Work package 2: Productivity mapping and literature review

November 2019

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Introduction

The AIMCH project aims to help tackle the UK housing crisis by using modern methods of construction (MMC) to deliver high quality homes faster, more reliably and at the same cost as masonry-built homes.

The University of Dundee in association with Whole Life Consultants Ltd has been commissioned by the Construction Scotland Innovation Centre (CSIC) on behalf of the AIMCH partners to undertake a wide-ranging literature research analysis and compile a report focused on construction productivity measurement studies and protocols.

The main aim of the literature review is to help understand the current landscape of productivity metrics and future trends, and to enable partners and industry to gain a good understanding of key tools and techniques in all areas of monitoring. The recommendations are being used to inform and influence the way in which project partners measure their on-site activities.

Main outcomes of the research:

- evaluated previous construction productivity measurement studies covering - productivity, quality, cost, efficiency, time, predictability, safety and material waste;
- provided different methods of measuring productivity with examples to determine what has worked well and why;
- provided recommendations to inform future AIMCH measurement studies.

Summary

The research highlights the potential improvements in construction performance through adopting modern methods of construction (MMC) and in particular offsite construction compared to traditional construction of houses i.e. brick and block.

The report highlights the choice of performance metrics is critically dependent on each organisation's strategic objectives and should be chosen with the utmost care to improve construction productivity.

In addition, the report provides a description of each recommended metric and method of measurement together with an assessment of its advantages and disadvantages including details on the level of uptake and examples of where it has been used in industry.

The headline recommendations are as follows:

- **Recommendation 1:**

Safety - Whilst lagging indicators are the most commonly reported, they do not necessarily lead to improved safety performance in the short term. The report therefore recommends the use of a combination of leading and lagging indicators.

- **Recommendation 2:**

Labour Productivity - It would be advantageous, not only to the AIMCH project but to the whole industry if tagging technology is supplemented by direct observations and activity sampling.

- **Recommendation 3:**

Quality - In applying quality metrics, it is important to distinguish between deficiencies in the process and deficiencies in the product. It is recommended that the NHBC Quality rating should be used.

Summary

- **Recommendation 4:**

Cost - The principal metrics used should be the average construction cost per plot, the average rectification cost of defects per plot and the design and size of each plot. Costs should exclude foundations.

- **Recommendation 5:**

Time - As with costs, times will have to be compared on plots of similar characteristics in terms of quality, design and size and functional specification.

- **Recommendation 6:**

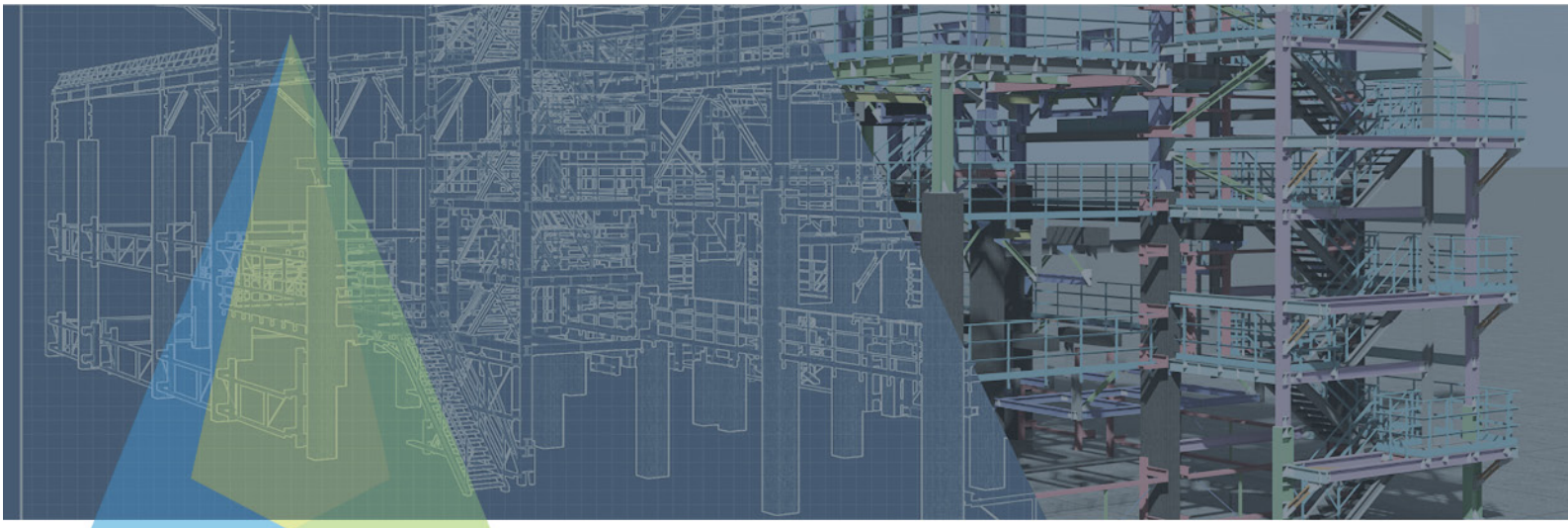
Predictability – It is recommended that time and cost predictability should both be measured in terms of the average percentage overrun per plot.

