

Industrialized house building productivity growth

House building
productivity

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143

Received 27 April 2022
Revised 9 January 2023
Accepted 4 April 2023

Abstract

Purpose – The purpose of this paper is to understand if and how industrialized house building (IHB) could support productivity developments for housebuilding on project and industry levels. The take is that fragmentation of construction is one explanation for the lack of productivity growth, and that IHB could be an integrating method of overcoming horizontal and vertical fragmentation.

Design/methodology/approach – Single-factor productivity measures are calculated based on data reported by IHB companies and compared to official produced and published research data. The survey covers the years 2013–2020 for IHB companies building multi-storey houses in timber. Generalization is sought through descriptive statistics by contrasting the data samples to the used means to control vertical and horizontal fragmentation formulated as three theoretical propositions.

Findings – According to the results, IHB in timber is on average more productive than conventional housebuilding at the company level, project level, in absolute and in growth terms over the eight-year period. On the company level, the labour productivity was on average 10% higher for IHB compared to general construction and positioned between general construction and general manufacturing. On the project level, IHB displayed an average cost productivity growth of 19% for an employed prefabrication degree of about 45%.

Originality/value – Empirical evidence is presented quantifying so far perceived advantages of IHB. By providing analysis of actual cost and project data derived from IHB companies, the article quantifies previous research that IHB is not only about prefabrication. The observed positive productivity growth in relation to the employed prefabrication degree indicates that off-site production is not a sufficient mean for reaching high productivity and productivity growth. Instead, the capabilities to integrate the operative logic of conventional housebuilding together with logic of IHB platform development and use is a probable explanation of the observed positive productivity growth.

Keywords Construction productivity, Industrialized house building, Fragmentation, House building, Prefabrication, Integration

Paper type Research paper

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Funding: For this article was provided by the CBBT research foundation, Wood Center North at Luleå University of technology and the Swedish Wood Construction Office.



Construction Innovation
Vol. 24 No. 7, 2024
pp. 143-162
Emerald Publishing Limited
1471-4175
DOI 10.1108/CI-04-2022-0097

Introduction

Improving the productivity of the construction industry has been on the agenda for many governments worldwide and is a longstanding theme in the general debate in Sweden. The standpoint taken in this paper is that: the way construction fragmentation is managed and channelled through a production system could explain construction productivity growth. The construction value chains are fragmented because companies organize their operations into projects around delivering discrete parts of buildings and parts of the specifications of buildings. Vertical fragmentation is evident as multiple layers of sub-contracting and horizontal fragmentation are caused by discontinuities between the specific project stages (Hughes and Stehn, 2019). In the next project, there are new constellations of companies vertically and horizontally fragmented, which hinder developments of common working methods over time (Reichstein *et al.*, 2005). Fragmentation is pointed out to be a root cause of the construction sectors' perceived performance insufficiencies (Fellows and Liu, 2012).

Generally seen, productivity can include both efficiency (outputs/inputs) and effectiveness (outputs/goals) so that goals can efficiently be accomplished by the production system (Pritchard, 1995). Caused by fragmentation, construction productivity developments, measurements and research must consider three specific levels (Pan *et al.*, 2019):

- (1) activity (labour);
- (2) project; and
- (3) industry/company.

Productivity in construction is primarily considered a metric for industry performance in official statistics. Productivity developments are hardly ever used for controlling and benchmarking project or company performance. At the project or industry level, average labour productivity and total factor productivity (albeit aggregated from many factors) provide just one metric of productivity to represent the whole system and are therefore more of index values that rather reflect changes in the composition of projects instead of productivity changes on operations *per se* (Huang *et al.*, 2009). Aggregate productivity estimations in construction are therefore debated and especially difficult to measure because of the many different stakeholders fragmented both vertically and horizontally. Mostly it seems that productivity gains for contractors come from implementing technology innovations at the labour level and effective management practices at the project level primarily to satisfy specifications and the client's demands (Zhang *et al.*, 2017). Caused by the horizontal fragmentation and project focus, these practises and innovations likely only affect the stages in singular projects. Coordination to reach specific project goals and sub-contracting seems to be the *modus operandi* for fragmentation control in conventional house building, not for increasing performance or productivity. Studies in construction on productivity improvements from using specific technologies are however scarce (Lucko *et al.*, 2014) or have overemphasized on developing separate measures of productivity instead of developing or discussing strategic approaches (Kenley, 2014). In that line, Hasan *et al.* (2018) propose that future research should connect the use of emerging technologies into productivity improvements by quantifying the benefits in terms of potential time and cost savings.

One different take on how to control fragmentation is found in industrialized house building (IHB). The contemporary business logic of IHB is to organize their operations around total deliveries reducing vertical fragmentation by e.g. long-term contracts and reducing horizontal fragmentation by integrating most of the project stages in design, off-site and on-site production in-house (Lessing and Stehn, 2019). Seen as a technology, IHB is centred on off-site prefabrication and standardization of recurring processes. In quality engineering, repetitiveness

and standardization of processes (Lillrank and Liukko, 2004; Palmberg, 2009), which contribute to continuity, are well-known characteristics for operational developments. Jonsson and Rudberg (2017) identified what and how to measure competitive priorities for IHB based on a production systems analysis mirrored from manufacturing research. Looking into industrialized construction, Attouri *et al.* (2022) could only pinpoint perceived benefits and list perceived qualitative factors contributing to productivity gains. All these studies indicate but do not validate or provide figures regarding IHB productivity and growth. Empirical evidence and research are needed on perceived advantages of IHB to expand the understanding if productivity improvements in terms of time and/or cost savings are realized.

Hughes and Stehn (2019) argued that horizontal and vertical fragmentation prevents introduction of innovative products into the design and construction processes. They showed that an IHB company could control horizontal and vertical fragmentation by entrepreneurial innovations and a supporting business model. Following this line of reasoning, IHB is considered as an integrating method of overcoming horizontal and vertical fragmentation. This article therefore proposes that IHB will display a positive productivity growth over time.

Therefore, the aim of this article is to understand if and how IHB could support productivity developments on project and industry levels. Following Nasir *et al.* (2014) that actual cost data derived from contractors' own internal project control systems provide a more relevant cost and time estimate compared to aggregated industry numbers, this study examines specific IHB company economic and project data.

