of joints has made it possible to use this (alternative) combination (Mr B2)".

Because the number of prefabricated parts increased, construction equipment had to become more efficient. Consequently, scheduling and stock management adapted to the new erection pace. However, the productivity of people-operated tasks has not changed much since then.

> "The capacity of tower cranes has increased. In the past, they lifted no more than 20t. Also, the provisional service elevators have become faster (Mr C1)".

It is worth noting that the term *fukugōka kōhō* became unused over time. There is an awareness that undertaking 100% *kōgyōka kōhō* (prefabrication), although not impossible, is complicated and not necessarily worthy depending on the project conditions.

> "I think the so-called *fukugōka kōhō* that flourished in the 1990s has provided good combinations of element construction methods. However, the technology was still in its infancy at that time. […] In our company, we have developed a comprehensive construction method called '*x-construction method*' (pseudonym). Since then, we probably have not called it *fukugōka kōhō* anymore (Mr A1)".

Similarly, in the idea, but without a standardised solution pattern, some companies referred to their subsequent *fukugōka kōhō*-ish arrangements as a "hybrid construction method" or merely a "rationalised construction method".

> "PCa (prefabrication) is the choice with the highest merit. However, the cost factor recurrently leads to hybrid options with *zairai kōhō*. The construction time might enlarge a little (compared to pure PCa). The so-called 'hybrid method' or 'rationalised method' takes the balance of cost and time (Mr E2)".

The theoretical concept of *fukugōka kōhō* was not uncontroversial and is hardly mentioned today. Young architects and contractors face the term as a simple description of an engineering strategy rather than an actual concept. The interviewees reacted with surprise when asked about their memories and reflected on how they could be helpful today. Besides, they demonstrated a certain nostalgia and conjectured that "almost everything today is a sort of *fukugōka kōhō*". They would not spend much energy on it because "it just sounds natural" to pursue prefabrication without "doing *muri*" and relying on *zairai kōhō* when inevitable.

DISCUSSION: DIRECTIONS FOR NEW BUILDING SYSTEMS

The compounding approach had taken part in construction rationalisation policies (*gōrika hōshin*) initially emphasising productivity and quality (Takada, 1999). Despite not using the word "lean" explicitly, many "*gōrika"* efforts resembled what the West would call lean-ish endeavours, pursuing eliminating waste and improving flow. *Fukugōka kōhō*, within that macro-concept, could be considered an unconscious and partial "lean construction" example.

Regarding the lessons to devise future construction systems, there was no consensus on whether the proportion of prefabrication shall increase, decrease, or continue at about the same level as today. It would depend on whether construction robotics will make local operations more advantageous than bringing on semi-ready parts. Ultimately, "new hybrid" construction systems could result from sophisticated prefabrication and on-site automation coordination. For the automation element, the *Construction RX Consortium* (2023) is an example of technology cooperation aiming at labour saving and worksite efficiency through site robots introduction in gradual steps. The initiative does not claim to be lean but features some lean-ish characteristics.

The interviewees suggested that a new *fukugōka kōhō* employing on-site robotics could be developed shortly, but probably without using the "composite construction method" name.

> "The changes are from hereon. Digital technologies have evolved a lot. However, the fundamental aspects of the production systems have not changed yet. There is progress in elemental technologies. Now, we are investigating 'how to link these element technologies to our productivity improvement actions' (Mr B2)".

The development of *fukugōka kōhō* had been partially *cumulative* on a succession of routine improvements (*kaizen*) and *disruptive* as part of innovation programs to anticipate response to social and market change. Compared to the robotics wave of 30-40 years ago, there is an increased willingness to employ assist robots. They are not meant to replace humans but aid the fewer (multi-skilled) of them who remain on-site to perform as much as many workers traditionally, reducing redundancy (waste). Still, systematic robotic utilisation shall satisfy certain conditions, including finding the necessary input to start operating. However, these robots still do not hold enough autonomy to handle "improvisations" and deal with their risks. The word "making-do", as defined by Koskela (2004), is not heard in Japanese gemba, but a similar "drive" or "impulse" to control them tacitly exists in *dandori* arrangements.

CONCLUSION

The labour shortage issue has been further aggravated in Japan and other countries. In response, construction firms have proactively set internal policies to promote off-site production. Nevertheless, they have been conservative about the time robots developed in the R&D laboratories will run in the real gemba. The lessons of the past showed that the hurdles of "full prefabrication" and "full automation" are exceedingly high. Thus, it has been more realistic to face automation as performing an "assist" function, and prefabrication as a spotted strategy.

Former versions of *fukugōka kōhō* brought out the best of "off-site and on-site" for optimal efficiency with a touch of parsimony. Future building systems are likely to follow the compounding rationale. However, the "on-site" part might be modified due to recent technologies. The "*new fukugōka kōhō*" will likely be a mix of "off-site/on-site" in which the on-site work will be more digitalised, contingent on technology robustness issues.

Since new combinations are subject to falling short in performance-quality trustworthiness (trial-and-error experimental nature), the transition will take time. The deployment of "*new fukugōka kōhō*" depends on the construction method technology in itself but also the ability of design teams to devise coherent and robust combinations in response to the project requirements. Procurement models integrating design and construction control (*sekkei-sekō*) provide a favourable ground to maximise the available machine's capabilities and realise frontloading.

Lastly, stakeholders must beware of the advantages and limitations of each elemental technology and communicate with construction planners and component suppliers to streamline the comprehensive production system. Therefore, the realisation of such building system design is the product of sophisticated internal and external teamwork pursuing the balance between optimal and feasible. It is, ultimately, a tacit expression of lean-like efforts. It may be a peculiarity of the Japanese construction industry and business environment and not necessarily applicable to projects where the underlying conditions are significantly different.

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