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WHAT ARE THE MAIN CAUSES OF DISCONTINUOUS WORK?

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ABSTRACT

Discontinuous work in construction refers to periods without resource or work continuity, leaving workers without designated locations to perform their tasks. Studies show in many activities idle durations are a significant portion of total work. Caused by poor production system design in projects, discontinuous work is a major cause of low trade productivity. This paper aims to identify factors affecting discontinuous work and quantify their impact. 346 datapoints (including 46 superstructure crews across 75 building levels in 10 multistorey buildings in London) were analysed using correlation and regression techniques. Data included crew size, batch size, activity type, work start and end dates. Results showed that reducing the batch size by increasing slab concrete pours per level minimised discontinuities by ensuring more available work locations. Synchronising the production rates of successive crews also reduced discontinuities by limiting idle time for faster crews. Surprisingly, although often considered a cause of discontinuities, out-of-sequence work had no statistically significant relationship with discontinuities. Possibly due to the constraints of superstructure work limiting the out-of-sequence work. Additionally, offsite construction methods exhibited greater variability in discontinuities compared to in-situ methods, likely due to clashes between in-situ activities happening at a different rate of work to offsite activities.

KEYWORDS

Resource continuity, flow, productivity, location-based management (LBM), out-of-sequence work

INTRODUCTION

The construction sector accounts for 13% of the world's gross domestic product (Barbosa et al., 2017). Yet, many studies indicate that it remains one of the least productive industries (Rathnayake & Middleton, 2023). In other words, a significant portion of inputs (i.e. worker-hours, materials, plant and equipment) are wasted in producing construction outputs. The construction sector comprises a collection of projects, each consisting of multiple activities. According to Koskela (1992), there is substantial potential at the interfaces between activities to enhance construction productivity. Discontinuous work is a major source of productivity loss

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at these interfaces. It refers to periods without resource or work continuity, where workers lack designated locations to perform tasks (Kenley & Seppänen, 2006). Rathnayake et al. (2023) and Rathnayake et al. (2024) found a strong correlation between discontinuous work and low trade productivity. However, the reasons behind discontinuities at the activity level remain less understood. At the same time, discontinuities can serve as a metric to compare variability between different trade methodologies delivering the same activity. There exists a significant research gap in quantitative evidence on how various factors influence the increase or decrease of discontinuities in actual construction activities.

This study aims to quantify how different factors affect work discontinuities using a substantial dataset of real-world construction activities. Different construction phases involve activities with varying interdependencies. For example, crews performing façade installation and fit-out may have multiple workfaces to choose from, reducing discontinuous work, whereas structural work typically follows a fixed sequence. Therefore, the scope of this research is limited to data from the structural phase of buildings.

REASONS FOR DISCONTINUOUS WORK

This section outlines some reasons for discontinuous work identified in the literature.

PLANNED DISCONTINUITIES

One of the most obvious sources of discontinuous work in a construction project arises when such discontinuities are intentionally planned into the construction schedules. This includes scheduling the succeeding locations of an activity to begin only after a gap following the completion of the previous locations (Seppänen, 2009). Most construction projects in practice use the critical path method and Gantt chart-based scheduling techniques, which have been criticised for their lack of focus on ensuring work continuity for crews (Olivieri et al., 2019). The lack of continuity can result from various factors, including an emphasis on completing each activity as early as possible and the need to incorporate buffers.

EXCESSIVE NUMBERS OF WORKERS IN CREWS

Crew size affects work discontinuities due to its impact on construction speed. Most construction work involves multiple activities, with crews working sequentially across locations. If one crew works faster (i.e. has a higher production rate), they may finish early and wait for the next location, creating a discontinuity. Synchronising the production rates of successive crews is crucial to minimising discontinuities (Arditi et al., 2002). Adjusting crew size can achieve the desired production rate, as larger crews typically work faster. However, assigning more workers to a location than planned (due to a lack of work elsewhere) can also lead to discontinuities (Kenley & Seppänen, 2006).

WORKING OUT-OF-SEQUENCE

If work discontinuities arise from workers lacking a specified location, finding an alternate location—even out of sequence—might seem to reduce discontinuities. However, out-of-sequence work can create further delays, such as time spent moving materials and equipment, cleaning and familiarising with the new location. Crews may also take breaks or finish early before moving to the next location. These delays are usually greater if the new location is far or different from the previous one (Kenley & Seppänen, 2006; Seppänen et al., 2014).

Additionally, work may start out of sequence just to keep workers busy, even if not all inputs—such as materials or equipment—are available. Koskela (2004) calls this 'making-do waste,' which increases rework, lead times and processing times, further reducing productivity.

