SDAR* Journal of Sustainable Design & Applied Research

Volume 2 | Issue 1 Article 2

9-12-2014

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Recommended Citation

Conway, Colin j.; Keane, Colin; McCarthy, McCarthy; Ahern, Ciara; and Behan, Avril (2014) "Leveraging Lean in construction: A case study of a BIM-based HVAC manufacturing process," *SDAR* Journal of Sustainable Design & Applied Research*: Vol. 2: Iss. 1, Article 2.
doi:https://doi.org/10.21427/D75739
Available at: https://arrow.tudublin.ie/sdar/vol2/iss1/2

Leveraging Lean in construction: A case study of a BIM-based HVAC manufacturing process

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Abstract

The impetus towards efficiency in the AECO (Architecture, Engineering, Construction & Operations) sector is driving the implementation of Lean practices. BIM technologies and BIM processes provide methods by which this can be achieved. Major clients of building services contractors have begun to mandate the use of BIM and some are using BIM preparedness/experience as pre-tender qualification criteria. In this case study, an initial review has been conducted of the achievements of a major Irish M&E contractor in implementing BIM. The firm purpose-built a facility for the off-site manufacture of building services components. The operations of the plant are efficient and quality-assured through the use of an appropriately skilled workforce at all stages of manufacture, and tracking software that has developed as the knowledge of the contractor grew. Standardised processes have been developed which have resulted in greater efficiencies and lower costs for the contractor as a result of fewer requirements for onsite modifications (such as those caused by clashes), less waste, and greater flexibility. Despite some initial objections, the employees of the company are now more satisfied with their working conditions and are, as a result, more productive. Through investment in BIM-based, Lean processes, the contractor can now better compete when tenerding for large-scale projects in Ireland and worldwide, including the rapidly-increasing number where BIM experience and preparedness is mandated.

Glossary

AECO: Architecture, Engineering, Construction and Operations

Autodesk Navisworks: project review software that enables AEC professionals to "holistically review integrated models and data with stakeholders to gain better control over project outcomes. Integration, analysis, and communication tools help teams coordinate disciplines, resolve conflicts, and plan projects before construction or renovation begins." (Autodesk, 2014)

BIM: Building Information Modelling/Management

BIM4M2: BIM for Manufacturers and Manufacturing

BOM: Bill of Materials

CITA: Construction IT Alliance

Eida: Tracking software used to record and document the progress of spools from time of issue to installation

IFC: Issued for Construction (process specific) or Industry Foundation Classes

Tool: a set of connected components carrying out the function of routing a particular service through an area of a building

SAP: Systems, Applications & Products in Data Processing software for data warehousing

Spools: the subdivisions of service lines in manageable lengths varying from a single component to a 6m pipe-run

WBS: Work Breakdown Structure

https://arrow.tudublin.ie/sdar/vol2/iss1/2
DOI: https://doi.org/10.21427/D75739

1. Introduction

Large scale manufacturing facilities, due to the nature of operations and the processes undertaken, frequently require additional building services that might include ammonia, acid waste, solvent waste, helium and argon (Gulledge et al., 2014). Design, fabrication, installation and management of these services are complex operations. While the design of such systems has long been carried out digitally using CAD-based software, due to inconsistencies and uncertainties in the process (Eastman et al., 2011), onsite fabrication of services prior to installation is still necessitated. This is, by its nature, inefficient due to, *inter alia*, the influence of remote stock locations, clashes with other trades, weather, etc.

Building information modelling (BIM) is a relatively new process and set of software tools that has the potential to improve the current situation. BIM is a shared knowledge resource for information that can be defined as "a digital representation of physical and functional characteristics of a facility" (National BIM Standard, 2014). The advent of BIM-based design and build processes enables the use of off-site fabrication through the "creation of a single source of truth" for all parties (Saxon, 2013) where potential clashes between services are identified and resolved in the virtual model and not onsite where their occurrence is much more costly. This enables more efficient work practices that leverage BIM for speed, economy, quality control, and health and safety improvements (Saxon, 2013).

