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Measuring the performance of construction site processes is an essential for the continuous improvement in building production efficiency. However, little is known about how this is done by industrialised housebuilding (IHB) companies. The purpose of this paper is to extend the body of knowledge of IHB to on-site performance measurement and management (PMM), thereby identifying reference practices and potential areas for improvement in order to prepare the field for the further development of significant performance management systems (PMS). A multiple case study by means of semi-structured interviews with company managers of eight companies within the IHB sector from three Central European countries has been conducted. The results show that the companies, to a greater or lesser extent, collect data on: customer satisfaction, environmental protection and CO₂ emissions, operating efficiency, productivity, quality and work safety. The data can be used to perform performance measurements that provide feedback on these criteria. Reference practices of performance measurements and their benefit are identified. Digital tools are increasingly being used for data collection on construction sites, although paper-based tools such as site and working time reports are still in use. The findings establish a basis for the further development of PMS within the IHB sector.

Keywords: Performance measurement, performance management, industrialised housebuilding, on-site production, case study

Introduction

Industrialised housebuilding offers solutions for many of the significant problems which the construction industry faces. It can contribute to a reduction of the on-site production period, mitigate the problem of qualified labour shortages in on-site production and contribute to waste reduction, to highlight just a few. Although significant parts of value generation in IHB takes place off-site, final assembly and interior fitting still needs to be performed on-site (Goulding and Rahimian, 2020). Looking at the on-site processes, it is evident that this is the part of the order fulfilment process where performance is most
difficult to control and manage (Segerstedt and Olofsson, 2010).

Literature shows that IHB companies normally only implement performance management system (PMS) for the assessment of core processes within prefabrication or for analysing simple indicators such as on-site assembly duration (Lessing et al., 2015). On-site performance assessment is however often overlooked. For this reason, it is not surprising that Barker and Naim (2008) showed that performance measurement of construction site processes is of little relevance to many contractors. As an example, more than 60% of British housebuilding companies did not collect data on construction site performance and majority of those that did collect data, did not use it for indicators.

This is often attributed to circumstances in construction operations such as the temporary nature of construction sites and project teams, making it difficult to implement PMS that are widely established in the site-based manufacturing industry (Navon and Sacks, 2007). Additionally, it is often argued that the complexity of the construction process and the uniqueness of the products make data collection and thus the definition of appropriate indicators, difficult (Thunberg and Fredrikson, 2018). Further, the spatial and temporal separation of construction sites from other parts of the order fulfilment process complicates the collection and reporting of data (Riley and Clare-Brown, 2001), and this delays the development of PMS. Consequently, continuous improvement of on-site performance is limited to the application of methods that are derived from the experience of employees (Yap et al., 2020). The lack of both systematic identification of problems, as well as the verification of the impact of improvement measures, limits the target-oriented improvement of operational efficiency and the productivity of on-site activities (Grenzfurtner and Gronalt, 2020).

As a result, the focus so far has been on achieving improvements in element and module prefabrication (Eastman and Sacks, 2008), where established PMS can be easily
implemented. Productivity has been substantially increased in prefabrication with positive consequences for the overall IHB order fulfilment process (Stehn et al., 2020). As a company’s order fulfilment process includes all activities that are necessary to process a customer’s order, from sales enquiry to handover of the building (Cannas et al., 2020; Kritchanchai and MacCarthy, 1999) with significant parts of the production still remaining at the construction site, there is a need to integrate all construction site activities into PMM approaches. Such an integration provides potential for further productivity, profitability and quality improvements.

The ongoing digitalisation of the construction sector and the implementation of new technologies, enables better data integration from construction site into PMS by a revision of methods and tools for data collection and analysis (Oesterreich and Teuteberg, 2016). Increasing digitalisation thus provides many opportunities for the integration of on-site production processes into performance management reporting (Raffoni et al., 2018) and, in the long term, to enhance the information exchange at the interface between construction sites and performance improvement at the organisational level (Meiling et al., 2014). However, in terms of on-site suitability and the dissemination within the industry, there is a lack of evidence as has been reported by Qi et al. (2021). According to Grenzfurthner et al. (2021), many IHB companies seem to have implemented performance management systems in the past, that allow for the targeted control of performance indicators and consequently support the achievement of strategic goals. However, how performance is currently measured on construction sites and thus how it supports the performance management and organisational learning processes at the level of the IHB company would require further investigation.

At an organisational level, there is a lack of empirical research analysing on-site data generation and analysis for PMM at the interface between on-site production and
the overall IHB process. Analysing the current state of on-site PMM will enable the systematic development of PMS, a prerequisite for increasing the efficiency of value generation on-site. This knowledge gap is addressed in this study.

The purpose of this paper is to extend the body of knowledge of IHB to on-site PMM, thereby identifying PMM reference practices and potential areas for improvement so as to prepare the field for the further development of significant PMS. To pursue this, a multiple case study within the IHB sectors of Austria, Germany and Switzerland was conducted and it investigated the following three research questions:

RQ 1: How are IHB companies measuring and managing construction site performance? RQ 2: What reference practices can be identified for the measurement of construction site performance within IHB? RQ 3: What tools are currently being used to collect working time and quality data on the construction site?