INSUFFICIENT WORK MADE READY BY EARLIER CREWS

The production rates of successive crews may vary due to factors other than crew size, which was discussed in a previous section. At times, this discrepancy cannot be corrected due to resource constraints or contractual obligations (Arditi et al., 2002; Kenley & Seppänen, 2006). As a result, insufficient work may be made ready by crews for their successors, which can be considered an indicator of work discontinuities.

TASKS THAT DO NOT REQUIRE CONTINUOUS ON-SITE RESOURCES

Most activities require continuous onsite resources, such as workers and materials, to ensure completion. Increases in resource durations lead to periods of discontinuous work and low productivity. However, some activities, like concreting, do not necessarily require continuous resources (Kenley & Seppänen, 2006). Concreting typically occurs over shorter durations, with crews having less involvement at the location, inherently leading to work discontinuities.

BATCH SIZE

In construction, a large batch size equates to crews occupying large working areas at a given time. This results in increased simultaneous use of space for multiple activities and, ultimately, longer lead times, i.e. work discontinuities (Murguia et al., 2023). Murguia et al. (2023) analysed data from the construction of structural frames for several multistorey buildings, using the number of concrete pours per level as an indicator of batch size (with a higher number of pours indicating a smaller batch size). Their study found a moderate correlation between the production rate and the number of concrete pours per level. Similarly, Maturana et al. (2003) demonstrated in a simulation exercise that increasing the number of concrete pours in a multistorey building could reduce crew idling time, leading to time savings of up to 10%.

RESEARCH METHOD

This section presents the steps taken to quantify the impact of different factors on work discontinuity. The process is outlined in Figure 1 and explained in the subsequent subsections.

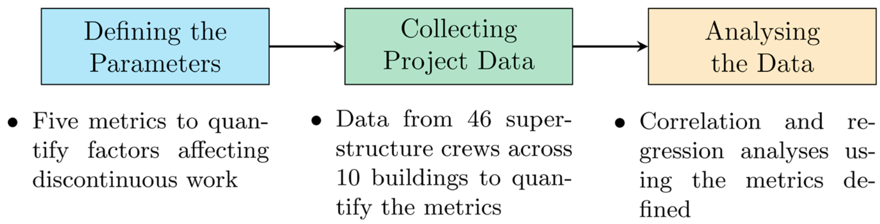

Figure 1: Research methodology followed

DEFINING THE PARAMETERS

Table 1 presents the factors affecting discontinuous work, as identified from the literature and mentioned in the previous section, along with the metrics used in this research to quantify them. First, regarding planned discontinuities, their duration should ideally be measurable from the construction programmes followed. However, in all the projects considered, considerable differences were observed between the plans and actual performance, especially at the activity level. As a result, performing such calculations was not feasible, and the factor of planned discontinuities was omitted from this analysis. Secondly, the calculation of some of the metrics is discussed in the subsequent subsections with the help of Figure 2. Figure 2 shows a flowline chart depicting the start and end dates of three crews—Crew 1, Crew 2 and Crew 3—on the X-axis, along with their working locations: Level 1 – Location A, Level 1 – Location B, Level 2 – Location A and Level 2 – Location B on the Y-axis.

Table 1: Metrics used in correlation and regression analyses

Factor	Metric	Definition
Excessive numbers of workers in crews	Average crew size	Average size of the crew (excluding general supportive workers) during the construction period
Working out-of-sequence	Proportion of out-of-sequence work	Total duration a successive location started before the start of a preceding location, divided by the start-to-start duration of the relevant building level
Insufficient work made ready by earlier crews	Relative production rate	Ratio of the mean (μ) production rate of a crew at a level to the minimum mean production rate of all crews at that level
Tasks that do not require continuous onsite resources	Lack of continuous onsite resources	0 if the activity requires continuous onsite resources; 1 if it does not (e.g. slab concreting)
Batch size	Number of concrete pours	Number of major slab concrete pours per building level, equal to the number of construction zones/locations
Work discontinuity (dependent variable)	Proportion of work discontinuity	Total duration spent by a crew without working in between locations, divided by the start-to-start duration of the relevant building level