Two ways of managing fragmentation

Conventional house building is about project management and sub-contracting

To ensure control, i.e. keeping to schedules, cost plans and the client's requirements, in the building process, coordination of the design team before construction and the coordination of the construction team during construction (Ireland, 1985) have long been advocated as the mechanism. The horizontal and vertical fragmentation in construction and the way the inter-organizational businesses are set up cause several difficulties (Love *et al.*, 1999; Greenwood, 2001; Harty, 2005; Green *et al.*, 2008; Hartmann and Caerteling, 2010), which are proposed to increase the likelihood of project time and cost overruns. The predominance of using multiple layers of sub-contracting to manage the combination of horizontal and vertical fragmentation evidently obstructs structured effectiveness developments amongst actors.

Maybe the most salient feature preventing a productivity development in construction is how contracts are used. Contracts must usually precede orders, and the project price and lead-time need to be estimated before the project. To include contingencies for unforeseen conditions affecting costs and lead-times that may occur during construction, the construction method – a specific production system – is fixed first after a contract is won. The important implication in relation to productivity development is that companies are to an extent unable to gain some of the benefits of centralized and planned production enjoyed by many large firms in manufacturing (Gann, 1996). Another important implication of the preferred use of specific one-off production budgets is that learning between projects is hindered. Baseline productivity should be an important standard, calculated by comparing different project performances, that could, but usually is not, be used in budgeting for the project estimation and scheduling for project control (Zhang *et al.*, 2017). Therefore, conventional house-building companies are unwilling to explore and make long-term fixed strategic commitments, with a purpose to achieve productivity development, when addressing the (short-term) risks associated to housing production and supply (Pan and Goodier, 2012).

The operation and business strategies of a construction firm mainly aim at supporting with corporate management tools for resources to be available for running projects, by using

project management principles and simultaneously bidding for potential projects (Shi and Halpin, 2003). Thus, two types of management and coordination are needed. On the one hand, project management to select production method setting up a production system around the single project based on strict cost management to reach project goals. On the other hand, financial management for bidding for new projects. This evidently delimits management of project operations from management of a portfolio of projects, on the company level, that creates a two-dimensional management continuum to handle for construction companies. Competitiveness at project and company level clearly refers to a contractor's capacity to win a contract and to undertake that project (Flanagan *et al.*, 2007), *de facto* not performance or productivity developments.

Industrialized house building is about efficiency and effectiveness in production

The literature review and long-term case studies of Lessing *et al.* (2015) and Lessing and Stehn (2019) present constructs that may explain perceived, and to some extent documented, benefits of IHB. The companies driving the development of IHB in Sweden since the mid-2000s can, in line with Lessing *et al.* (2015), be characterized as specialized based on continuity and learning between building projects and in the repetitive use of methods and techniques. The continuity (in use of pre-engineered solutions, processes and partnerships) and specialization (in terms of offerings sold in niche markets) define how these companies operate. Standardization creates control and stability that facilitate repetition and continuity, which together form the cornerstones in quality management to improve process performance (Lillrank and Liukko, 2004; Palmberg, 2009). Hvam *et al.* (2008) introduced the platform approach, found in the scientific field of operations strategy, to housebuilding. The explanations of means for continuity and learning in IHB are partly based on Hvams' work and are described as platforms aimed at specific customer segments (Johnsson, 2013; Jansson *et al.*, 2014) and continuous improvements (Meiling *et al.*, 2014; Jansson *et al.*, 2015). Lately however, Grenzfurtnner and Gronalt (2020) claim that some IHB companies still lack a structured use of continuous improvements, particularly regarding on-site data collection and analysis.

The exploitation of the IHB product platform (platform use) takes place in separate construction projects, the exploration (platform development) of the product platform (including process, product and business development) is decoupled from singular housing projects (Lessing *et al.*, 2015). Exploitation in unique projects and exploration of the product platform also creates a two-dimensional structure, but for continuity and learning of unique projects that are incorporated in the development of long-term processes. Stehn *et al.* (2021) saw that two-dimensional structure but explained it as the build-up of corporate assets by using dynamic capabilities theorizing. Popovic *et al.* (2021) also found that two-dimensional structure but expressed it as the alignment between using the IHB platform and developing it.

On the one hand, an IHB company must have the capabilities of managing the unique project dimension, and on the other hand, it should be able to manage the recurrent product dimension. To capitalize on investments done and be able to stay competitive on their selected market niches, it is of importance for the IHB companies to be proficient and handle their two-dimensional structure. From a production strategy perspective, which partly symbolizes IHB, the key challenge is to link the market requirements with the production systems (Hayes and Wheelwright, 1984). This means that an IHB company requires capabilities and investments to be both effective and efficient in the development of platforms and its organization to ensure a good fit of the chosen the degree of off-site assembly vs degree of standardization to win orders on the market (Jonsson and Rudberg, 2015). Importantly, the IHB products (houses) are offered in competition with conventional house building projects. The IHB projects are in essence therefore following the business and operative logic of conventional housebuilding projects why

the two-dimensional structure of IHB (platform development and use) needs to be overlaid by the two-dimensional structure of conventional house building of project and portfolio management. The IHB company must also be proficient in the sense of conventional house building, i.e. share same core capabilities as conventional house building (Johnsson, 2013), and in parallel integrate and emphasize both flexibility (to win a contract and undertake that contract) and efficiency/productivity (in platform development and use) as a source of competitive advantage.

Theoretical framework for industrialized house building productivity growth

The level of analysis is how management of fragmentation effect productivity at project and company levels. The view adopted is that productivity is assured by the production system (Pritchard, 1995). Productivity is a qualitative or quantitative metric that provides indications of how well a system performs with respect to certain targets (Sink *et al.*, 1984). Various direct and indirect, interdependent and interconnected flows and activities influence productivity in house building production. How well the building process is designed, and activities organized, not only separately but together as a whole, will have an influence on the production system's productivity achievements (Green, 2016). The views adopted in this article are that fragmentation of construction is one salient explanation for the lack of:

- productivity growth (Fellows and Liu, 2012);
- benefits of centralized and planned production (Gann, 1996);
- long-term fixed strategic commitments to achieve productivity development (Pan and Goodier, 2012); and
- baseline developments for learning (Zhang *et al.*, 2017) and to compare between projects.