**Theoretical background**

*Process improvement in IHB*

The introduction of building systems, the off-site prefabrication of elements and modules as well as the establishment of standardised processes revolutionised the way orders are processed in IHB (Lessing et al., 2015). Tested, robust technical solutions for the design, prefabrication and construction of buildings as well as related processes have been structured and systematised accordingly Johnsson (2011). These innovations have enabled the retention and transfer of production knowledge between employees within a company and its supply chain as well as the continuous improvement of processes and technology (Goulding et al., 2015; Lessing et al., 2015; Lessing and Brege, 2018).
While it is normal that the operational processing of individual construction projects is still project-oriented, the improvement of building systems and processes takes place at an organisational level (Pan et al., 2012). Improvement potential identified in individual construction projects is used to systematically develop improvements at an organisational level in order to implement them for use in future construction projects (Stehn et al., 2020). The systematic interaction of these levels through the application of continuous improvement methods was presented in the work of Lundkvist et al. (2014) and Meiling et al. (2014). Figure 1 shows this interaction between the organisational level, where the building system and related processes are located, and the level of individual building projects (Jensen et al., 2015). Problems and improvement potentials are mainly identified at the latter level, which can then be used to achieve improvements at the organisational level, such as the revision of design standards and processes (Jansson et al., 2015). This systematic evolution of the building system and related processes facilitates the improvement of a companies’ performance and its supply chain, enabling it to better adjust to market requirements (Jones et al., 2021; Jonsson and Rudberg, 2014, 2015).

Performance measurement and management

PMM facilitates better control of the development of IHB organisations’ financial performance and its ability to benefit from experience based learning (Abu El-Ella et al., 2013; Bessant and Caffyn, 1997). Consequently, measurements for helping to control ongoing processes are indispensable in: identifying latent problems, the assessment of the effect of intended actions as well as to provide feedback on target setting for managerial decisions (Raffoni et al., 2018). Kaplan and Norton (1996)
outlined the necessity of meeting the information needs of an organisation by the measures unified within a PMS.

It is obvious that performance measurement is only one of the contributing factors to the performance improvement process of an organisation. Without taking management action based on a measurement, the resources invested in data collection and analysis are wasted (Bourne et al., 2002). In order to use invested resources wisely and generate benefits from indicators, Raffoni et al. (2018) suggested addressing the following four points: (1) From where can the data be acquired? (2) Is it possible to access the data in the IT systems regarding indexing, storing, use and archiving? (3) Are the appropriate tools and methods for data manipulation and analysis available? (4) Are the indicators used in decision-making?

It is widely acknowledged that, in theory, indicators within PMS should be derived from the strategy of an organisation which consequently determines the data needs and its collection. Following the identification of critical performance variables, data sources and their availability need to be clarified. Once this has been determined, the collection, cleansing and storage needs to be solved. Additionally, the quality of the data must be kept in mind and whether such data can be processed appropriately without creating an information overload. Finally, the analytical methods and tools need to be carefully selected (Raffoni et al., 2018).

**Performance measurement in IHB**

From an indicator perspective construction site assembly is currently considered to be a weakness of IHB production (Lessing et al., 2015). Although the IHB has a clear advantage in the assessment of on-site production due to its higher process orientation (Höök and Stehn, 2008) and the introduction of building systems (Johnsson, 2011), it seems that there are still some difficulties arising from on-site fulfilment (Jonsson and
Rudberg, 2017). Its temporal and spatial separation from other parts of the order fulfilment process, as well as the methods of data collection and performance assessment, do not provide accurate evaluations of the effects of interventions (Grenzfurtnert and Gronalt, 2020) as they are not reliable enough and are too cost- or time-consuming for regular performance management (Raffoni et al., 2018). Accurate measurements of performance are impacted by many factors such as: the complexity of an IHB order fulfilment process (Sardén, 2005; Thunberg and Fredriksson, 2018), the nature of on-site working, the segmented order fulfilment processes as well as the number and disparity of in-house, subcontractor and suppliers' employees involved (Bäckstrand and Fredriksson, 2020; Grenzfurtner and Gronalt, 2020; Knauseder et al., 2007).

Within the literature there is little information on the implementation of PMM in the IHB industry. Lessing (2006) showed that performance measurement and the re-use of experience for continuous improvement activities are essential for increasing efficiency. This author also found, that within the industry, the use of measures for the assessment of key activities within the design and prefabrication phases as well as the identification of total on-site construction duration are the most established indicators. Höök (2008) argued that IHB companies often relied on inappropriate performance indicators such as total construction time. Such measurements make it almost impossible to identify the causes of either poor or outstanding performance in on-site production. Further approaches show that the performance of improvement interventions is assessed either through feedback from a small number of on-site visits or the analysis of working time through REFA time studies (Söderholm, 2010). However, many companies have implemented performance management systems in the past which continue to maintain the targeted control of on-site production performance.
and contribute to a systematic continuous improvement of the IHB order fulfillment process at the organisational level. This should be analysed in detail in order to provide best practice cases and show improvement potentials (Grenzfurtner et al., 2021). The following section details the shortcomings of data collection and analysis within IHB.

**Data collection and analysis from construction sites**

One potential shortcoming of performance measurement is its neglect of data acquisition issues (Raffoni et al., 2018). In some instances, the data collection seems to be a weak part within PMS, since collected data cannot be prepared to support the information requirements, or its timely transmission proves impossible.

A common reason why PMS fails to support business decisions is the lack of suitable infrastructure for data collection and the lack of access to existing data (Bourne et al., 2002). The Economist Intelligence Unit (2012) showed that companies often have no access to structured data and lack trained data analysts. Commonly, data are not retrievable from databases, but are scattered among a wide variety of documents and are often not even available in digitalised form. This particularly applies to construction site reports where, in many cases, data on defects, non-conformities, faulty materials, etc. are collected, but cannot be retrieved because it has not been digitised or it is not processed since the analysis requires too much effort (Lundkvist et al., 2014). A frequently encountered problem is that data on the criteria “quality” cannot be easily measured, described or analysed. Consequently, the development of experience-based solutions appears to be more effective (Grenzfurtner and Gronalt, 2021; Koch and Schultz, 2019).