While perhaps best-known as assisting at the design stage of a project, the 2014 McGraw Hill Business Value of BIM report (McGraw Hill Construction, 2014) found that between 59% (UK) and 97% (Japan, Germany, France) of contractors who had adopted BIM practices reported a positive return on investment (ROI). The variation in success was dependent on the levels of overall adoption of BIM in individual markets. The report also recommends that throughout the developed world, for contractors to remain competitive, they must "embrace emerging uses for leveraging model data" among which are "simulation and analysis to optimise logistical planning and decision-making". Enabling contractors to benefit from BIM adoption is being facilitated by groups such as BIM for Manufacturers and Manufacturing UK (BIM4M2 Task Group, 2014), who focus on the standardisation of interfaces between BIM and existing systems and processes and, in Ireland, by the Construction Information Technology Alliance's Construction Technology Series, BIM-2-Win, and Smart Collaboration Challenge events (CITA, 2014).

Much of the pressure to adopt BIM processes is being applied by building owners because the improvements in operational processes and the associated costs achievable through BIM have the greatest potential for financial benefit (Azhar, 2011; Carmona and Irwin, 2007). In America, contractors who do not use BIM tools are no longer able to compete in tendering processes on even low-value contracts (AGC, 2010). This has changed from the situation in the mid-2000s when the use of BIM was recommended, rather than required, but with contractors who were not BIM-enabled having to add their services last during fit-out (AGC, 2006).

Thus, many owners and operators, for example Irish Water and the Grangegorman Development Agency, are requiring that the design and build of new and retrofitted facilities be implemented though BIM. The developers are required, as part of the final handover, to deliver a virtual building that is compatible with the PAS 1192-3