The IHB production system [Figure 1(a)] integrates off-site manufacturing (including technical installations installed in the factory), on-site construction (including transportation and most of the site installations) and architectural and engineering design into a platform. Depending on the project specifications, some designers and sub-contractors must be procured. That platform consists of standardized components, recurring processes and long-term stakeholders (specialized consultants and specialized sub-contractors). Highlighted in Figure 1(a), **P** denotes the prefabrication, or industrialization, degree as the relation of off-site to on-site construction. The prefabrication degree is in this article considered to be one indicator for integration of the production system.

The conventional house building production system is not only set up around the single project, i.e. a temporary on-site system [Figure 1(b)], but also dismantled after project completion. The conventional house building project-based production setup is more service oriented and can be said to serve several types of projects with different organizational setups. The production system is in essence a converging supply chain directing all materials to the construction site; a temporary supply chain based on one-off production systems with low use of structured repetition. Contractors, sub-contractors, designers, suppliers, etc. are often involved in multiple projects (temporary organizations) organized and coordinated by multiple layers of sub-contracting to manage the combination of horizontal and vertical fragmentation.

The two-dimensional structure (project and company levels) to cope with fragmentation in conventional housebuilding is shown in Figure 2(b). On the project level, the control for specific project goals (e.g. follow-up of costs and schedule) in the specific production system is carried out according to well-established project management practices. On the company level, project portfolio management is used to maximize usage of resources for the projects at hand and for bidding for new projects. On the company level, the support to the production system is to

develop general “this-is-our-way” management systems. Productivity performance is often considered as just a quality parameter and with less attention on learning and changing a baseline productivity for further project productivity growth. This way of managing and operating (the contracting modus operandi) the many different production systems by offering flexibility at the company and project levels keeps fragmentation complexity at a high level.

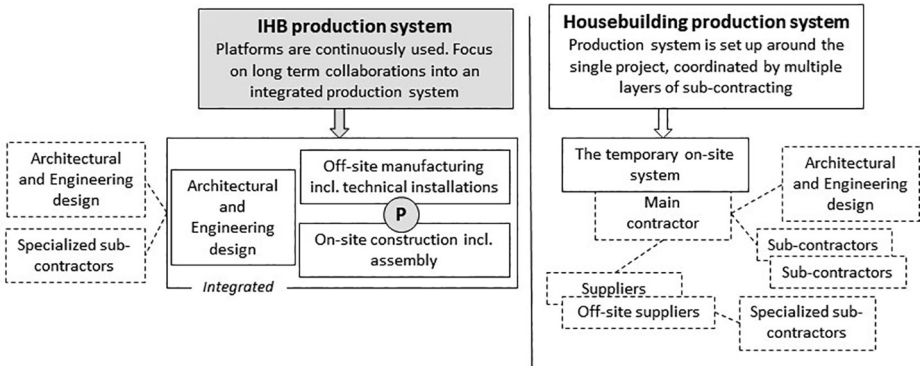


Figure 1. Schematic illustration of (a) IHB production system, (b) conventional house building production system

Source: Author’s own creation

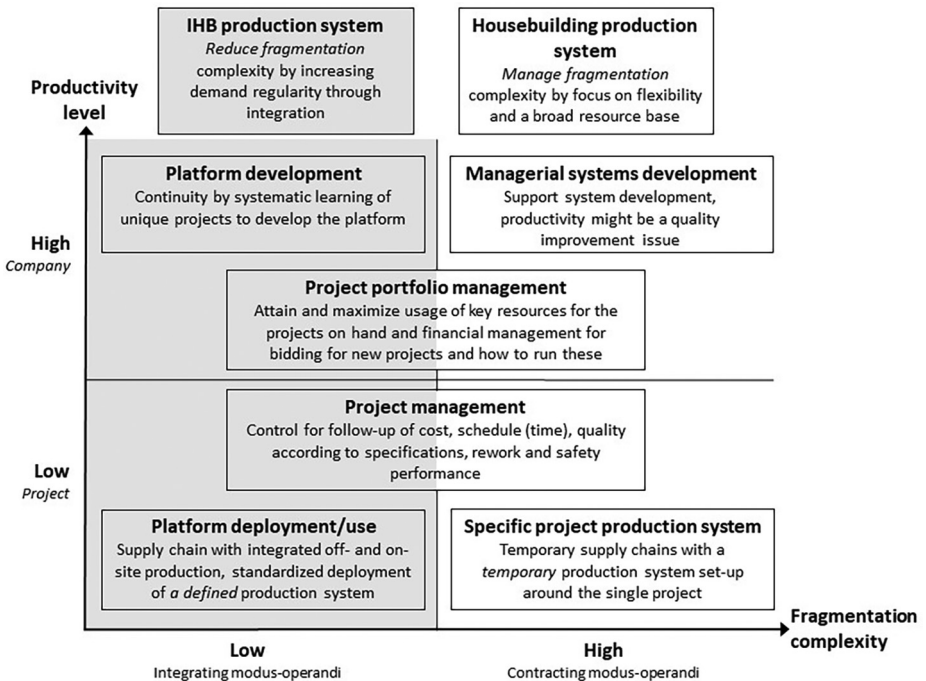


Figure 2. Managing and operating production systems at company and project levels

Source: Author’s own creation

Figure 2(a) shows the overlaid two-dimensional structure for IHB, i.e. components from conventional housebuilding overlapping the IHB structures at company and project levels aimed to ascertain efficiency and effectiveness by the developed and invested platforms. On the project level, project management is still needed and must be coordinated together with the deployment of the platforms to control of specific project goals. On the company level, portfolio management is used but primarily only for the financial and resource management of the firm and is overlaid on platform management that is performed to create continuity by systematic learning of unique projects to develop the platform. Productivity development is considered as one key parameter. Standardization and continuity is a strategy to reduce the negative impacts of fragmentation to create control and stability to improve production system performance. This way of managing and operating (the integrating *modus operandi*) the production system through increasing demand regularity through standardization and continuity therefore reduces the fragmentation complexity to a lower level.

The theoretical reasoning, highlighted in Figures 1 and 2, served as the base for formulating three propositions regarding productivity effects of the used means to control vertical and horizontal fragmentation.

Proposition 1. Integration of off-site manufacturing, on-site construction and design into a platform as one mean for reducing fragmentation complexities can explain productivity growth. This leads to the first proposition:

P1. Integration to cope with fragmentation can explain productivity growth.

P2. Reducing fragmentation complexity by continuity and systematic learning of unique projects will show more productivity gains at the company level of IHB (based on an integrating *modus operandi*) in relation to *managing fragmentation complexity* by subcontracting with focus on flexibility in portfolio and managerial systems developments at the company level of conventional house building (based on a contracting *modus operandi*). This leads to the second proposition:

P2. IHB companies will have high productivity and productivity growth in relation to conventional house building companies.