Many new technologies exist for improved data collection or analysis of on-site performance (Oesterreich and Teuteberg, 2016). These include, for example, technologies for the recognition and analysis of site workers’ performance (Akhavian
and Behzadan, 2016; Luo et al., 2018), for recording deliveries (Li et al., 2017) as well as for the identification of defects (Laofor and Peansupap, 2012; Valero et al., 2019).

**Research approach**

In the past, PMM of construction site processes in IHB has not been a priority. However, significant value-adding processes take place on the construction site, making it necessary to address this issue in order to achieve efficiency improvements in this area. Consequently, this paper’s focus is on the building of theory for IHB on-site performance management, with research conducted within the IHB sector from Austria, Germany and Switzerland. A multiple case study sets the framework for the investigation providing the opportunity to study this phenomenon in its real-life context as well as enabling the consideration of evidence from multiple cases (Yin, 2018). The study includes an analysis of the IHB sector in order to map different strategic corporate orientations. In a second step, eight cases from the pool of companies within the IHB sector were selected according to a maximum variation sampling. Data are collected through guideline interviews with company representatives from the selected cases, which are finally analysed using a thematic coding and content analysis approach according to Flick (2018).

**Sector analysis and case selection**

It is generally acknowledged that in defining the strategic objectives of an organisation, the goals which it intends to achieve and the actions which it needs to measure and manage are revealed (Raffoni et al., 2018). The data basis for indicators collected on construction sites may therefore differ in terms of content, structure and quality depending on different strategies. It is assumed that the tools used for data collection will be adapted to the data required. In order to collect insights from the
various strategies represented within the IHB sector, the strategic orientation of companies is evaluated, with a systematic qualitative analysis of published company data on production principles. The sample comprises of 76 companies from the selected countries with data for this analysis derived from the three national IHB trade associations, Österreichischer Fertighausverband, Schweizerischer Verband für geprüfte Qualitätshäuser and Bundesverband Deutscher Fertigbau e.V. The analysis focused on the following characteristics: (1) segment of customers served, (2) flexibility of the building system, (3) level of prefabrication of components delivered to construction site and (4) strategic orientation towards either diversification or cost leadership. The analysis of the IHB sector is provided within the chapter “case description and sector analysis”.

Case selection was based on the logic of theoretical replication, with eight specific cases selected to ensure maximum variation sampling. According to this concept the approach enables an investigation of all the criteria’s combinations and ensures a convenient empirical grounding (Eisenhardt, 1989; Voss et al., 2002). An overview of the cases selected is given in table 1 and these are divided among the chosen countries: three cases from Austria, three from Germany and two from Switzerland. The analysis of the IHB sector and the applied case selection strategy aimed to improve the ability to generalise the findings. However, all cases cover IHB within Central Europe, which limits the ability to generalise beyond this area.

Data collection

The items analysed are the PMS’s which have been developed and applied by the IHB companies in order to control and manage construction site performance. Based
on Yin (2018) various sources of evidence have been considered for data collection. However, documents and archival records were excluded due to unavailability or factual redundancy. Direct and participant observations were not suited for this study as they would have exceeded the time and cost budget available. Companies might also be cautious about directly involving researchers in such highly sensitive areas as PMM. Consequently, the best option was to collect data from the cases through guideline interviews, whilst being aware of the weakness of this data collection method. It does, however, specifically gather information on the interviewee’s perspective on defined topics (Flick, 2018).

The national trade unions informed company representatives about the research project and provided contacts for the researchers. Between March and September 2019 interviews were conducted by two researchers in each of the eight companies, either in a group setting with attendees with different roles in the company or with individual interviewees conversant with the overall company process. An overview of the interviewees role within their company is given in table 2.

***************Insert table _2_ about here***************

Each interview lasted between one and a half and four hours. To correctly focus the interview, a guideline was established based on the theory of PMM in the construction industry, structured into five thematic fields and included 12 main questions and potential follow-ups. An overview of the principal questions is given in the appendix within table A1. The interviews involved open questions on performance criteria and performance indicators, how decisions were made based on these measures, how and which data is collected in an on-site context, the requirement to improve the weaknesses of current PM as well as a check for case classification. To avoid bias in the
interview guide, it was developed iterative by two authors following the procedure from Helfferich (2011) and was pretested by research colleagues.

As the interviewers were not allowed to audio record the interviews, the proceedings were documented separately and subsequently combined into one interview protocol, which was then sent to the interviewees in order to provide them with the opportunity to read the protocols and give feedback if any clarification was necessary. In two cases interviewees gave feedback, which was check by one researcher and then included within the protocol.

**Data analysis**

All interviews were analysed with a thematic coding and content analysis according to Flick (2018). First, the interview protocols were read several times and subsequently a code system was generated. Secondly, the protocols were coded sequentially, using Atlas.ti, to identify passages which are similar and/or repetitive within both single, as well as, multiple cases. Subsequently, to identify and elaborate their characteristics, content analysis is separately performed to provide a within-case analysis for each single case. The themes which emerged from the analysis were then applied in order to re-examine the individual cases. Finally, a cross-case analysis was undertaken, to detect the similarities and differences between cases and identify cross-case patterns.