- **Recommendation 7:**

Efficiency - When no other viable option is available, the adoption of percentage financial margin as an umbrella metric for efficiency is suggested.

- **Recommendation 8:**

Material Waste - The most relevant metric is the net waste measured as the difference between the 'value of materials not incorporated in the construction works' and the 'value of additional recovered materials incorporated in the construction works or in off-site applications.'



Findings

In total eight principal metrics were researched/evaluated and are listed below with recommendations as to which metric should be applied in different circumstances.

Safety Metrics

Leading

- Number of safety observations (over a given period)
- Percentage of negative randomly performed drug and alcohol tests
- Number of times work has been stopped due to safety breaches
- Percentage of audited items in compliance
- Percentage of tasks which are planned in advanced
- Percentage of orientation events attended by the owner's project manager

Lagging

- Incidence rates
- Frequency rates
- Severity rate

Recommendation

Based on the review of the literature, it is recommended the use of two leading metrics: percentage of audited items in compliance and percentage of tasks which are pre-planned. The report also recommends the use of one lagging metric: frequency rates, and in particular, number of days of lost work per 100,000 hours worked. Consideration should also be given to supplementing this metric with the number of near misses recorded per 100,000 hours worked.

Findings

Labour Productivity Metrics

- Gross value added/number of jobs
- Gross value added/total hours worked
- Gross value added/labour cost
- Value of work completed/total hours worked
- Value of work completed/labour cost
- Labour hours per plot
- Output of physical units/total hours paid
- Output of physical units/available hours worked
- Output of physical units/productive hours worked
- Delays
- Earned value/Actual cost
- Earned hours/Actual hours
- Construction Industry Institute Construction Performance Assessment

Recommendation

If detailed information about the process of construction, its context and constraints is required, and if the labour force cannot be used to keep the necessary records, then direct, continuous observation by a trained observer should be used.

If the purpose is simply to determine the reduction in labour inputs occasioned by off-site manufacture, then the use of RFID or BLE should be piloted after suitable investigation of any constraints or shortcomings that might arise. In any case, it would be advantageous, not only to the AIMCH project but to the whole industry if RFID were supplemented by direct observations and activity sampling so the relative merits of each approach could be determined in more depth.

Findings

Quality Metrics

- HBF star rating
- Field Rework Index
- ISO 9001 Accreditation
- Yield (ratio of number of non-defective items to total number of items manufactured
- Quality rating ($\frac{\text{Total construction capital cost} - \text{Cost of post occupation defects}}{\text{Total construction capital cost}}$)
- Costs due to error/total construction cost
- Number of reportable items
- Number and type of items that did not pass visual inspection

Recommendation

In applying quality metrics, it is important to distinguish between deficiencies in the process and deficiencies in the product. Internal audits are most effective for early rectification of deficiencies, whilst external audits generally provide information only after completion of the work.

It recommends that the NHBC Quality rating should be used. This has the advantage of identifying the causes of deficiencies allowing improvement measures to be determined and implemented but requires the maintenance of comprehensive and accurate cost records.

Cost Metrics

- Average construction cost/m^2 (GIFA)
- Construction cost/bedroom
- Average construction cost/plot
- Construction cost/item or element

Findings

Cost Metrics (cont.)

- Cost variance
- Change in cost of construction
- Cost of rectifying defects
- Prelims cost/capital cost
- Cost growth (%)
- Phase cost ratio
- citiBLOC/m^2 (a citiBLOC is the average price of a basket of 'representative construction items')

Recommendation

The principal metrics used should be the average construction cost per plot, the average rectification cost of defects per plot and the design and size of each plot. Costs should exclude foundations, which are assumed to be the same for conventional and OSM but should include the costs of prelims which may vary between conventional and off-site construction. The costs of solutions using off-site manufacture should include the costs of investment in the necessary facilities, design of bespoke solutions, manufacturing, logistics and assembly. Clearly, costs will have to be compared on plots of similar characteristics in terms of quality and functional specification e.g. two bedroom terraced social housing.