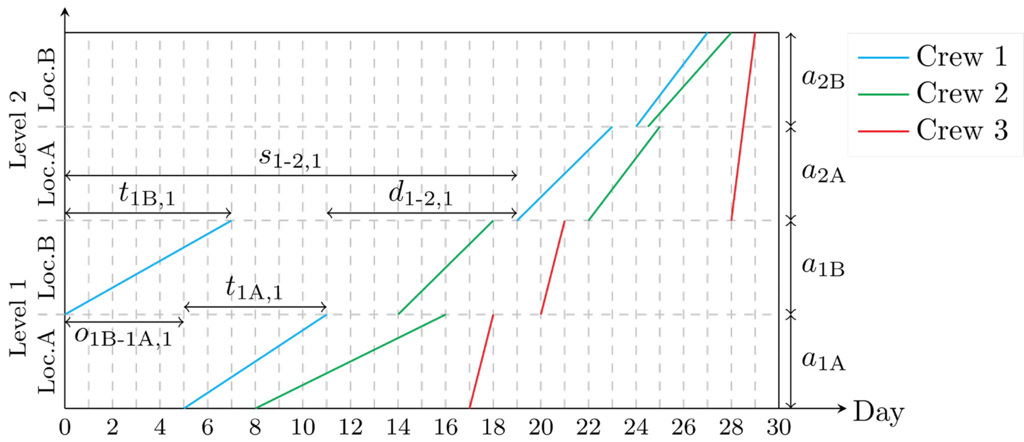

Figure 2: Calculating factors affecting discontinuous work

Proportion of out-of-sequence work

Figure 2 shows Crew 1 starting work on Level 1 – Location B before Location A, creating an out-of-sequence duration ($o_{1B\text{-}1A,1}$) between the starts of Locations B and A. To calculate the proportion of out-of-sequence work, this duration is divided by Crew 1's total time on Level 1. Although one might assume this to be the time between the start and finish of their work, labour records show that workers were onsite during periods of work discontinuity. Therefore, the total duration is considered the start-to-start duration between Levels 1 and 2 ($s_{1\text{-}2,1}$). The proportion of out-of-sequence work for Crew 1 on Level 1 is then calculated using Equation (1).

$$\text{Proportion of out-of-sequence work for Crew 1 on Level 1} = \frac{o_{1B\text{-}1A,1}}{s_{1\text{-}2,1}} \tag{1}$$

Relative production rate

The relative production rate of a crew, compared to the slowest crew at a location, indicates the level of synchronisation between production rates and whether sufficient work was made ready by earlier crews. Comparing production rates is challenging due to differing output units (e.g. m^3 of concrete and m^2 of formwork). To standardise, floor area (m^2) was used to measure output for all crews. Crew 1's production rate at Level 1 – Location A was calculated by dividing the floor area of Location A (a_{1A}) by the time taken ($t_{1A,1}$). Crew 1's average (μ) production rate on Level 1 was the average of Locations A and B. Similar values were calculated for Crews 2 and 3, and the relative production rate for Crew 1 on Level 1 is determined using Equation (2).

$$\text{Relative production rate for Crew 1 on Level 1} = \frac{\mu\left(\frac{a_{1A}}{t_{1A,1}},\frac{a_{1B}}{t_{1B,1}}\right)}{\min\left(\mu\left(\frac{a_{1A}}{t_{1A,1}},\frac{a_{1B}}{t_{1B,1}}\right),\mu\left(\frac{a_{1A}}{t_{1A,2}},\frac{a_{1B}}{t_{1B,2}}\right),\mu\left(\frac{a_{1A}}{t_{1A,3}},\frac{a_{1B}}{t_{1B,3}}\right)\right)} \quad (2)$$

Proportion of work discontinuity

According to Figure 2, Crew 1 spent the duration $d_{1\text{-}2,1}$ without work between Levels 1 and 2. If they had a period without work between Locations A and B on Level 1, it would have been denoted as $d_{1A\text{-}1B,1}$ (which, in this case, is zero). As mentioned earlier, the total duration of Crew 1 on Level 1 is considered the start-to-start duration between Levels 1 and 2 ($s_{1\text{-}2,1}$). Therefore, the proportion of work discontinuity for Crew 1 on Level 1 is calculated using Equation (3).

$$\text{Proportion of work discontinuity for Crew 1 on Level 1} = \frac{d_{1A\text{-}1B,1}+d_{1\text{-}2,1}}{s_{1\text{-}2,1}} \quad (3)$$

COLLECTING PROJECT DATA

The scope of this research was limited to the structural phase of multistorey buildings to enable comparisons among similar activities. The factors affecting discontinuous work were quantified by applying the metrics developed in the previous step to the superstructure stage of ten commercial and residential buildings (A to J) in London. These buildings were part of seven projects involving four main contractors, with Buildings A and B, F and G and I and J belonging to the same projects. The superstructure stages were completed between 2020 and 2023, with buildings having 7 to 16 floors and above-ground floor areas ranging from 5,300 m^2 to 24,100 m^2. Due to the similar location, period of construction and focus solely on superstructure work, it is believed that the results are comparable across the buildings.