**Case description**

Table 1 provides an overview of the IHB companies’ characteristics which are included in the case study and comprises of companies which have different strategic orientation according to (1) the positioning of a company as cost leader or differentiator, including gradations of these strategies, (2) the alignment of their production system to
either higher type variations or more standardisation of the offered products, (3) the prefabrication degree, (4) the size of buildings produced, (5) the customer segment served and (6) the remuneration policy to site workers. Cases 4 and 7, representing two business models, are special. In case 7 the business model, which provides a highly individualised product, is dominant and significantly influences the development of PMS. Case 4 has two business models one of which is based on modular buildings though this is currently of lower importance since it has only recently been established. Its second business model, in which buildings at the "prefabrication and pre-assembly" level are produced, is dominant in terms of its influence on the evolution of the PMS.

Results

The results chapter provides an overview of the data collected on construction site performance and presents the criteria on which indicators are evaluated. Subsequently, sub-chapters deal with the data collection, evaluation and use of indicators for the criteria of economic efficiency, productivity and quality, which were identified as particularly relevant in the course of the case study. Finally, the last sub-chapter deals with the tools used for on-site data collection.

In order to measure and manage on-site performance, data for the various criteria presented in table 3 was collected, including that of: customer satisfaction, environmental protection & CO2 emissions, operating efficiency, productivity, quality and work safety. All cases showed both similarities and differences in the data collected and used for performance measurement. However, it also became apparent that some data bases and experiences on the construction site could not be directly converted into measurable indicators due to their complexity or to the effort involved in their collection. Especially, some building processes are so extensive and interconnected that they cannot be easily described. Nevertheless, some companies found innovative
management approaches to improve their performance. These approaches will be identified and presented in the form of reference practices in the following paragraphs.

The collection of data to the criteria “customers’ satisfaction” with the work of on-site team as well as to the criteria “environmental protection & CO₂ emissions” was only observed for some of the companies interviewed, since these criteria were not significant for all.

Data on the criteria “operating efficiency”, “productivity”, “quality” and “work safety” was collected from all companies, but the form of the data and the resulting analyses differed to some extent. Different approaches to the use of the performance measures to achieve improvements within these criteria are identified.

**Assessment of operating efficiency**

The data for operating efficiency analyses are mainly derived from cost accounting and are based on invoices, stock records and salary statements. In most cases, analysis of deviations between target and actual performance is performed. The case study shows that, for operational efficiency, material costs and the costs of subcontractor services are most relevant for the management of construction processes.

Performance indicators for logistic costs are relevant for case 6, as this company use this analysis to identify truck downtimes. Due to the high degree of prefabrication, this company requires very well coordinated processes in distribution logistics and on-site module assembly. In this case, costs for truck downtimes serve as a good indicator.

Wage costs are used as a performance indicator in cases 3 and case 7. In both cases this necessity arises from the highly individualistic nature of the buildings. If major deviations from targets are found, in-depth analyses of a building project will
follow. As both companies have a very clearly defined allocation of working time to construction phases, the causes of deviations can be easily identified. However, other companies argued that this data category is used for cost accounting purpose only and not for PMM. As shown below, some of these companies rely on the assessment of labour productivity as part of their performance management, rather than the assessment of the operational efficiency of this category.

**Productivity assessment**

The collection of data and measurement of performance for the criteria “productivity” is characterised by substantial diversity. Indicators were identified which evaluated: the duration of the construction period, the working time of the employees, the adherence to schedules of services performed, the use of employee and machine resources, the availability and supply of materials as well as the effort for reworking non-conformities before handover.

The duration of the on-site construction phase is analysed by cases 1, 3 and 6. In case 6 this is aligned with the companies’ strategy of providing customers with a fast on-site completion.

The working hours of on-site staff are the basis for remuneration for those companies that have introduced a time wage system, with the data also used for performance measurement. As can be seen in cases 3, 6 and 7 the data collected is very detailed. Working times are reported for defined construction phases in order to record the duration of different construction variants. In these cases, the collected data is also used to update the standard time values, which form the basis for target-actual comparisons and bid calculations for future projects. Cases 1, 2, 4, 5 and 8 update their standard time values based on REFA-time studies. For the companies 4 and 5, these
calculated standard time for a building also represent the piecework wage for their construction site teams.

Some companies within the case study collect and analyse data on deviations from the pre-determined construction schedule for both in-house and subcontracted processes, although one of the companies collects data but does not use it for PMM purposes.

In three cases data on absences and vacation time is collected to improve labour planning which is then compared with the staffing needs for those projects that are in planning or have been sold. This is intended to reduce employee downtime and counteract capacity bottlenecks.

In two cases, the utilisation of cranes rented for the structural work on the construction site is analysed, since this is a significant cost factor. The companies also use this indicator to assess whether the material supply and erection processes are well coordinated. Further measures for machine resource utilisation are not identified during the case study.

The case study recorded the collection of data for indicators within the areas of material availability and supply. Within these areas, material re-ordering (which in itself can be an indicator of missing or faulty material), as well as on-time delivery by suppliers and in-house material supply is evaluated. An innovative approach for collecting data on support reorders was found in case 4. Here, the on-site team only reorders missing material via an app which sends data directly to the inventory management system of the company, where the re-ordered material is picked and prepared for dispatch. This data is then used for the evaluation of faulty materials, as is the case with other procedures in which repeat orders are recorded in the ERP system. This results in an innovative synergy between the improvement of the material supply
processes and the data acquisition for performance measurement purposes. However, this could be a weakness, since it proved easier to reorder material than to locate it on site.