P3. Deploying a production system for various single projects will show more project productivity goals improvements in relation to *setting up a single project production system*. This leads to the third proposition:

P3. IHB projects will have high project productivity and productivity growth in relation to conventional house building.

Methods and data analysis

Data sources and selection of industrialized house building representation

Data was collected to demonstrate IHB productivity developments at industry/company level and project level. A clearly technically distinguishable branch in Sweden is IHB companies involved in multi-storey residential building production in timber. All companies that together form this branch were selected for this article. Based on the IHB production system classification of Jonsson and Rudberg (2015), the IHB companies can be categorized as modular building in terms of prefabrication but with a span from tailored to segmented standardization in relation to customization. Following the reasoning that productivity is assured by the production system, similarities must exist between the different IHB companies' production systems to make them comparable in terms of cost and value units

regarding productivity developments [cf. [equations \(1\)–\(3\)](#)]. From the point of prefabrication, i.e. the off-site manufacturing production system setup, the technical similarities between the IHB companies indicates comparability. However, in terms of standardization and customization (manifested in their on-site construction work), the comparability between IHB to IHB company is lesser that will result in variability of productivity development. To cover this issue, the prefabrication degree P is used to strengthen comparisons.

The survey covers the years 2013–2020. The data consists of company-based information on financial and construction project information reported by the four participating companies themselves. House building projects are represented by data from 103 projects with a geographical spread throughout Sweden. The projects correspond to 8,417 apartments in multi-storey timber houses.

Comparisons on productivity developments between the years 2013 and 2020 necessitated that costs were adjusted for inflation. Two price conversion methods were used. In labour productivity comparisons at the company level, data was adjusted downwards using the Consumer Price Index (CPI) produced by Statistics Sweden (responsible for official statistics in Sweden) for adjustment of price increases in comparisons with 2014. Calculated labour productivity was compared with data extracted from Statistics Sweden industrial classification NACE system.

At the construction project level, data for construction costs for 2020 to 2015 was adjusted downwards using the Contract Index for adjustment for price increases in comparisons with 2014. Contract Index is determined by Statistics Sweden for cost changes (excluding Wage slippage and VAT) to calculate coverage factors for house construction, civil engineering contracts and various subcontracts. Using a form of meta-analysis, the quantitative findings from the IHB productivity measurements were cross-analysed with data from two existing studies to make comparisons between IHB and conventional housing production. The two studies (in Swedish) by [Josephson \(2013\)](#) and [Koch et al. \(2020\)](#) present productivity data, inter alia for conventional house building, for the year 2013 and for the year 2018 adjusted to 2014 price using the Contract Index. Those studies were, in terms of [Lucko et al. \(2014\)](#) valuable retrospective studies, based on structured questionnaires and follow-up question to project managers and site managers on estimated economical and project facts. This meant that the data was entirely based on the actors' professional values.

Labour productivity

The data collection was based on calculations from structural business statistics defined by Statistics Sweden. Actually worked hours was used as a measure for labour input. It is acknowledged that there is still an unknown portion of non-value-adding time inherent in hours actually worked. A weakness of company-based information is that it is usually linked to the salary system; reported time will therefore be paid time or agreed time instead of actual time worked.

[Equation \(1\)](#) displays the labour productivity expressed as a single-factor productivity measure on company level:

$$\text{Labour productivity} = \frac{\text{output}}{\text{input}} = \frac{(\text{Production value} - \text{Input consumption})}{\text{Actually worked hours}} \left[\frac{\text{SEK}}{h} \right] \quad (1)$$

Production value refers to net sales in SEK generated from the revenue from the sum of all goods and services produced. Input consumption refers to the value in SEK of the goods and purchased services used as input in the production process, excluding fixed assets. Actually worked hours refers to the total hours actually worked by all employees in the own company.

Project lead-time productivity

In the construction setting, lead-time need to be estimated before or in the beginning of a house building project. The estimation of project lead-time is therefore not only a measure of efficiency but also influenced by partly unknown non-value-adding factors, even so lead-time is a normally used indirect performance measure in Swedish house building. Equation (2) calculates the lead-time efficiency expressed as a single-factor measure on project level:

$$\text{Lead time efficiency} = \frac{\text{Lead time}}{\text{m}^2\text{GFA}} \left[\frac{h}{\text{m}^2} \right] \quad (2)$$

The lead-time is calculated as the time, in months, from the start of the design work to the end of production (final inspection). Therefore, the lead-time includes time for procuring sub-contractors, materials and component, off-site and on-site construction and finalizing work that for IHB is integrated in their working methods and for conventional house building is made per project. The Gross Floor Area, m^2 GFA, is the sum of the area of all storeys and is limited by the outside of the enclosing building parts. Two important notes concerning equation (2):

- (1) A reduced lead-time efficiency is an indicator for increased project lead-time productivity. Hence, a reduced lead-time for a given GFA leads an increase of lead time productivity.
- (2) Gross floor area m^2 GFA is an estimation of project size and a rather rough proxy characterizing product (house) complexity. A proper characterization of project complexity to enable more reliable project comparisons should include several technical characteristics such as number of storeys, number and type of buildings and e.g. learnings that appears in larger housing projects.

Project construction cost productivity

The single-factor construction cost efficiency was calculated according to equation (3) in SEK per m^2 GFA. This is a frequently used efficiency measure in Swedish house building to indicate project productivity, i.e. how much construction cost has been incurred to produce one m^2 gross area GFA:

$$\text{Construction cost efficiency} = \frac{(\text{Off site production costs} + \text{On site production costs})}{\text{m}^2\text{GFA}} \left[\frac{\text{SEK}}{\text{m}^2} \right] \quad (3)$$

Off-site production costs refer to the sum of the costs of producing the various prefabricated building elements/modules. On-site production costs refer to costs of the contract; transport, materials, assembly of prefabricated elements/modules, salaries for white-collar workers and craftsmen, machinery, establishment, all sub-contractor costs (e.g. electrical installation, plumbing installation, ventilation and painting). Site-based production costs such as client costs, VAT and price for land acquisition are not included. Two important notes concerning equation (3):

- (1) A reduced construction cost efficiency is an indication for increased project construction cost productivity. Hence, a reduced cost for a given GFA leads to an improvement of construction cost productivity.
- (2) Again, it must be remembered that the GFA is a rather rough proxy confining the cost productivity comparison between different projects.