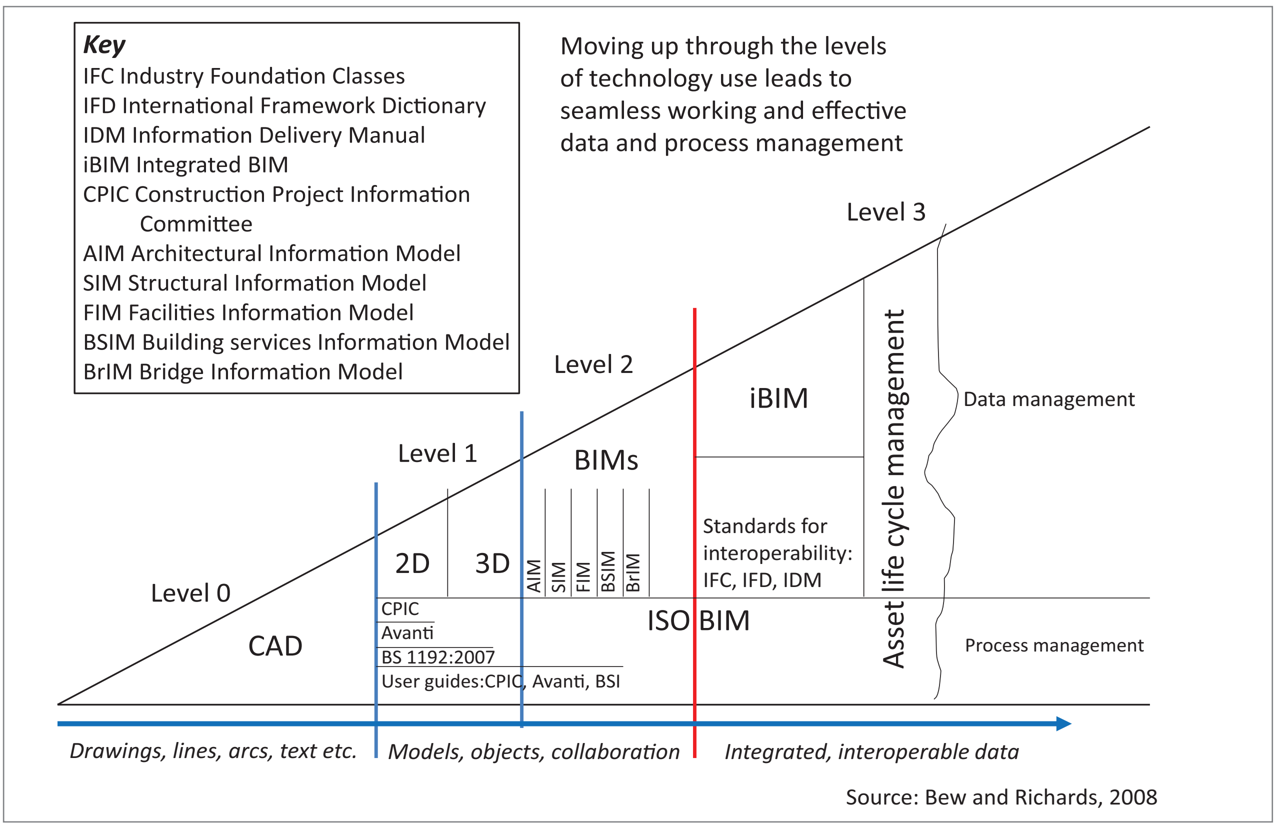

Figure 1: The Bew and Richards BIM Maturity Levels Model (Bew and Richards, 2008)

Standard for Information Modelling for the Operational Phase of Assets (British Standards Institute, 2014). BIM for asset and facilities management is sometimes called 6D or 7D BIM and PAS 1192-3 is facilitating a move towards the "integrated interoperable data" and "asset life cycle management" defined by Bew & Richards (2008) as Level 3 BIM Maturity. Major component fabrication plants are among the types of facility seeking operational BIM compatibility upon completion of building and retrofit works.

Thus an Irish-based mechanical and electrical contracting firm has developed an off-site HVAC manufacturing facility to support the implementation of BIM-based processes. This paper describes the manufacturing facility, its associated work practices, and the initial impacts of implementing this new method. The optimisation and streamlining of the processes resulting from lessons learned on two major building servicing campaigns are detailed in Section 2. Section 3 examines the impact of BIM-based practices on the staff and the necessity of staff "buy-in" to enable the realisation of new work processes from the ground up. Section 3 also evaluates the associated business benefits and Section 4 discusses the potential of BIM-enabled off-site manufacture for the mechanical and electrical building services sector.

2 The Process

In this case study, the contractor's aim is to provide a "right-first-time" service where delivery to and installation on site is timely and defect-free. The workshop process discussed in detail in the following requires that all elements of design and reworking are completed prior to issuing fabrication information from site to the manufacturing facility. Thus, at the client's site in the BIM control and modelling facility, the designs, which include pipework, valves, meters, flanges, bends, welds, etc, are iteratively reviewed while being modelled in connection with existing on-site components (e.g. to main lines known as laterals). These components were measured via high-end surveying and laser scanning techniques. The BIM-based modelling process also leverages the abilities of the associated software, in this case Autodesk's Navisworks, to carry out clash detection between all planned installations.

Although the work in the assembly line of the fabrication facility only begins when the design is finished at Day 28, an "early detailing start point" occurs just after the kick-off meeting in order to facilitate the take-off of materials and long lead-in components. Even before the 45-day process begins in relation to the fabrication of any tool, there is a 60-day period in which all long-lead components are procured. These components are specialist items that would not be stored in general stock and without this 60-day period delays would be unavoidable. Fabrication of all tools is limited to four weeks but, as the number of tools under fabrication at any time can vary, there is a fluctuation in the workload for the workshop over time.