Among those enterprises that record working time on an ongoing basis, companies 1, 3, 7 and 8 record the reworking time for non-conformities separately. With the exception of case 1, this data is used for systematic performance measurement and reduction of wasted time. In cases 2 and 6, rework time is not recorded separately from productive working time. Consequently, it is not possible to identify reductions in productivity due to rework.

**Assessment of quality**

The analysis of the criterion “quality” showed very different approaches. It is noticeable that, within this category, the ability to process the data collected into useful performance measurements is lacking, with the complexity of the data collected as the probable reason. Nevertheless, very interesting approaches to performance improvement within this area were identified.

Measurable quality parameters such as blower-door tests and sonic measurements are recorded on site by all companies. These measurements are usually carried out in accordance with legal regulations and are documented for quality assurance purposes. In two cases these measurements are used for the identification of on-site teams’ specific knowledge as well as benchmarking between teams which, as a competitive measure can be used to incentivises productivity.

It is common to document the number of defects and non-conformities for each building throughout the construction process. Handover is a key point and it is here and throughout the liability period, that all companies collect data on the number of defects and record a qualitative description which is supported, if necessary, by a photo or
video document. It is at this point that retentions for defects are stipulated. Some companies attempt to identify the causes of defects and, additionally, in cases 1, 4, 5 and 8 record which components have been affected. Subsequently, defects are rectified and cost recorded. Both retentions and rework costs are an innovative opportunity for systematic performance measurement, as established by case 5. This company conducts Pareto analyses based on data on: the kind of defects, the defects per component, the associated retentions and the frequency of defects. This enables a systematic evaluation of which defects have the greatest influence on the operating result and consequently which solutions must be prioritised.

Finally, the case study recorded the collection of data on execution quality of in-house and subcontracted work as well as on the quality of products and components supplied. The data obtained is usually a graded assessment of quality or is a simple checklists used for the acceptance of construction work.

In general, the systematic measurement of performance in the area of quality is rather limited. Many interviewees stated that the data collected on defects and failures is not used for systematic performance measurement, rather, it is utilised to develop experience-based solutions with their employees. This is usually accomplished in the form of a quality circle or by applying continuous improvement methods. This explains why a lot of data on the category “quality” is not used for systematic performance measurement. Much data is, however, still documented and stored for quality assurance purposes.

**Tools for on-site data collection**

This section provides an analysis of tools used to collect data for working time reporting, for recording non-conformities and defects as well as reporting on rectification efforts. At the time of the interviews, many of the companies had recently
implemented digitalised working time reporting. As shown in table 4 the companies 1, 3, 6 and 7 implemented either a mobile device for time reporting or enabled the time reporting from site directly to an ERP system. Company 6, however, used paper-based working reports from site workers as a supplement, which were then digitalised by the site foreman. Company 2 was testing the implementation of an app to report on working time. Thus, with case 8, only one of the companies paying time wages still relied entirely on paper-based time sheets.

Both paper-based and digital construction site reports are used to describe and record defects and non-conformities, as shown in table 5. One company also uses audio files, which are subsequently typed. Photos and videos are also used to illustrate and document the defects. Of those companies that still used paper-based construction site reports, some were preparing for the introduction of digital systems for recording defects. The advantages of these systems were mainly stated to be the reduction of duplicate entries, the guarantee of data entry in databases and their faster transmission to administrative staff. However, little benefit was attributed to these systems for performance measurement, which was excused by the complexity of the problems.

The reporting of the effort required for rework of non-conformities and defects is done via both paper-based reports and digital tools, as shown in table 6. Both tools are used to list the defects or non-conformities, describe the workload and express it in hours. Both the paper-based and the digital reports documenting non-conformities are integrated as a separate tool in the time reporting system of companies 1, 3, 7 and 8.
The cases 2, 4, 5 and 6 do not separately report the effort for reworking non-conformities. However, all companies record working time spent on defects from the time of handover. The tools are again integrated into working time reporting systems. The companies 4 and 5, have implemented their own paper-based reports for their customer service staff, as these do not pay a time wage for regular construction site workers.

The data obtained on the amount of rework is currently not used for systematic performance measurement by any of the companies. Occasionally only individual incidents are examined. However, the companies 1 and 5 mentioned that their aim was to use the data obtained for Pareto analyses.

**Discussion**

This research employed a multiple case study approach to reveal the current status of performance measurement and management practices of IHB and make contributions to both industry and academia. These are summarized below.

The paper reveals that IHB companies collected construction sites data for the criteria: “operating efficiency”, “productivity”, “quality”, “customer satisfaction”, “environmental protection & CO2 emissions” and “work safety” in order to extract performance indicators. The research demonstrates that the assessment of “operating efficiency” and “productivity” is mostly based on indicators and although the analysis found differences in the specific characteristics of the indicators, it can be stated that the management of these criteria is predominantly data-based. To some extent this is due to the easier collection and analysis of the data required for this category. These data-based approaches are especially important for the assessment of the on-site construction period as well as working time productivity. Additionally, the identification of problems causing systematic time overruns remains important as is also shown by Lindhard et al.
To identify them, companies currently use a more fine-grained set of productivity measures based on: the data of staff working time, time predictability of in-house and subcontracted services, material availability and supply as well as machine resource utilisation as shown by the case study. For the assessment of working time, productivity indicators are more relevant than the evaluation of wage costs since it facilitates a more precise target-to-actual comparison. The study revealed three different approaches for controlling the efficiency of working time expended. The approach in which the data from time recordings are used to update the standard times’ values has so far not been mentioned in the IHB literature. Consequently, through the presentation of the current state of PMM in IHB, the paper extends the research on construction site performance measurement as presented by Lessing (2006), Söderholm (2010), and Lessing et al. (2015). IHB companies can use the analysis presented to benchmark their own PMM practices and identify processes as well as systems requiring improvement.