How validity and reliability were ensured

The level of analysis is single-factor productivity measures on the project and company levels. Except official data and previously published research data utilized for comparisons, this article is based on economical and project data reported by companies. The overall validity of the analysis is dependent on the validity of the information provided by companies.

Four qualitative measures were used to strengthen construct validity following the recommendations of [Hardesty and Bearden \(2004\)](#) and [Thornton et al. \(2014\)](#) that the data reflects what it is intended to measure (ensuring face validity) and represents a proper sample (ensuring content validity) by using the following semi-iterative steps:

- (1) Expert interviews involving two senior researchers with Statistics Sweden on use of and interpretations of economic data from companies. This formed input for the data collection methods, delimitations and analysis considerations.
- (2) A pre-test data collection and expert interview with one of the larger participating IHB companies aiming to increase validation of data reporting procedure and how asked for data issues could be interpreted. Adjustments were made according to the pre-tests.
- (3) Review of the data collection spreadsheets with all participating IHB companies for explaining the aim and later data use for the companies' finances and production managers.
- (4) Iterative process of interpretation and analysis between the two authors regarding both company- and project-level data. Pre-presentation of analyzed results to individual company representatives for their judgements of data correctness preceded the final analysis.

A recurring problem with the company-based data collection was detected in the process. Some of the companies had the asked for data but did not have a structure that facilitated data reporting for the analysis, i.e. more than 103 building projects were built during the period, but lack of structures excluded those projects from this analysis. Some of the companies did not have complete set of required data, i.e. only 86 of the 103 projects included in the study could be analyzed in relation to [equation \(2\)](#) because of lack of reported data for lead-time for 17 different projects.

The variation of standardization and degree of customization, i.e. the IHB companies are using different setups in respect to the degree of product standardization, causes some variability that may have an impact on content validity. Even though the production setup in terms of off-site manufacturing is comparable, it is acknowledged that the analyzed data may not be a complete representative operationalization (following the terminology by [Hardesty and Bearden, 2004](#)) of the productivity measures primarily caused by the individual company adaptations to customization and individual project goals. The goal for generalizability in this article is not towards statistical validation but rather generalization based on descriptive statistics. Comparisons in the article were made on average values and the variation in data is reported as 90% confidence intervals.

Productivity measures*Labour productivity*

The labour productivity [[Equation \(1\)](#)] and growth is displayed for the four IHB companies and compared to general construction and manufacturing as smoothed curves based on average values ranging from 2013–2020 in [Figure 3](#). The IHB labour productivity shows improved growth, albeit a large variation. The adjusted labour productivity has *increased* on average with 26% from 406 SEK/h for 2013 to 511 SEK/h for 2020.

The average (90% confidence interval) labour productivity between the years 2013 and 2020 was 538 ± 41 SEK/h for IHB and 490 ± 23 SEK/h for general construction. The result indicates that the labour productivity is on average 10% higher but with a slightly lower growth rate per year for IHB than for construction in general. It should be noted that construction in general not only includes construction of buildings but also civil engineering and specialized construction. The civil engineering numbers for the output value (value added) in equation (1) contributes to about 64% of the total value added counted in as the labour productivity for general construction in Figure 3. The officially produced data could not provide number for actually worked hours in equation (1). The productivity growth for general construction might probably therefore originate from developments in civil engineering, not from house building. For comparison, the average labour productivity over the same period for general manufacturing was 589 ± 15 SEK/h.

Project lead-time productivity

The average lead-time for 86 projects between the years 2014 and 2020 was 17.1 ± 1.0 months, and the development shows an average *increase* of 51% from 2014 to 2020. The lead-time depends on the size of the construction project [Figure 4(a)]. The trend indicates that an increase in project size of 1,000 m² GFA results in an increase of average lead-time in about 0.5 months.

The project lead-time efficiency is estimated according to equation (2) where a *lower* number indicates less hours per m² produced and a *higher* productivity. The development of the project lead-time efficiency [Figure 4(b)] for 86 projects shows an increase of 45% on average from 2014 to 2020, implying a *decreasing* lead-time productivity, as more hours are needed to produce one m² GFA.

The specific IHB lead-time dependency on increased project size combined with the fact that the average project size increased with 24% from 2014 to 2020 could be explanatory factors of the decreasing lead-time productivity growth.

Project construction cost productivity

The average and adjusted cost productivity for 103 projects was $12,654 \pm 531$ SEK/m² GFA. The productivity growth is *progressing* over the six-year period [Figure 5(a)]. The adjusted

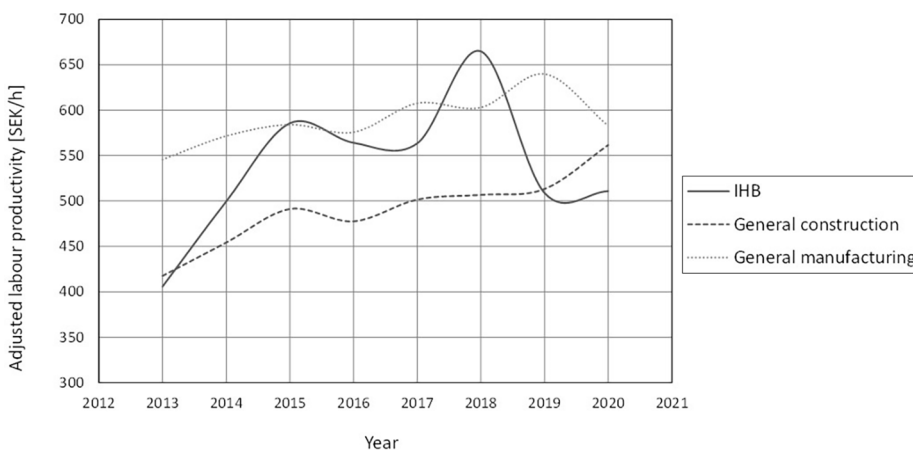


Figure 3. Adjusted labour productivity (SEK/h) development for IHB, general construction (Statistics Sweden NACE 41–43) and general manufacturing (Statistics Sweden NACE 25–30, 33)

Source: Author's own creation

cost (to SEK 2014) efficiency [Equation (3)] has decreased on average by 14% from 2014 to 2020, implying an annual average *increase* of cost productivity by 2.3%.