Once the on-site design review is completed, each service line is split into "spools", examples of which are shown in Figure 3 in modelled form, during manufacture, and ready for transfer to site. Spools can range from a single component to a 6m pipe-run. To avoid cutting and welding on-site, the selection of splitting points for spools is crucial because if the spools are too large it may not be possible to install them on site. By contrast, if the spools are too small, on-site installation work will require more effort than necessary. The service requirements for the manufacturing "tools" are numerous. In this case study an average of 168 spools and over 1000 components were used per tool totalling 67,200 spools and 400,000 components for a single facility.

A number of key components and software functions are required in order to facilitate the BIM manufacturing process:

a. Isometrics: all fabrication takes place using 2D isometric drawings generated directly from the 3D model as shown in Figure 4. This is an automated function and represents another advantage of using BIM software. Where an issue of interpretation arises with the isometrics, a supervisor can access the 3D model in Navisworks. However, this is not part of

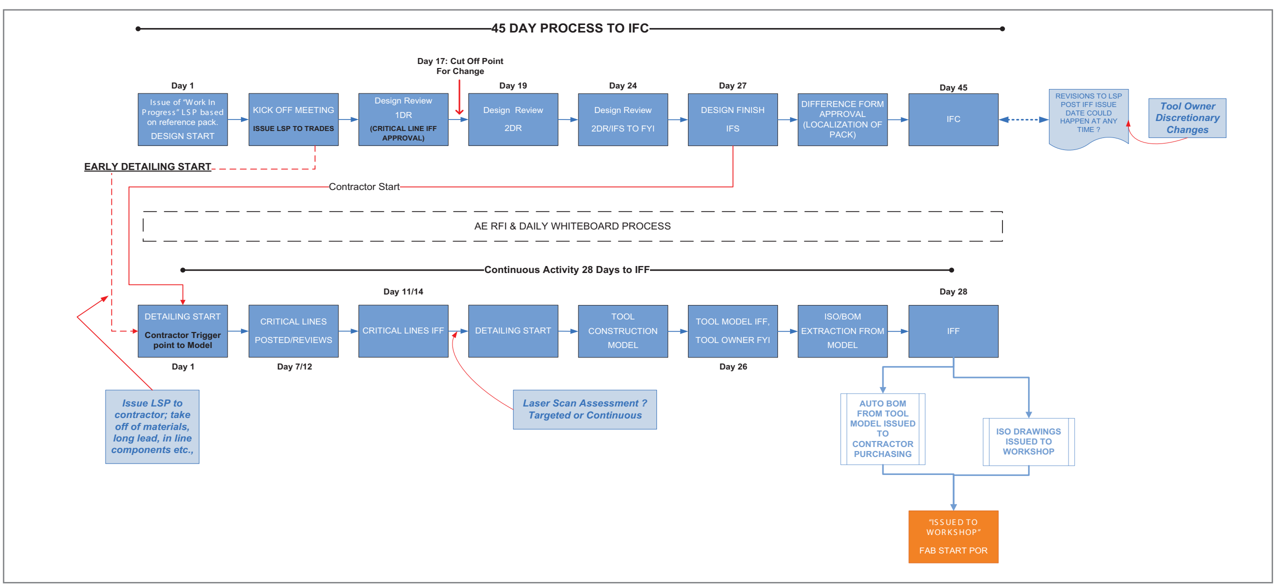

Figure 2: 45-Day Process to IFC (Issued for Construction)

DOI: https://doi.org/10.21427/D75739

the standard process and most staff are not trained in the use of the software;

b. SAP software: used for stock management to ensure that all required components are available prior to the beginning of the manufacturing process;

c. Eida software: used for tracking the manufacturing progress of all spools.

Figure 3: Various components in modelled form (a), during manufacture (b) and ready for transfer to site (c).