In addition, reference practices are presented which can help companies to introduce these, or similar, approaches to achieve targeted improvements in their performance management. In line with Raffoni et al. (2018) and Grenzfurtner et al. (2021) the research shows that the collection and analysis of data as well as the development of a PMS is expected to be relevant from a strategic point of view. Consequently, the research will help companies identify those relevant indicators which are able to improve the alignment of their PMS with own strategic goals. In addition, this paper helps to illustrate how construction site data is collected and analysed and how it contributes to the governance of construction sites and facilitates the continuous improvement of the industrialised housebuilding process. From this, more general governance structures can be derived.
The assessment of on-site performance has often been described as the weakest part of performance measurement within the order fulfilment process (Thunberg et al., 2017). As was found during the study, one reason is that the processing of the data varies considerably between the respective criteria. The number of incidents generally represents the relevant factor for work safety. More detailed analyses of the causes of accidents is carried out at individual case level. In contrast, the assessment of the criteria "quality" is not always achievable by evaluating such simple indicators. The structure of the data generated often does not enable the design of useful indicators. Consequently, many companies just use simple indicators such as the number of defects at a specific time to assess quality. For many companies the lack of suitable measures creates the need to continuously improve quality by experience-based methods, without designing sophisticated indicators. In the end, a relatively large amount of data concerning the criterion “quality” is collected, but not processed for performance measurement purposes, as already criticised by Lundkvist et al. (2014). This reveals the need to improve the analysis of data especially for the criteria quality, which definitely influence the design of further PMS. Academia needs to develop and provide design solutions for PMS to better assess quality in on-site production.

A starting point may be the two reference practices identified during this research, which demonstrated that the appropriate selection of quality data can produce easily useable indicators for performance improvement. These reference practice include an approach where defect data is systematically categorised, providing the basis for the analysis of their impact on the operating results whereby the application of Pareto analysis is possible. The basis for this is a precise categorisation of deficiencies and the recording of retentions. The use of measurable quality parameters to identify unique, team-specific, knowledge is the second reference practice identified in the field
of quality. This approach contributes to a systematic improvement in the knowledge management of IHB companies. In the line with Addis (2016), knowledge management can thus move away from purely experience-based approaches towards data-based quality improvement. These reference practices provide a guide for other companies seeking to improve their own performance management capabilities and demonstrating the integration of on-site performance measurement using PMS into the continuous improvement processes of the industrialised housebuilding process.

This paper reveals the current state of the application of both digital and paper-based tools for on-site data collection. Working time reporting is frequently performed with digital tools. With the exception of one of the analysed companies that has implemented a time wage system, all have implemented such tools or are in the process of doing so. The recording of defects and non-conformities is performed with both digital and paper-based site reports. However, the value of both tools for measuring performance is questionable due to the complexity of the data and problems in the field of quality management. Although Lundkvist et al. (2014) believe that site reports provide a useful database for identifying weaknesses within the production process, currently, the complexity of the documented problems creates too many difficulties for effective use of this data source. Consequently, for these kinds of data, the limiting factor is not the tools for data collection but their analysis. In line with Qi et al. (2021) the case study found that the increased use of digital tools for on-site data collection improves access to, and timely delivery of, data. If data is collected with paper-based tools, it is often only stored in this form, or after a certain period recorded within the ERP system. By capturing data with digital tools in real time, its availability for administration and performance measurement purposes is significantly faster. This advantage applies to all applications, e.g. the recording of working hours, the reordering
of material, the recording of defects and much more. This mitigates the risk inherent in the temporal and spatial separation of the construction site from the management location and the potential for data loss. The findings for the application of tools for on-site data collection are a contribution to both academia and industry since their advantages and disadvantages for data collection for various analysed performance criteria, is presented. Companies can thus better assess which tools provide a benefit for their PMS and scientists can deduce where specialised tools, systems or approaches are required to increase the efficiency of PMS.

Conclusion
The objective of this research was to identify and analyse on-site PMM practices in the IHB sector. To pursue this, three research questions were formulated. The first asked how IHB companies measure and manage construction site performance. The second sought to identify and present reference practices in the field of measuring construction site performance within IHB and the third concerned the tools currently being used to collect working time and quality data on the construction site. In order to respond to the questions arising, a multiple case study within the IHB sectors of Austria, Germany and Switzerland was conducted. Following an analysis of all companies in the sector, eight companies were selected. This was done based on maximum variation sampling. To collect data, semi-structured guideline interviews were conducted with company managers. The interview protocols were coded, followed by both a within- and a cross-case analysis.

The resulting findings show that IHB companies measure their construction site performance using specific performance indicators, with a variety of indicators commonly used to assess productivity. These include; the duration of the construction period, the working time of the employees, the adherence to schedules of services
performed, the use of employee and machine resources as well as the availability and supply of materials, and the effort for reworking non-conformities before handover. Efficient quality data preparation and integration in PMS is still a difficulty for many companies. Although a large amount of data is collected on defects and the resulting costs, it has become apparent that companies lack the ability to properly process this type of data. For this reason, companies prefer to apply experience-based solutions using CI methods such as quality circles or similar approaches.

However, several approaches from PMM reference practices have been identified and described, providing ideas for improving the measurement and management of quality. These are; the systematic use of quality parameters to identify unique, team-specific knowledge or the evaluation of defect rectification costs by means of Pareto analyses. Further reference practices were identified and described for the criteria of productivity and economic efficiency.