The construction cost efficiency for 86 projects depends on the lead-time (Figure 5b). The trend indicates that an increase in lead-time with five months results in a slight increase in cost in about 150 SEK/m² GFA. An increased lead-time is an indicator of increased project size [Figure 4(a)]; hence, the larger the project size, the higher the cost/m². However, contrary to the downturning lead-time developments in Figure 4(b), the IHB cost productivity growth was still improved [Figure 5(a)] also including effects of the project size increase over the six-year period.

The prefabrication degree [*P* in Figure 1(a)] reflects how much (measured in currency, SEK) of work is carried out off-site, i.e. in the factory, compared to total construction cost [see explanations in equation (3)]. The prefabrication degree is measured in % and calculated according to equation (4):

$$\text{Prefabrication degree, } P = \frac{\text{Off site production costs}}{(\text{Off site production costs} + \text{On site production costs})} [\%] \quad (4)$$

The prefabrication degree for 102 projects shows a variation between 72% and 19% but with an average value of 45 ± 1.7%. One possible interpretation of the variation of the used prefabrication degree in relation to the project size in m² GFA [Figure 6(a)] can be the degree of off-site assembly vs degree of product standardization. The higher numbers of used prefabrication degrees depicts that those IHB companies probably use segmented customization production systems with higher product standardization, and lesser adaptation to different client needs. The interpretation of the use of lower prefabrication degrees is that these IHB companies are probably using tailored customization in terms of product standardization, indicating a higher degree of project adaptations to client demands.

The cost efficiency depends on the deployed prefabrication degree [Figure 6(b)]. The trend for 102 projects indicates that a 10% *higher* prefabrication degree yields 33% decrease of cost efficiency or 33% *increase* of the cost productivity. The adaptation (lowering) of the prefabrication degree to meet (higher) client demands (indicated by the use of tailored customization) apparently comes with the price of a reduced cost productivity.

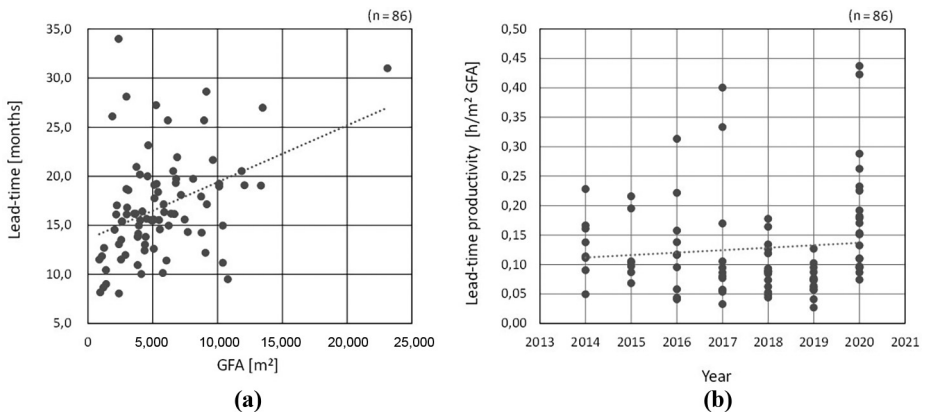


Figure 4.
(a) Lead-time (months) relative the GFA (m²), (b) lead-time productivity (h/m² GFA) development over the six-year period

Source: Author's own creation

Industrialized house building project productivity and productivity growth in relation to conventional house building

The two studies by Josephson (2013) and Koch et al. (2020) presents productivity data, inter alia for conventional house building, for the year 2013 and for the year 2018. Results based on the same definitions used in equations (1)–(3), presented for 39 projects in these studies can be compared to the data for 15 projects in this article for the year 2018 and thus enables a comparison between productivity development for conventionally multi-storey buildings and IHB multi-storey buildings in timber. The comparison is presented in Table 1 for projects completed during the year 2018.

Four observations can be distinguished:

- (1) IHB, for the year 2018, presents a median lead-time efficiency of 0.09 h/m² GFA, which is more productive than the 0.53 h/m² GFA reported for conventional housebuilding (less hours are needed to produce one m² GFA).
- (2) A declining lead-time development (longer lead-times) is visible both for conventional (39%) and for IHB (27%). For conventional house building, the median project size value was 7,645 m² GFA, and for IHB, the median value was

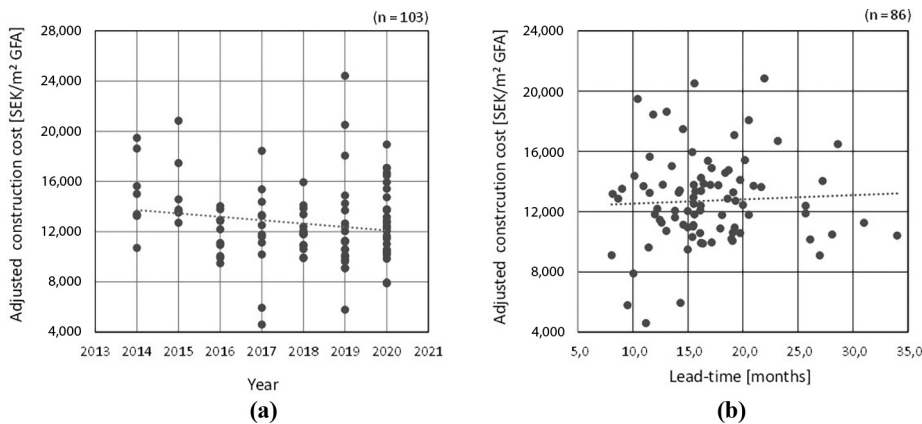


Figure 5. (a) Adjusted cost efficiency (SEK/m²GFA) development over the six-year period, (b) adjusted cost efficiency relative the lead-time (months)

Source: Author’s own creation

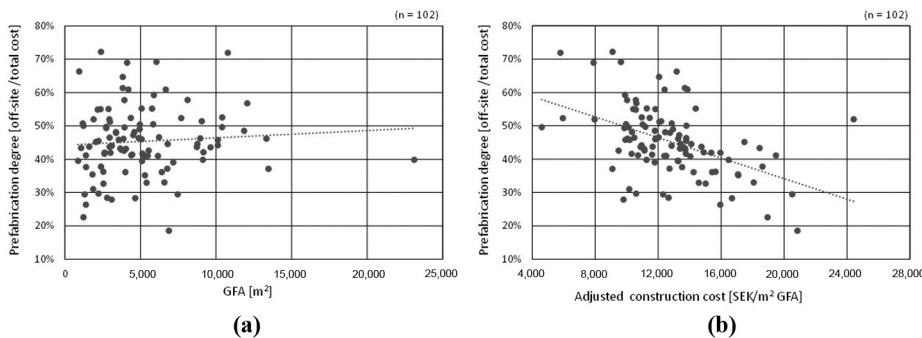


Figure 6. (a) Prefabrication degree (%) in relation building project size in m²GFA, (b) Prefabrication degree (%) in relation to adjusted cost efficiency (SEK/m² GFA)

Source: Author’s own creation

5,886 m² GFA, indicating roughly comparable project sizes. Considering the project sizes as roughly comparable, the absolute lead-time is on average 3.3 months shorter for IHB than for conventional house building.