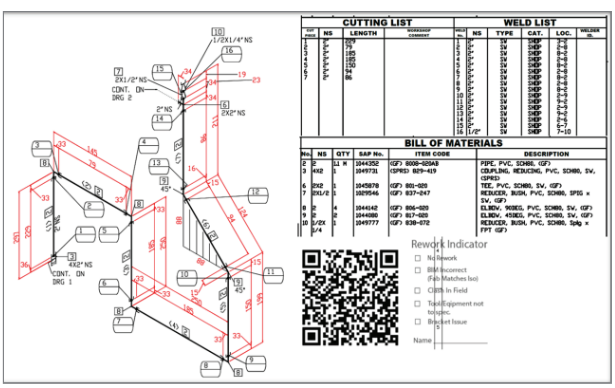

Figure 4: An example isometric drawing showing a single spool, its associated Bill of Materials, the QR code used for scanning and populating Eida, and the Rework Indicator, in case of errors at point of installation.

Figure 4 illustrates an isometric drawing of a spool manufactured from 2″ PVC and designed to carry acid waste water. Isometric drawings, including all of the annotations, can be extracted automatically from the 3D model provided that the model has been developed at a sufficient level of detail. No separate redrawing is required. Under the cutting list section, the lengths of the seven pipe sections are shown in millimetres. This allows cutting to commence immediately as part of the processing steps set out below. This is a direct improvement on site work where the length of each pipe must be determined on the basis of installation conditions before being cut. The isometric also includes the following information:

- Bill of materials (BOM) providing information on each component such as 90° and 45° elbows, reducers and tees;
- Unique identifying and traceable scan code (QR code), tracked by the staff using iPad minis which send live updates to the Eida tracking software;
- Date and time of receipt;
- *Rework Indicator*, completed on-site in case of failure.

The QA, recording and actions that form part of the workshop process are detailed in Figure 5 which follows on from Day 28 of the 45-day process presented in Figure 2.

1. Isometric drawings of all spools and a bill of materials (BOM) are issued to the workshop;

2. The BOM is cross-referenced with the previous list of long-lead items as a QA procedure before the tool is recorded into the

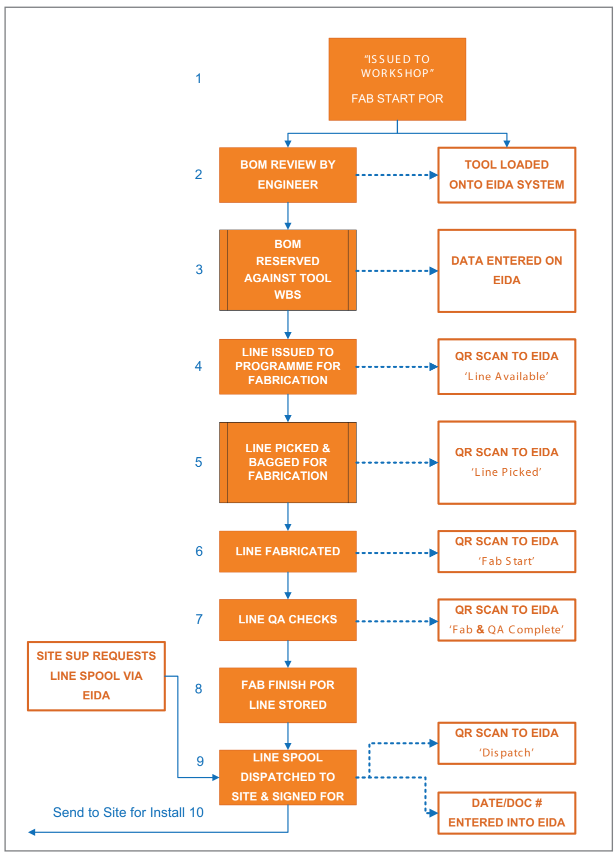

Figure 5: Numbered workshop process at manufacturing facility

stock management software. The requirements for the tool are compared to what is already in stock and what has already been ordered. The software then lists the required elements for completion of the tool. The goal is to finish fabrication with as little left-over stock as possible, thus creating a lean process.