The main source of data for this research was commercially available site camera systems. The contractors used these to create time-lapse footage for marketing purposes and as a security measure. Each project had one or more cameras installed on tower cranes and/or adjoining buildings, capturing photos of the site at regular intervals, ranging from 1 to 15 minutes. The photos were accessible through online platforms. These images were manually analysed to determine the start and end dates of each superstructure crew at each location. The accuracy of the data collected was verified using installation records prepared by subcontractors (in case there were areas not visible from the cameras) and through discussions with site managers. These dates were used to calculate the metrics for the proportion of out-of-sequence work, relative production rate and the proportion of work discontinuity. The number of concrete pours per building level was also determined from the site cameras and verified using installation records and discussions with site managers.

Data related to crew sizes were obtained through discussions with site personnel and verified using records from site access control platforms. Finally, the floor areas needed to calculate production rates were obtained from building information modelling (BIM) models.

In total, the sample size included 346 data points related to 46 crews across 10 buildings. This total represents the sum of the number of crews per building multiplied by the number of building levels (e.g. for Building D, five crews × 9 levels = 45 data points). Note that the lower levels of some buildings were excluded from the analysis due to having different structural systems and, therefore, different activities and crew arrangements. Additionally, the higher levels of some buildings were excluded due to insufficient visibility from the cameras.

DATA ANALYSIS

IBM SPSS 29 was used to conduct correlation and regression analyses between work discontinuity and the factors affecting it. According to Evans (1996), correlation values between 0.00–0.19, 0.20–0.39, 0.40–0.59, 0.60–0.79 and 0.80–1.00 represent very weak, weak, moderate, strong and very strong linear relationships, respectively, with similar interpretations for negative values. Additionally, Cohen (1988) states that R^2 (coefficient of determination) values of 2%, 13% and 26% indicate small, medium and large effect sizes between independent and dependent variables in linear regression.

RESULTS

CALCULATING THE PROPORTIONS OF WORK DISCONTINUITY

Figure 3 presents site photos of Building E, showing its four superstructure activities at one of the locations (Level 3 - Location 1). Figure 4 (left) presents a flowline chart for Building E, with flowlines indicating the start and end dates of the four work crews at different locations and levels. The X-axis represents working days, adjusted for holidays and weekend hours, while the Y-axis shows building levels, with each level's length proportional to its floor area.

In Figure 4 (left), consider the precast column installation crew from Levels 1 to 2. There were three locations on Level 1. This crew experienced a discontinuity of 4.5 days between Level 1 – Locations 1 and 2. Similarly, there was a discontinuity of 4.5 days between Level 1 – Location 2 and Level 2 – Location 1 (Level 1 – Location 3 commenced a day after Level 2). The total discontinuity for this crew on Level 1 was 9 days. Dividing this by the start-to-start duration between Levels 1 and 2 for precast column installation (20 days) gives 0.45. This is illustrated in Figure 4 (right), which shows the variation in the proportion of work discontinuity for the four superstructure crews in Building E. Plots similar to Figure 4 (right) could be produced for other buildings. However, no noticeable pattern of increase or decrease was observed as crews moved from lower to higher levels.