Time Metrics

- Overall time (or programme duration)
- Time/output of physical units
- Time per plot

Findings

Time Metrics (cont.)

- Time/m^2
- Delivery speed
- Change in time for construction
- Projects schedule variation (%)
- Schedule growth (%)
- Project schedule factor ($\frac{\text{Actual total project duration}}{\text{Initial predicted project duration+Duration of approved changes}}$)

Recommendation

As with costs, times will have to be compared on plots of similar characteristics in terms of quality and functional specification. Additionally, because urgency is driven by demand, it will be necessary to ensure that that build contexts are comparable too if comparisons between on-site and off-site construction are to be meaningful. To achieve this, it may be necessary to compare both average and minimum construction times.

Again, the report recommends that the time to construct foundations is excluded since these will be more or less the same for on- and off-site construction. For off-site construction, consideration will have to be given to any time required for bespoke design, for manufacture, and for transportation as well as assembly on site. Finally, the report recommends that the time taken for each of these phases is recorded.

Findings

Time Metrics (cont.)

The following diagram shows the relationship between a programme duration and its constituents.

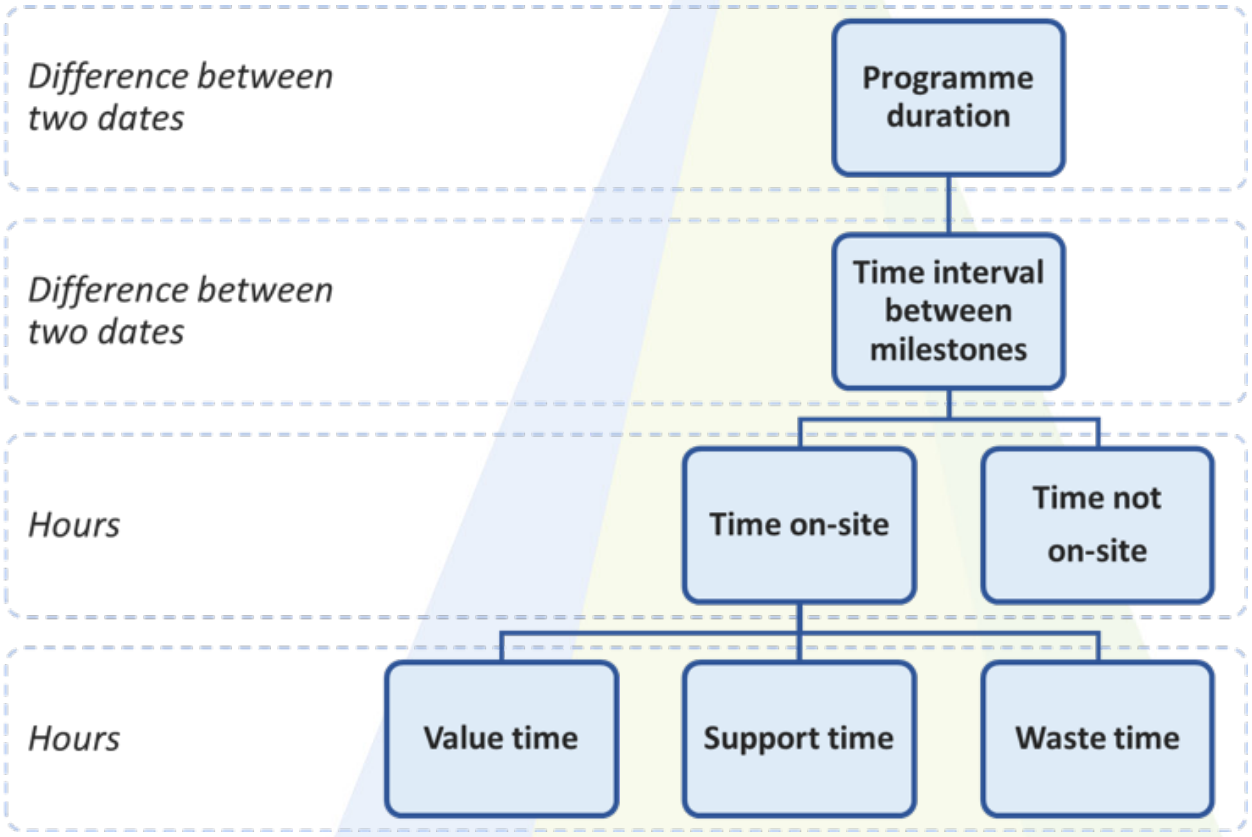


Figure 1 Hierarchy describing the relationship between a programme duration and its constituents. On the left-hand side of the picture the most commonly used units of measure are listed. The distinction of time at the lowest level is based on the concept of waste in lean management.