The information for every spool is sent to Eida, which produces .pdf files containing a unique QR (Quick Response) code for each spool. This QR code is used to track the progress of the spool during fabrication, delivery, and installation;

3. The BOM is then reserved against the tool's WBS (Work Breakdown Structure code) and the date is entered onto Eida under the "material reserved" column. As shown in Figure 6, components that are in stock become reserved specifically for an individual tool facilitating the tracking of costs;

4. The next step is another QA procedure. All isometric drawings are reviewed by engineers to check for constructability, corruptions, omissions, etc. Once the isometric is approved by the engineer, the QR code is scanned and the "Line Available" column in Figure 6 is populated. At this point some spools may be identified and prioritised as more urgent than others;

5. A general operative (GO) collects and bags all items for a spool. This part of the process means that skilled tradespeople do not waste valuable time collecting items for fabrication. An engineering technician or experienced GO checks the bag before it is scanned to make sure all items are correct. Once the bag has been scanned, the "Line Picked" column in Figure 6 is populated and the bag is placed on a shelf ready for fabrication;

6. An engineering craftsperson selects a bag from the shelf and scans it, thus populating the "Fab Start" column. Fabrication takes place at a workstation where all tools are readily available and where each worker has plenty of workspace (Figure 3(b)). Once the spool is complete and the event scanned, it is passed to another table where all spools are QA checked;

7. At this point the spools are checked for accuracy of length, angles, joints, welds, etc. If any problems are identified the spool is returned to the technician. If the spool passes QA, the QR code is scanned and the "Fab & QA Complete" column in Figure 6 is populated;

8. The completed spool is "bagged and tagged" and placed in storage for up to a month, depending on when it is needed on site;

9. The foremen on site can order spools to be delivered once the "Fab & QA Complete" step (8) has finished. They can log into Eida and select the spools which they require and enter the desired delivery date. This step fills in the "Load Plan Request" column in Figure 6. Due to the in-house logistics involved in loading trolleys with spools for delivery, a 48-hour turnaround between order and delivery is the norm, except for urgent requirements. The foreman decides the order in which the spools should be installed and how many he wants delivered each day. The goal on site is to install spools on the day they arrive, thereby reducing the storage requirements by the contractor on the client's site;

10. The spools are scanned when they are dispatched and again when delivered on site as proof of delivery;

Each isometric drawing has a *Rework Indicator* checklist which is populated during installation on the rare occasions when a spool is incorrect. This step provides feedback as to the source of the problem. Issues can result from fabrication, tools not meeting with specification, or bracket issues. Using traditional processes clashes with other new or existing services frequently but the ability to carry out clash detection in the virtual world of the BIM software practically eliminates that problem. Issues of this nature only occur if the As-Built model used during design is different to the As-Built conditions at the time of delivery.

Using the *Rework Indicator* checklist the source of any problem can be identified and operational improvement can be promptly achieved; thus enhancing the leanness of the process.

3 The Impact of New Processes

The significant changes in the day-to-day operations of the M&E contractor achieved through BIM-based, Lean processes has resulted in improvements in relation to financial returns and employee satisfaction. However, there was a steep learning curve for all concerned and this caused more problems for some employees than others. This impact will now be evaluated from both a business point-of-view and in relation to the human and behavioural aspects.

Spool Progress

		System No.	FAB Start Date	FAB Finish Date	No Of Spools	Fab & QA Complete	% Fab & QA Complete	% Earned	Balance	Requested	Delivered	Pending Delivery
		Tool X										
1	–	Tool X	22/07/2014	19/08/2014	185	185	100	89.14	0	179	184	1