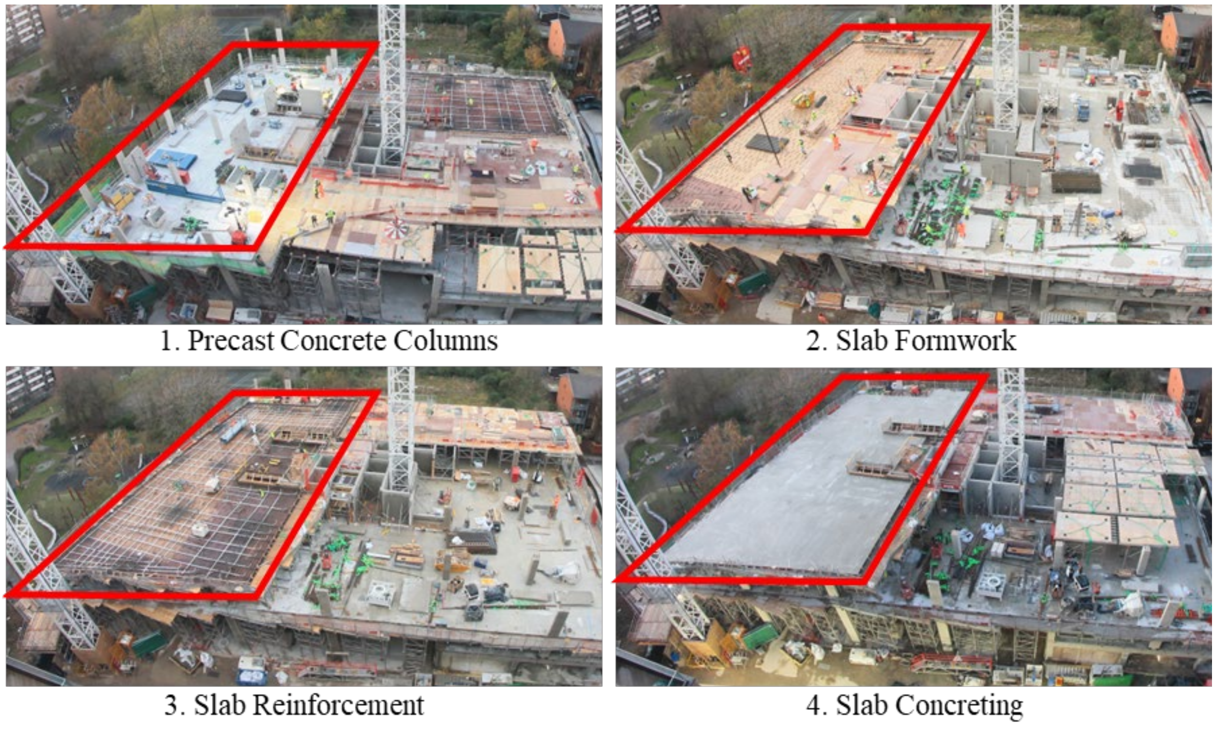

Figure 3: Superstructure activities at Building E, Level 3, Location 1

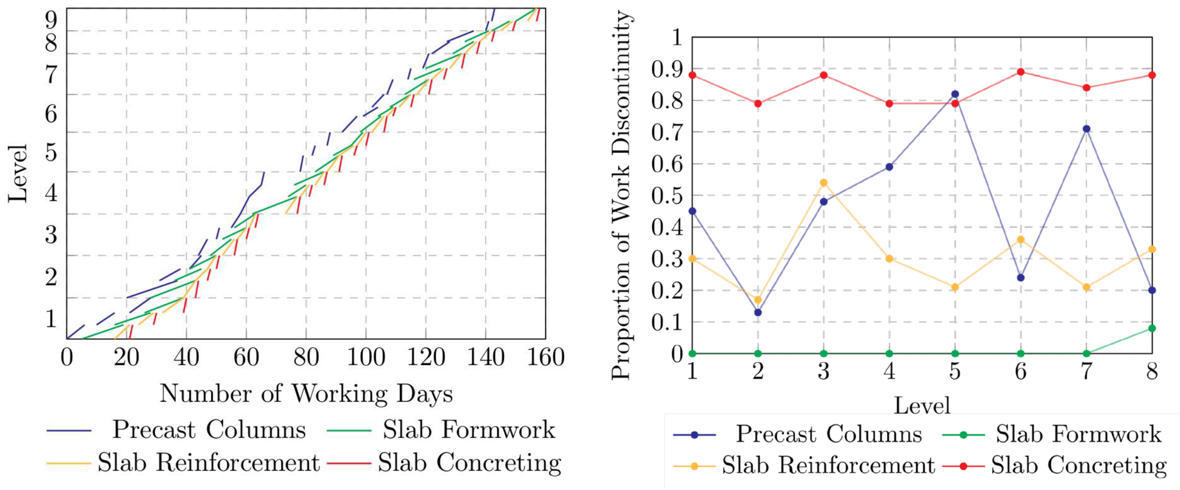

Figure 4: Superstructure flowlines for building E (left) and proportions of work discontinuity across building levels (right)

COMPARISON OF THE PROPORTIONS OF WORK DISCONTINUITY AMONG DIFFERENT CREW TYPES

Figure 5 presents a comparison of the variability of work discontinuity proportions for different crew types (10 types across the 10 buildings). The superstructure activities in multistorey buildings were classified into two groups: those related to vertical elements (i.e. columns) and those related to horizontal elements (i.e. slabs). Similarly, the activities were further classified based on whether they were performed using in-situ or offsite methods. As a result, the 10 activities were divided into four categories. According to the figure, slab formwork installation generally had the lowest levels of work discontinuity, while slab concreting had the highest, possibly due to its lack of continuous onsite resource use. It should be noted that low proportions of work discontinuity could also result from low production rates and thus may not necessarily be a good indicator.