Both digital and paper-based tools are used to collect construction site data. The use of data collection tools was analysed for: reporting working time, recording non-conformities and defects as well as providing feedback on the rectification effort. This case study shows that in recent years, many of the companies have introduced digital tools for data collection or are preparing for their implementation. The advantages of this are realised in access to the data and its timely delivery. Digital working time reports are gaining importance since data on working time spent is available earlier than paper-based forms. Unproductive activities, such as digitally recording paper-based working time data, is eliminated. In order to record and describe defects and non-conformities, either digital or paper-based site reports are used. However, the value of both tools for measuring performance is questionable due to the complexity of quality evaluation. Either digital tools or paper-based reports are used in reporting on the effort
required for reworking defects and non-conformities. The function of both is to enumerate the defects, describe the workload and express it in hours. Frequently these tools are integrated into working time report systems. However, the data on “quality” collected with these tools are not yet used for systematic performance measurement.

The main contribution of this paper is that it analyses the current state of PMM in the on-site working of IHB companies, with the additional description of approaches from reference practices. IHB companies can use the findings to benchmark their own PMM practices and identify processes as well as systems requiring improvement. It contributes to the development of governance structures to control construction sites and facilitate the continuous improvement of the industrialised housebuilding process. The findings show that solutions are required to improve the evaluation of the criteria “quality”. In addition, the application of tools for on-site data collection are analysed, providing an assessment of these tools, and reveal the need to develop tools, systems or approaches to increase efficiency of PMS. The findings of this research can thus provide a yardstick for the evolution of PMS and serve as a basis for the further development of PMM within the IHB sector.

This case study was conducted in Central Europe, so the findings cover the IHB sectors of Austria, Germany and Switzerland. Further studies in other regions will be required to make generalisations about the findings, since the IHB sectors in other regions may differ in terms of market requirements, techniques used and potential additional criteria. The availability of data sources and possibilities for data collection is limited since, for most companies, it is a sensitive issue. Consequently, this study was only able to build on interviews with representatives of the selected companies. Although a very sound methodological approach was chosen to ensure the quality of the data obtained, it would be beneficial to corroborate the results with future research
based on other data sources as well as methodological approaches such as an industry wide survey.

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### Table 1. Case description

<table>
<thead>
<tr>
<th>Case</th>
<th>Strategic focus</th>
<th>Production system classification</th>
<th>Kind of clients</th>
<th>Volume of the buildings</th>
<th>Remuneration-system for own on-site work</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(1) Cost leadership shifting its position towards more quality management &amp; assurance (QM/QA)</td>
<td>Customised standardisation</td>
<td>PF&amp;PA</td>
<td>BC, GC, PC</td>
<td>LVB &amp; SVB</td>
</tr>
<tr>
<td>2</td>
<td>Diversifier with focus on (1) customer satisfaction and (2) scope of services</td>
<td>Tailored customisation</td>
<td>PF&amp;PA</td>
<td>Primarily PC, few BC</td>
<td>LVB &amp; SVB</td>
</tr>
<tr>
<td>3</td>
<td>Diversifier with focus on (1) scope of services and (2) QM/QA</td>
<td>Tailored customisation</td>
<td>PF&amp;PA</td>
<td>PC</td>
<td>SVB</td>
</tr>
<tr>
<td>4</td>
<td>Diversifier with focus on (1) customer satisfaction, (2) scope of services, (3) material-, product- and service quality</td>
<td>Customised standardisation (small portion MB)</td>
<td>PF&amp;PA</td>
<td>Primarily PC, few BC</td>
<td>SVB</td>
</tr>
<tr>
<td>5</td>
<td>(1) Cost leadership with focus on environmental issues &amp; energy efficiency</td>
<td>Segmented standardisation</td>
<td>PF&amp;PA</td>
<td>PC</td>
<td>SVB</td>
</tr>
<tr>
<td>6</td>
<td>(1) Cost leadership with focus on fast realisation time</td>
<td>Segmented standardisation</td>
<td>MB</td>
<td>BC, GC</td>
<td>LVB</td>
</tr>
<tr>
<td>7</td>
<td>Diversifier with focus on (1) material-, product- and service quality</td>
<td>Segmented standardisation (MB &amp; Tailored customisation (3D structural building))</td>
<td>MB &amp; PF&amp;PA</td>
<td>BC, GC, few PC</td>
<td>LVB</td>
</tr>
<tr>
<td>8</td>
<td>Diversifier with focus on (1) material-, product-, service quality and (2) QM/QA</td>
<td>Customised standardisation</td>
<td>PF&amp;PA</td>
<td>Primarily PC, few BC</td>
<td>SVB</td>
</tr>
</tbody>
</table>
Prefabrication & Preassembly (PF&PA)
Modular building (MB)
Large volume buildings (LVB)
Small volume buildings (SVB)
Business Clients (BC)
Governmental Clients (GC)
Private Clients (PC)
Quality management & Quality assurance (QM/QA)
Table 2. Role of the interviewees within the companies