- (3) The cost efficiency in SEK/m² GFA for IHB is on average 32% lower compared to conventional buildings, which is translated to a 32% higher cost productivity for IHB than for conventional buildings.
- (4) In terms of cost productivity growth, IHB displays an average of 19% in cost productivity *improvement* (indicated by the minus, cost reduction, in Table 1) compared to conventional house building that show a cost productivity *decline* of 20% (indicated by the plus, cost increase, in Table 1).

Discussion of industrialized house building productivity growth

This section first presents a summary of the results, then the analysis on the plausibility of the three propositions. The idea when reporting, comparing and analyzing IHB company-based productivity and project data is not towards statistical validation but should be considered as reasoning based on descriptive statistics.

The results on company level depicting labour productivity developments are based on data from four companies. The average IHB labour productivity has *increased* with 26% between the years 2013–2020, which is on average 10% higher but with a slightly lower growth rate per year than for general construction companies.

The data on project productivity stems from 103 house building projects. Due to difficulties for the four companies to report data, all 103 projects are not represented in all results, and the number of actual data points varies between different sets of 86 to 103 projects. All data points with reported numbers for lead-time, off-site and/or on-site production costs and m² GFA for equations (2)–(4) were included in the analysis, no calculatable data point or outliers were excluded. The project lead-time increased by 51%, and the lead-time efficiency increased by 45% on average between the years 2014 and 2020. Concerning lead-time, the results imply a *decreasing* lead-time productivity (more hours to produce one m² GFA) for IHB. The cost efficiency in SEK to produce one m² GFA decreased over the six-year period, which, seen as cost productivity, displayed as an annual average *increase* of cost productivity with 2.3%. The deployed prefabrication degree (off-site cost/total cost) was on average 45%, and a higher prefabrication degree resulted in a higher cost productivity (less SEK to produce one m² GFA).

Comparing factors	Conventional house building ^b	IHB timber house building
Number of multi-storey housing projects	39	15
Lead-time 2018, mean value [months]	20.6	17.3
Lead-time development 2014–2018	+ 39%	+ 27%
Lead-time efficiency 2018, median value [h/m ² GFA]	0.53	0.09
Construction cost efficiency 2018, mean value [SEK/m ² GFA]	19,783	14,930
Construction cost productivity growth 2014–2018 ^a	+20%	-19%

Notes: ^aConstruction costs for comparisons between 2018 and 2014 was adjusted downwards using the Contract Index to get cost figures in 2014 SEK. ^bBased on data in Koch *et al.* (2020). It was inaccessible to deduct if some IHB projects were included in the data set

Source: Author’s own creation

Table 1. Comparisons of lead-time (months) and cost productivity (SEK/m² GFA) for conventional and IHB timber multi-storey building projects for the year 2018

Developments between 2014 and 2018 shows that IHB in timber is more productive than conventional house building both at the company level and at the project level. The lead-time development over the six-year period is however increasing for both conventional and for IHB, but the median lead-time efficiency for IHB is $0.09 \text{ h/m}^2 \text{ GFA}$, which is much lower than $0.53 \text{ h/m}^2 \text{ GFA}$ for conventional house building. The cost efficiency in $\text{SEK/m}^2 \text{ GFA}$ for IHB is lower compared to conventional buildings, which is translated to a 32% higher cost productivity for IHB than for conventional buildings. IHB displayed an average increase in cost productivity growth of 19% (equals to a cost efficiency *reduction* in $\text{SEK/m}^2 \text{ GFA}$ of 19%) compared to the 20% declination of productivity growth for conventional house building (equals to a cost increase in $\text{SEK/m}^2 \text{ GFA}$ of 20%) comparing 2014 and 2018.

The first proposition states that integration to cope with fragmentation can explain productivity growth. The prefabrication degree is in this article seen as a measure of IHB integration. To address this proposition, the analysis of the prefabrication degree displays some answers. A prefabrication degree of 45% not only reflects the extent of the deployment of the production system but also that approximately 55% of the cost still emanates from the on-site operations indicating that traditional coordinating is still needed. The IHB companies apparently have capabilities to integrate their resources [Figure 1(a)] and create a predictable off- and on-site process. By adapting the deployment of their production system by varying the prefabrication degree, the IHB projects were able to meet changing demands and complexities rising from increasing project sizes and still produce sustained and positive productivity growth over the years [Figure 5(a)]. The used prefabrication degree of 45% indicates a plausibility of the proposition that integration of all elements in the production system and those procured for specific projects could explain the positive productivity growth. The observed positive productivity growth connected to a prefabrication degree of 45% indicates that off-site production is a necessary mean for reaching high productivity and productivity growth while meeting flexible demands but not sufficient alone to explain the observed productivity gains in/of IHB.

The second proposition states that IHB companies will have high productivity and productivity growth in relation to conventional house building companies. The results indicates that the labour productivity is lower for the general construction company setup of project-specific systems [Figure 1(b), Figure 2] compared to the IHB fashion of platform deployment on the project level [Figure 1(a)] and platform development on the company level (Figure 2) to achieve continuity beneficial for productivity growth. However, the results cannot fully support this proposition. Firstly, it was not possible to deduct conventional house building from the aggregated data of Statistics Sweden. However, civil engineering contributes to about 64% of the value-added (output) portion of productivity development in general construction that indicates that productivity growth for general construction mostly originates from developments in civil engineering, not in house building. Secondly, the overlapping 90% confidence intervals between the mean values for IHB and general construction implies that it is only possibly to *indicate* a positive IHB labour productivity and growth in relation to general construction.