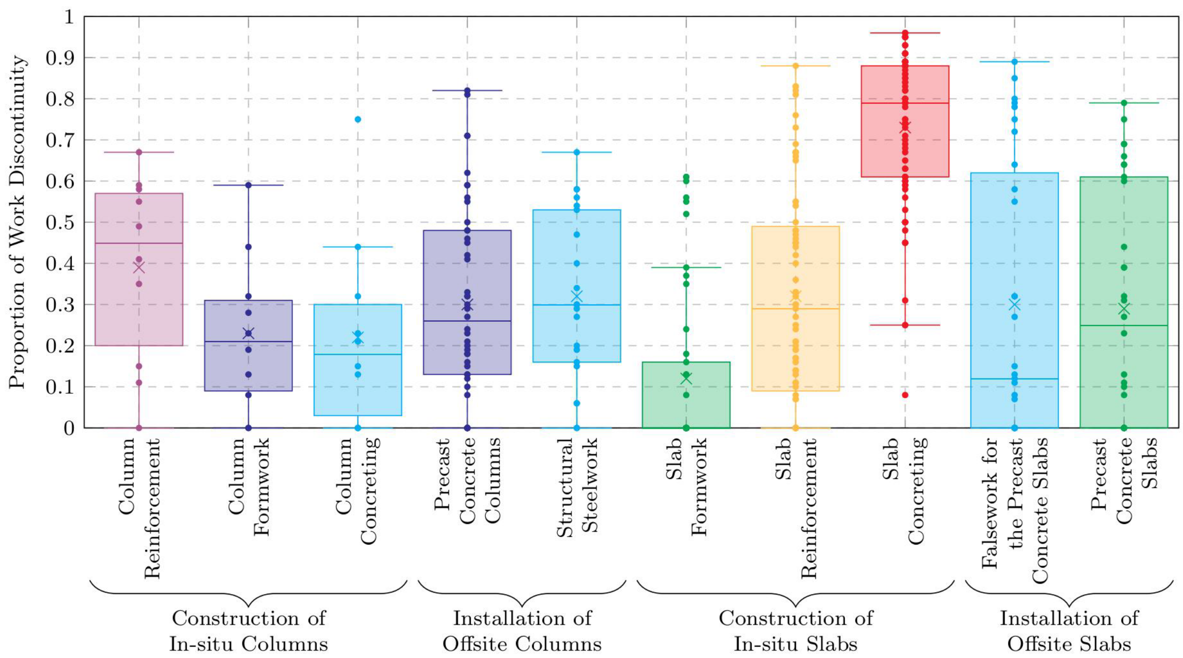

Figure 5: Boxplots of work discontinuity across different crews

Figure 5 also highlights an interesting distinction between onsite and offsite construction. While offsite methods do not necessarily exhibit higher levels of work discontinuity compared to in-situ methods, they show comparatively high variability in their discontinuities, especially those related to slab construction. This could be due to interfacing issues between offsite and in-situ construction activities. We hypothesise that high variability can emerge with the use of different types of offsite solutions across various projects, as well as in matching the rate of work between in-situ activities which shares interfaces with offsite elements which are erected faster.

CORRELATION AND REGRESSION RESULTS

Tables 2 and 3 present the correlation and regression results of the analysis conducted. Four out of the five factors tested were found to have statistically significant associations with the proportion of work discontinuity. The lack of continuous onsite resources, relative production rate and the number of concrete pours show strong positive, moderate positive and moderate negative correlations, respectively. These factors also appear in the linear regression model with variance inflation factors below 3, indicating low levels of multicollinearity. The linear regression equation has an R^2 value of 0.689, which indicates a large effect size.

Table 2: Correlation matrix for factors affecting discontinuous work (**p<0.01, *p<0.05)

Metric	Average crew size (ACS)	Proportion of out-of-sequence work (POW)	Relative production rate (RPR)	Lack of continuous onsite resources (LCOR)	Number of concrete pours (NCP)	Proportion of work discontinuity (PWD)
ACS	1.000					
POW	0.241**	1.000				
RPR	0.166**	0.129*	1.000			
LCOR	0.260**	0.031	0.702**	1.000		
NCP	0.421**	0.401**	0.030	-0.006	1.000	
PWD	-0.165**	-0.089	0.576**	0.605**	-0.507**	1.000

Table 3: Linear Regression Results (p<0.01)

Dependent variable	R^2	R^2 (adjusted)	Independent variable	Unstandardised coefficient	Standardised coefficient	Variance inflation factor
PWD	0.689	0.685	Constant	0.584		
			LCOR	0.309	0.409	2.099
			NCP	-0.099	-0.459	1.242
			RPR	0.025	0.325	1.981
			ACS	-0.015	-0.132	1.330

DISCUSSION

RELATIVE PRODUCTION RATE

According to the correlation and regression results, the production rates of different crews should be synchronised as much as possible, either by reducing resources allocated to faster activities or increasing resources allocated to slower activities. In other words, the proportion of work discontinuities seems to increase as the synchronisation between different crews at a location decreases, which aligns with previous studies (Arditi et al., 2002).