	Isometric No.	Sheet No.	Rev. No.	Spoo #	Status	Material Reserved	Line Available	Line Picked	SAP goods issue	Fab Start	Fab & QA Complete	Load Plan Request	Despatch	Delivery
1	Line B	1/1	0	1	LIVE	15/09/2014	15/09/2014	15/09/2014		15/09/2014	15/09/2014	18/09/2014	15/09/2014	16/09/201
2	Line C (SP-001)	1/1	1	1	LIVE	13/08/2014	13/08/2014	16/08/2014		16/08/2014	16/08/2014	03/10/2014	02/10/2014	02/10/201
3	Line C (SP-002)	1/2	1	1	LIVE	13/08/2014	13/08/2014	20/08/2014		20/08/2014	20/08/2014	03/10/2014	02/10/2014	02/10/201
4	Line D	2/2	1	1	LIVE	13/08/2014	13/08/2014	20/08/2014		20/08/2014	20/08/2014	03/10/2014	02/10/2014	02/10/201
5	Line E	1/1	0	1	LIVE	24/07/2014	24/07/2014	07/08/2014		07/08/2014	07/08/2014	04/09/2014	02/09/2014	03/09/201
6	Line F	1/1	0	1	LIVE	24/07/2014	24/07/2014	07/08/2014		07/08/2014	07/08/2014	04/09/2014	02/09/2014	03/09/201
7	Line G	1/1	0	1	LIVE	24/07/2014	24/07/2014	07/08/2014		07/08/2014	07/08/2014	04/09/2014	02/09/2014	03/09/201
8	Line H	1/1	0	1	LIVE	24/07/2014	24/07/2014	07/08/2014		07/08/2014	07/08/2014	04/09/2014	02/09/2014	03/09/201
9	Line J	1/1	0	1	LIVE	24/07/2014	24/07/2014	07/08/2014		07/08/2014	07/08/2014	04/09/2014	02/09/2014	03/09/201
10	Line K	1/1	0	1	LIVE	24/07/2014	24/07/2014	07/08/2014		07/08/2014	07/08/2014	04/09/2014	02/09/2014	03/09/201

Figure 6: Progress of the fabrication of individual spools from reservation of materials (Material Reserved) to delivery to site based on Isometric Number via Eida software.

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DOI: https://doi.org/10.21427/D75739

3.1 Business Appraisal

The Eida tracking system that is central to the fabrication process provides a level of traceability previously impossible for the contractor. When first used the software did not have all of the functions currently available but the M&E contractor's engineers, in conjunction with the developer of the software, customised and developed it to optimise the solution and to ensure that it supported rather than hindered the workflow.

Among other items, the software records who fabricated and QA checked each spool, and how many spools each employee fabricated daily. If a problem arises on site in relation to a faulty element, the system can reveal the identity of the fabricator and the checker. This acts as an incentive to improve the quality of each individual's work. It also ensures that staff maintain comparable levels of productivity and enables management to identify areas in the pipeline where problems may be occurring and/or personnel changes (including increases and decreases in numbers carrying out particular tasks) may be required. The data recorded on a perpetual basis facilitates the continuous improvement of the fabrication workflow and associated inputs and outputs. It also supports more accurate cost estimation, thus impacting on operational costs.

Although there are still some occurrences of failures that require reworking, as indicated by the fields on the Isometrics (Figure 4), the amount is significantly lower than would have occurred using traditional practices. During one month this year, 1311 spools were dispatched with only 26 spools needing to be remade. However, 24 of these spools were required only because they were lost on site while the other two had been incorrectly fabricated. Therefore, less than 0.2% of spools required reworking as a result of failures in the fabrication process. It should also be noted that, despite protocols that discourage the practice, minor issues related to fabrication may have been fixed on site because installation engineers chose to carry out necessary works rather than return the spools to the workshop. No statistics on these occurrences are available.

Some additional costs have been incurred by the contractor, for example, parts are now stored in 40-foot containers external to the main building. Most containers hold a specific pipe type: high purity, low purity, PVC etc. while a quarantine store is used to prevent parts that do not belong in any other store causing mix ups. Despite this additional requirement, materials in these stores are now retained for shorter periods as a result of the just-in-time process meaning that overall efficiency has improved.