The third proposition states that IHB projects will have high project productivity and productivity growth in relation to conventional house building. The plausibility of this proposition is supported by the results concerning IHB cost efficiency growth [Figure 5(a)] and by comparing IHB to conventional house building (Table 1) but not concerning lead-time productivity developments. The integrated IHB production system [Figure 1(a)] aimed to reduce fragmentation complexities to achieve better control of factors contributing to

lead-time are not enough to counterbalance the lead-time losses observed but seemingly adequately enough to contribute to the annual average increase of cost productivity with 2.3%. The four observations emerging when comparing IHB to conventional housebuilding indicate that deploying the specified IHB production system results in improved lead-time productivity (less hours per m²) and improved cost productivity (less cost per m²) and a progressing cost productivity growth over time relative the conventional house building setup of a single production system.

Conclusion and implications

The aim of the article was to understand if and how IHB could support productivity developments on project and industry levels. The views adopted in this article are two folded. Firstly, fragmentation of construction is one salient explanation for the lack of productivity growth. Fragmentation causes conventional contractors to steer away from long-term strategic commitments to centralize production and planning and therefore do not achieve controlled benefits for productivity developments. Secondly, that IHB is recognized as an integrating method of overcoming horizontal and vertical fragmentation. The constituents of the integration modus operandi of IHB gave this development. The productivity development was shown to be explained by the capabilities to integrate the operative logic of conventional house building (project and portfolio management) together with the logic of IHB platform development and use. The article used company data to calculate and quantify the effects of IHB in timber in terms of cost savings and time savings and compare the productivity developments to conventional house building.

Concerning if IHB can support productivity developments, the descriptive statistical reasoning displayed IHB showed an increasing productivity development considering company- and project-level productivity measures. The IHB labour productivity was on average 10% higher but with a slightly lower growth rate per year than for conventional house building (mostly civil engineering). The annual average increase of project cost productivity of IHB was 2.3%, and for a specific year (2018), this displayed as a 32% higher cost efficiency than for conventional house building.

IHB is not only prefabrication, but integration of the means for production. Off-site production technologies, off-site manufacturing and modern methods of construction are implicitly used to put words of prefabricated construction (Goulding *et al.*, 2014). On the activity level, not project level, Eastman and Sacks (2008) found that off-site labour productivity was growing at a faster rate than on-site construction. A high prefabrication degree, high amount of off-site production, could possibly be a commonly thought metaphor for IHB. The found prefabrication degree of 45% implies that prefabrication and off-site manufacturing alone is not sufficient to explain the observed productivity growth of IHB. The prefabrication degree is not used as a static construct that is predefined to match the IHB production system but rather a factor that (depending on the chosen standardization strategy) can be adjusted to specific needs. These results therefore implies that an optimum might be possible to seek between prefabrication degree, project size (customization), standardization strategy and cost productivity growth. The integration of off-site manufacturing, on-site construction, architectural and engineering design and long-term stakeholders into a platform deploying varying prefabrication degrees to cope with varying client demands is instead the plausible explanation supporting that IHB should be considered an integration mechanics that favours a positive productivity development.

Considerations of generalizability and further research

The drawbacks of single-factor measurements and using different company data to present IHB productivity trends and to compare project to project using proxies are acknowledged. Single-factor measurements are considered as indices for changes in the composition of projects instead of productivity changes *per se* (Huang *et al.*, 2009). However, the comparisons between IHB and conventional house building are based on the same definitions in equations (1)–(3) on e.g. value added and m²GFA, and are therefore based on comparable data both regarding the company and the project levels. But even so, the data display rather large variability [cf. Figures (3)–(6)]. Although, technically seen, the IHB companies use comparable technical production setup in their off-site operations, the variability of factors influencing the IHB productivity and the comparisons to conventional house building spring from the many different project goals in terms of cost, time, quality and safety in relation to several complexity factors. The single-factor project productivity measures presented in this article should therefore be considered as proxies for cumulative costs and lead-time occurring with respect to the size (m² GFA) of building floors produced. In itself, the GFA is a rather rough parameter confining cost and lead-time productivity comparison between different projects. With the aim of further improving productivity and improving the comparisons between companies, projects and even countries, supplementary measures connected to different activity levels could be needed to improve processes (Kenley, 2014) and comparisons supplementing the GFA proxy to include other recognizable house building characteristics, e.g. number of stories, layout of buildings, façade systems, stairwell solutions, type of contracts, etc.

The presented IHB productivity growth has the Swedish context and official data as its vantage point. Enhanced by a comprehensive literature review that used a political, economic, social, technological, environmental and legal (PESTEL) framework, Pan *et al.* (2019) envision that strategy replication between industries and regions applying successful combinations of productivity enhancements could be difficult due to the lack of necessary social and cultural norms to understand and integrate the used strategies. Embracing the reasoning by Pan *et al.* (2019) implies that the results found in Swedish IHB must be estimated into other contexts and PESTEL settings before a broader generalization towards a generic IHB productivity could be stated. Besides a PESTEL type of consideration for cross-country assessments, proper currency comparisons, comparing e.g. SEK to US\$, and price conversion methods must be identified and compared to the used official Swedish data on CPI, industrial classification system and contract indexes.

The results of this study indicate that an increased prefabrication degree fosters a higher cost productivity growth, which could be connected to the applied production system archetype (following Jonsson and Rudberg, 2015). An avenue for further research would therefore be a clarification of the use of prefabrication degree as a measure for production system applicability to varying customer requirements, which would enhance theoretical understanding on platform design in relation to the customer-order-decoupling point theorization. Following this line of reasoning, the results also point to that an optimum for a given contextual setting might be possible to seek. A contextually based optimum between used prefabrication degree, customization, product standardization and cost productivity growth, which would be interesting from a managerial point of view. The data shows large variation, particularly at the project level, probably explained by the used single-factor productivity measures. For productivity cause-and-effect analysis aimed for continuous improvements, it would be interesting to investigate how project complexity factors could be defined into normative values to compare different

projects for aggregated productivity estimations. The results further proposes that the IHB means for integration control was not able to improve the lead-time productivity. Plausible explanation would be that the vertical and horizontal fragmentation and stakeholder influence and even planning for an integrated procurement of materials and components is still out of control, or not accurately handled, by IHB companies, and that the increased complexity of buildings and supply chain lock-ins in general increases why research to explain the driving and hindering factors to improve lead-time productivity would be interesting to pursue.

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