PROPORTION OF OUT-OF-SEQUENCE WORK

The proportion of out-of-sequence work was found to have no statistically significant association with the proportion of work discontinuity. This may be because the dataset of structural work analysed did not include many instances of out-of-sequence work. In any case, structural work cannot be performed with high levels of out-of-sequence work (e.g. Level 3 of a building must be constructed before Level 4). It would be valuable to analyse a different work package, such as façade or building services installation, which could demonstrate higher degrees of out-of-sequence work. In summary, it cannot be conclusively stated that out-of-sequence work has no effect on work discontinuities, but for relatively sequential types of activities, the effect could be considered negligible.

NUMBER OF CONCRETE POURS

The lack of continuous onsite resources showed the very significant correlation with the proportion of work discontinuity. However, this is a feature of certain activities, such as slab concreting, and is not controllable. Conversely, the number of concrete pours and the relative production rate are more useful for reducing discontinuities. According to the results, the number of locations or working zones per level (which corresponds to the number of major slab concrete pours in structural work) should be increased. This trend is observable even within a single building in some cases. For example, Building F had 3 concrete pours per level from Levels 2-5, 2 on Level 6 and 1 on Levels 7-10. Although the higher levels had smaller floor areas and, therefore, less output to be delivered, Levels 2-6 only took 57 working days, compared to the 64 working days required for Levels 7-10 (see Figure 6). The higher levels had more discontinuous work, which lowered production rates. Workers, though present, were engaged in less productive tasks, wasting skilled labour. On the other hand, asking workers not to come to the site carries the risk of losing workers and changes to crew composition, showing how discontinuous work disrupts operations. These findings align with previous studies showing that reducing batch size improves construction productivity (Murguia et al., 2023).

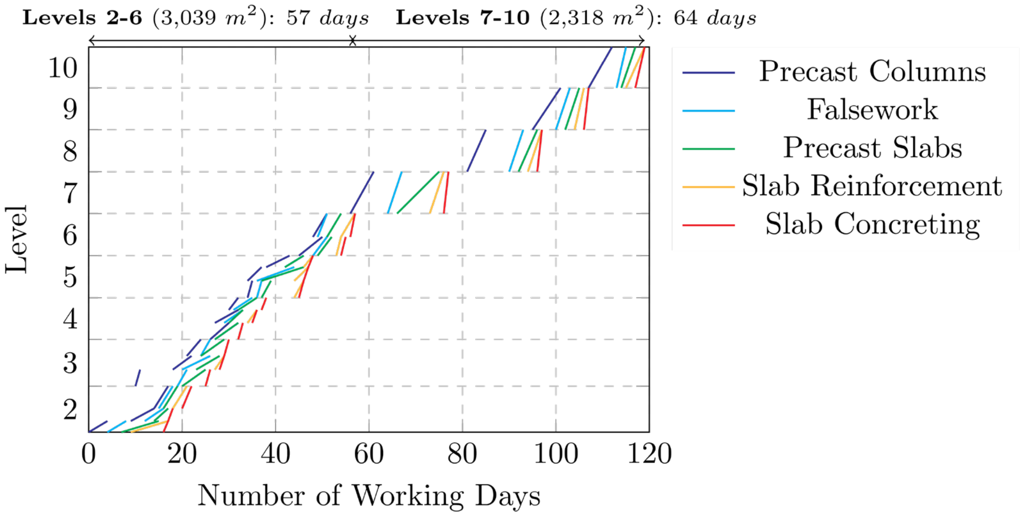

Figure 6: Building F superstructure flowlines

The effect from number of concrete pours on work discontinuity is also evident when comparing different buildings as a whole. One of the common activities across all 10 buildings was slab reinforcement. For which, Figure 7 compares the average batch size (average number of slab concrete pours per level), the overall proportion of work discontinuity across all levels (from the start to finish of a building) and the average production rate. According to the figure, the proportion of work discontinuity appears to decrease with the number of concrete pours (R^2

value of 81%), while the production rate seems to increase with the number of concrete pours (R^2 value of 76%). In summary, reducing the batch size by increasing the number of slab concrete pours in structural work can lead to a reduction in work discontinuities.