3.2 Human and Behavioural Aspects

The new process has had a profound impact on the work practices of individuals and the contractor's workforce as a collective. Prior to implementation of BIM-based Lean processes, tradespeople were involved in many trivial tasks in relation to the acquisition and maintenance of components and tools. Skilled workers can now focus solely on fabrication because they work at secure, well-equipped benches in a purpose-built facility where the components required for each fabrication task are delivered in a Quality Assured state.

The workshop environment is very different to the traditional onsite conditions known to most tradespeople. Those fabricating the spools simply select a bag containing all the required parts and immediately work on it at a bench where all tools and power are available. When stopping for breaks, tools and equipment can be left unattended without fear of theft. Canteens and toilets are of a standard expected in offices. Workshop conditions are quieter and more comfortable. Hard hats are replaced with bump caps which are lightweight and comfortable.

Upskilling is also encouraged where staff rotate between functions to learn new skills. This has the dual benefit of motivating staff and allowing management to re-allocate staff as necessary, depending on requirements at different times during a project.

The tracking aspect of the process, which is considered a major positive from the business perspective, was initially considered to be very invasive by some of the workers. Some fabricators thought that the new processes undervalued their skills by requiring so much QA and adherence to stringent practices. However, after a short period these methods became embedded and accepted.

During the early stages of implementation of the process, a point of failure was identified in the ordering of spools by the site foremen over the phone. Each spool has a unique code but these were often miscommunicated via this process resulting in the wrong spools being delivered to site. This created delays on site until the correct spool arrived, necessitated extra delivery runs, and served to undermine the entire operation by reducing confidence in the system, particularly among the onsite installers. Management responded quickly by implementing an online spool selection mechanism which the site foremen can access from anywhere and this has significantly reduced these errors and resulted in a corresponding increase in confidence in the system.

Anecdotal evidence suggests that tradespeople at the fabrication facility preferred the new conditions over site work. This favourable response has allowed the contractor to attract and retain the most skilled tradespeople available on the market.

The contractor reports a significant increase in efficiency through the use of Lean processes when compared with a traditional installation. Metrics on the value of this increase will be evaluated in the future. The current evidence enables the firm to tender more competitively for new work thus providing increased stability of employment for its workforce.

4. Conclusions and Future Developments

The case study presented here demonstrates the results of applying BIM on a large scale in the M&E manufacturing context for the first time in Ireland. It has shown that innovation and streamlining of the process can be achieved, particularly through working closely with software developers and valuing your workforce.

The introduction of a BIM-based process has enabled this M&E contractor to apply and benefit from the principles of Lean Construction including:

- Elimination of waste;

- Clear identification of the elements of operation that deliver what the customer values, i.e. the value stream, and eliminates all non-value-adding steps;
- Not making anything before it is needed and then making it quickly;
- Striving to achieve perfection by continuously monitoring and improving performance (Lean Sigma 60, 2014).

The Eida tracking system that has been developed and implemented in support of the process agrees with the Association of General Contractors of America's assertion that "any well-planned and well-executed BIM project should necessarily include procedures and protocols for creating a detailed audit trail" (AGC, 2006, p. 38).

Continually reviewing operations and processes with a view to achieving improvement has become embedded within the firm's psyche. At present, for example, the laser scanning and BIM modelling portions of the workflow are under examination as part of a Construction IT Alliance (CITA) technology challenge.

As a result of this project, the firm has built a uniquely-skilled team, experienced in the production and installation of components using the Lean BIM process that was developed and improved by the company. It is envisaged that these factors will enable the contractor to be successful in tendering for, and engaging in future large-scale projects within and outside Ireland, both where BIM competence is a criterion for pre-qualification to tender (SEC GROUP, 2012) and where BIM-based Lean processes provide an advantage over competitors who have not engaged in similar upskilling. This may also result in a significant shift in operational methods for a large number of other contractors who will need to adopt leaner processes in order to compete in the new BIM-focussed market.

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