Predictability Metrics

- Time predictability – change in completion date
- Time predictability – average percentage overrun
- Cost predictability – average percentage overrun

Findings

Predictability Metrics (cont.)

- Cost and time predictability – SmartSite KPIs
- Safety, productivity, quality and material waste predictability

Recommendation

In the light of the AIMCH partners' strategic objectives, and in the pursuit of simplicity and consistency the report recommends that time and cost predictability should both be measured in terms of the average percentage overrun. For complete houses, it should be measured at the plot level (i.e. average percentage overrun per plot). It can however be measured in the same way for any element or activity in the construction process e.g. walls, floors or roofs.

Efficiency Metrics

- Ratio of input to output
- Reduction in amount of wasted resources
- Field of quality management

Recommendation

The report concludes that there is no unique, comprehensive and generally accepted metric describing efficiency. We therefore suggest that metrics describing wastage in labour, plant, material and finance are developed on a case by case basis taking inspiration from sectors such as manufacturing where, for example, the efficiency of a plant is often described by the so called "down time". When no other viable option is available, we suggest the adoption of percentage margin as an umbrella metric for efficiency whilst recognising that it is also a measure of 'efficiency' of the whole process including for instance sales and marketing.

Findings

Material Waste

The following metrics were reviewed.

- Volume of waste/100m^2
- Weight of waste/100m^2
- Volume of waste/£100k
- Weight of waste/£100k
- Percentage of segregated material waste
- Amount of material waste to landfill
- Amount of material diverted from landfill
- Percentage waste
- Net waste
- Tonnes/£m revenue

Recommendation

The most relevant metric is the net waste measured as the difference between the 'value of materials not incorporated in the construction works' and the 'value of additional recovered materials incorporated in the construction works or in off-site applications.'

If the intention is to eliminate waste entirely in the recognition that recycling and re-use have costs associated with them, this metric is directly relevant. At the same time, it can be used for particular types of materials, for particular elements of construction, for complete projects or across the whole company

Findings

Material Waste (cont.)

The following diagram shows the tools for waste management.