<table>
<thead>
<tr>
<th>Case</th>
<th>Position of the interviewees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(1) Production Manager</td>
</tr>
<tr>
<td></td>
<td>(2) Assistant production manager</td>
</tr>
<tr>
<td>2</td>
<td>(1) CTO</td>
</tr>
<tr>
<td>3</td>
<td>(1) CTO</td>
</tr>
<tr>
<td></td>
<td>(2) CFO</td>
</tr>
<tr>
<td></td>
<td>(3) Controller</td>
</tr>
<tr>
<td></td>
<td>(4) Head of construction site assembly department</td>
</tr>
<tr>
<td>4</td>
<td>(1) CEO</td>
</tr>
<tr>
<td></td>
<td>(2) CTO</td>
</tr>
<tr>
<td>5</td>
<td>(1) CKO</td>
</tr>
<tr>
<td>6</td>
<td>(1) CEO</td>
</tr>
<tr>
<td>7</td>
<td>(1) CTO</td>
</tr>
<tr>
<td></td>
<td>(2) Head of construction site assembly department</td>
</tr>
<tr>
<td></td>
<td>(3) Production manager</td>
</tr>
<tr>
<td>8</td>
<td>(1) Head of controlling</td>
</tr>
</tbody>
</table>
### Table 3. Data collection on construction site and use for performance measurement

| Criteria | Case 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8
| **Ongoing data collection** |       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| **Data collection through delimited visual checks and time studies** |       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| **Systematic use of data for performance measurement** |       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| **No systematic use of collected data for performance measurement & management** |       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| **Productivity criteria** |         |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Construction time | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Staff working hours | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Working hours for dedicated construction phases | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Time predictability of own services | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Time predictability of subcontractor services | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Workforce planning | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| **Quality criteria** |         |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Measureable quality parameter | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Defects & Failure |         |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Number of buildings without defect at handover | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Number of defects without non-conformities from construction phase | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Number of defects at handover | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Number of defects during defects liability period | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Defects & Failure description/documentation | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Documentation of the defect cause | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Number of defects per component category | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Time to rectify defects after handover | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| **Work safety criteria** |         |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Number of incidents | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Cause analysis | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
Table 4. Tools to report working time from construction site

<table>
<thead>
<tr>
<th>Tool application</th>
<th>Case 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tbody>
<tr>
<td>No periodic time reporting</td>
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<td>x</td>
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<tr>
<td>Paper-based working time report</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Mobile device for time reporting</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
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<tr>
<td>ERP system for time reporting</td>
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<td>x</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Table 5. Tools for recording defects & non-conformities

<table>
<thead>
<tr>
<th>Tool application</th>
<th>Case 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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</thead>
<tbody>
<tr>
<td>Paper based site reports</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Digital site reports</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photos of defects</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Video documents of defects</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Audio documents</td>
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<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

Table 6. Tools for recording the effort for rectify non-conformities and defects

<table>
<thead>
<tr>
<th>Tool application</th>
<th>Case 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tr>
<td>Digital report for reworking of non-conformities</td>
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<td>x</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Paper-based report for reworking of non-conformities</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td>Digital report for customer service work</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
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<td>Paper-based report for customer service work</td>
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<td>x</td>
<td>x</td>
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</table>
Table A1. Interview guide

<table>
<thead>
<tr>
<th>Question</th>
<th>Follow-up question</th>
</tr>
</thead>
<tbody>
<tr>
<td>What strategies does your company use to convince customers of the superiority of your products (prefabricated house)?</td>
<td>Which products do you mainly sell? Which customer groups do you mainly address? To what extend do customers influence the design of houses? What makes your company stand out from the competition?</td>
</tr>
<tr>
<td>Which performance criteria related to on-site production are essential for your company such that you speak of a successful business year (/construction projects)?</td>
<td>How is the target for key figures/criteria defined in your company?</td>
</tr>
<tr>
<td>What are your most important performance measures which you currently apply to evaluate the on-site performance in your company?</td>
<td>With which indicators do you measure the respective criteria? What is the purpose of the applied PI? What time frame do the measured PI cover? Will the data collected be used for future analyses after completion of construction? What is the time/cost/resource effort required to measure and evaluate PI?</td>
</tr>
<tr>
<td>To what extent that your company’s decisions are based on results from PI or other quantified performance measures?</td>
<td>How reliable do you consider the analyses used? To what extent are adjustments of operational processes or long-term strategy changes based on PI? Where do you identify a need to increase or decrease measurements?</td>
</tr>
<tr>
<td>For which categories are data collected at your construction sites?</td>
<td>What is the data and information exchange regarding performance measurement and management within the supply chain? Which data is exchanged? From which category?</td>
</tr>
<tr>
<td>Can you describe the cooperation within the supply chain concerning on-site performance measurement and management?</td>
<td>Which data do you consider reliable? Which data / information do you not trust? Why not? Do you consider the data collected on your construction sites reliable? Why?</td>
</tr>
<tr>
<td>In your opinion what makes on-site production data reliable?</td>
<td>Which tools / concepts do you see as useful for performance measurement? Which tools / concepts would you like to use for performance measurement in the future?</td>
</tr>
<tr>
<td>Which tools for data collection (information collection) do you apply for on-site production?</td>
<td></td>
</tr>
</tbody>
</table>
To what extent do you trust the information obtained through these tools?
For which applications do you use automated data collection?
Which requirements regarding tools for data acquisition and analysis on construction site are essential for you?
Which tools / concepts do you expect will improve the evaluation of on-site production performance in the future?
Do you consider the use of automated data collection to be beneficial for your company? What potential improvements could be possible?
What are the changes in your performance measurement system for analysing on-site production that you are interested in?
What is the purpose of this change?
How would you assess the success or failure of these amendments?
What do you consider the most urgent issue regarding performance measurement in your company?
Do you have any further information you would like to share with us on the subject of performance measurement in IHB?
Figure 1. Interaction of the building project level and the organisational level to achieve a continuous improvement of IHB performance