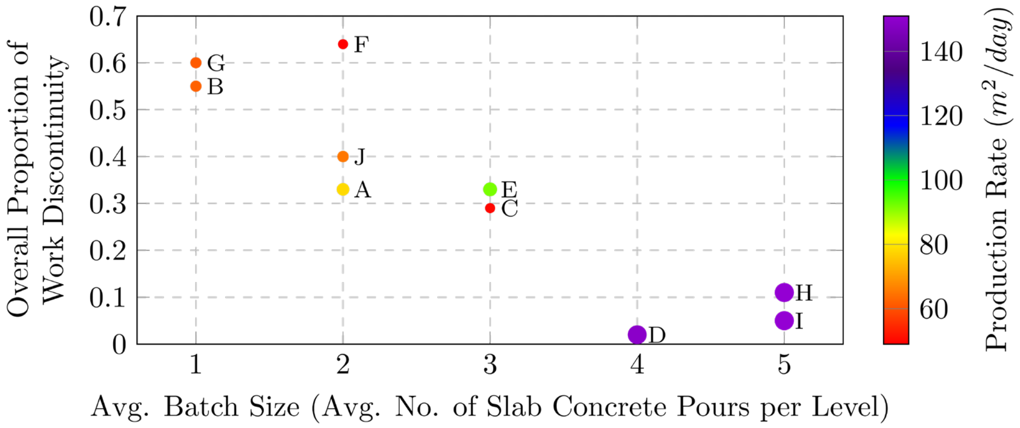

Figure 7: Effect of batch size on discontinuity and production rate in slab reinforcement work

NUMBER OF WORK DISCONTINUITIES

Instead of the proportion of discontinuous work, the number of work discontinuities could also be used as an indicator. The argument is that longer discontinuities might allow crews to work on other projects, whereas many short discontinuities would not. To identify any differences between these two metrics, correlation and regression analyses were repeated, including the number of work discontinuities. The results showed a strong correlation of r = 0.702 between the proportion and the number of work discontinuities. The only difference was the metric of the number of concrete pours, which showed a very weak negative correlation with the number of work discontinuities, compared to a moderate negative correlation with the proportion of work discontinuity. This suggests that having fewer concrete pours or a larger batch size would not necessarily disrupt the work by causing a large number of discontinuities. Instead, it would result in long durations without work due to the unavailability of working areas. Finally, all other metrics showed similar correlation and regression results for both measures of discontinuity. In summary, the number of discontinuities could also be used as a metric for work discontinuities, yielding nearly identical results.

CONCLUSIONS

This research sets out to quantify how various factors affect work discontinuities across five metrics, viz. average crew size, proportion of out-of-sequence work, relative production rate, lack of continuous onsite resources, and the number of concrete pours. The results showed that the lack of continuous onsite resources, relative production rate and the number of concrete pours had linear correlations of 0.605, 0.576 and -0.507, respectively, with the proportion of discontinuous work. In other words, activities such as slab concreting exhibited the highest levels of discontinuity, as they are naturally performed as short, discrete tasks. For other activities, high work discontinuities were observed at locations where there were significant differences in the production rates of successive activities and at building levels with fewer construction zones or locations (i.e. larger batch sizes).

Surprisingly, out-of-sequence work, which is often cited as a cause of work discontinuities, showed no statistically significant relationship with work discontinuities. This may be due to the study focusing only on the superstructure work package, which is primarily carried out in sequence due to practical constraints. Future research should consider other work packages, such as façade, fit-out and building services installation.

While offsite construction methods did not necessarily exhibit higher discontinuities compared to in-situ techniques, they exhibited greater variability in discontinuities. This study also demonstrated that, in addition to production rate (output per unit of time), which is affected by work discontinuities, labour productivity (output per worker-hour) is also impacted, as skilled workers spend periods without work onsite performing unskilled tasks.

On the other hand, while reducing work discontinuities is important for improving construction productivity, it is all but one aspect of the puzzle, as continuous work may simply mean a crew remains at a location for an extended period without making meaningful progress. Further, discontinuous work describes operations or trade flow, representing the movement of a single trade through different locations. Construction productivity is also influenced by process or location flow, which refers to the movement of different trades through a single location. Therefore, further studies on process flow-related metrics are necessary to fully understand how construction productivity can be improved. Finally, the correlation results of this study do not imply causation, meaning other unknown factors may contribute to work discontinuities. This limits the generalisability of our results to other construction activities such as installation of building services or construction of linear infrastructure.

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