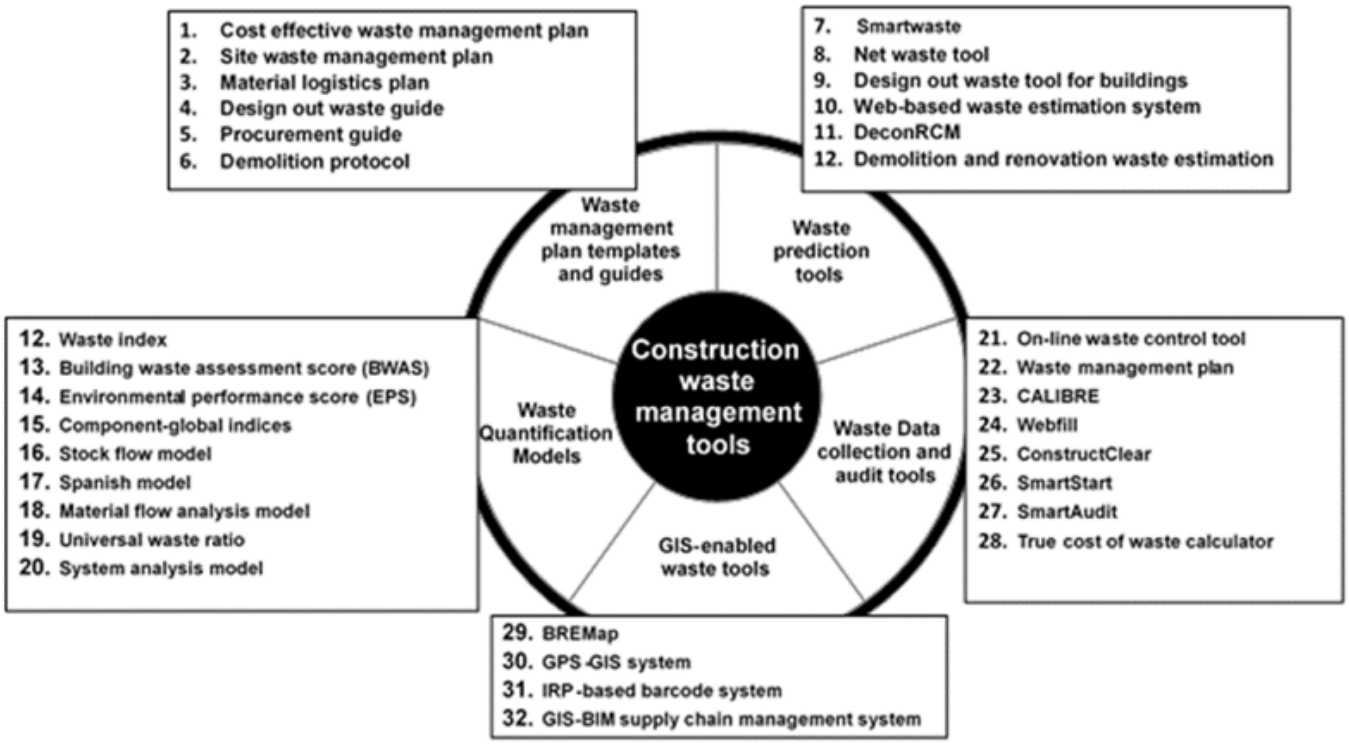
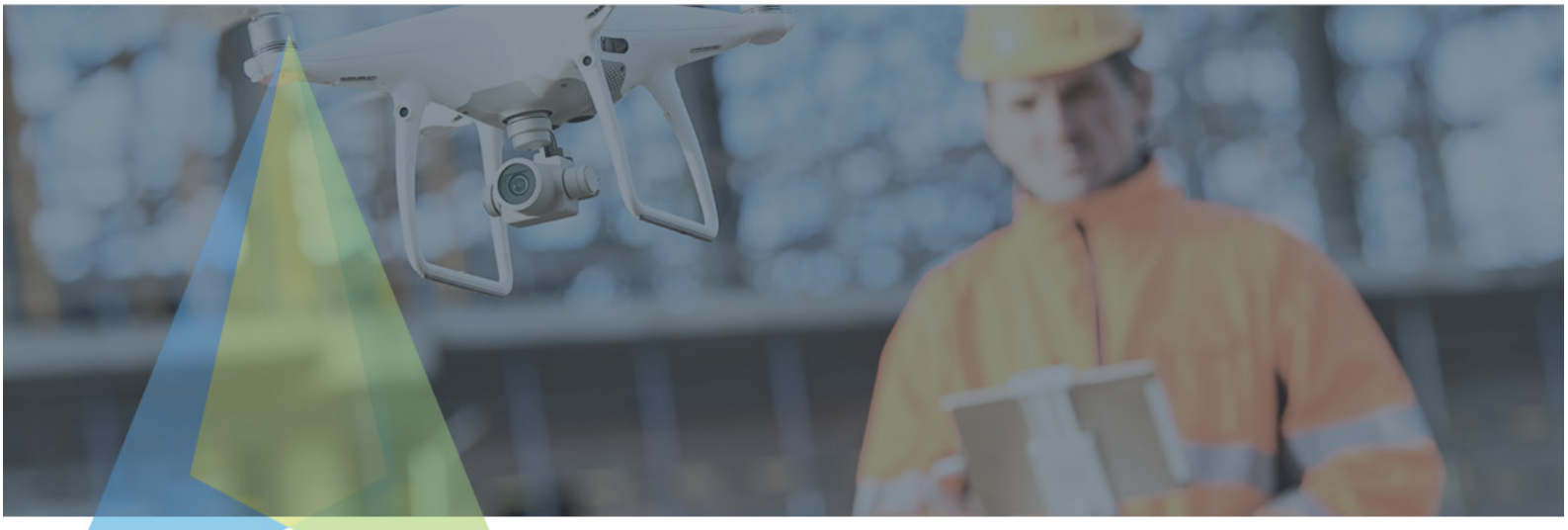


Figure 2. Graph showing the 32 tools for waste management identified by Akinade et al. (2016)[Error! Bookmark not defined.].



Conclusion

The literature review provides the AIMCH partners and wider industry with an understanding of the current landscape of productivity metrics and future trends. This enables them to gain a good understanding of key tools and techniques in all areas of monitoring.

The choice of productivity metrics is critically dependent on strategic objectives. Since different organisations have different objectives, it is unlikely that a single set of metrics will find ready acceptance. However, the report provides comprehensive evidence and recommendations on which to base productivity measurement decisions.

Ultimately, the research has provided AIMCH partners with vital data to inform decision making on current and emerging productivity measures as well as shaping future work packages, in particular on-site monitoring.

It also highlights potential improvements in construction performance through adopting modern methods of construction (MMC) and in particular offsite construction compared to traditional construction of houses i.e. brick and block.

Full report findings can be accessed here: https://www.aimch.co.uk/outputs/work-package-2-productivity-mapping-and-literature-review