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Established in 1977, Ardmac is an international construction specialist delivering complex and high-value workspaces and technical environments. Headquartered in Dublin, with offices in Manchester, Craigavon, Brussels, Cork, and Switzerland, Ardmac is supporting projects all over Ireland, the UK, Denmark, Belgium, the Netherlands, Switzerland, and have this year announced their expansion into Finland and Germany. Ardmac employs over 350 people and are a leading global provider of cleanrooms, data centres, fit-out and refurbishment, and modular solutions.

At Ardmac, we work Smart, meaning we deploy innovative technology throughout our business to empower our people, drive performance, and delight our customers. We believe in setting new standards for our industry and driving innovation, we believe in tailoring solutions to our clients' evolving needs, and in working hard to harness our unrivalled knowledge to deliver safety first and excellence as standard across award-winning projects.

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Overview & Background to the Lean Initiative

The successful construction of complex technical environments for the data centre industry involves the carefully sequenced integration of multiple building components. To aid this process, modern digital construction techniques within the data centre construction sector require the use of BIM to integrate and coordinate components in a 3D virtual environment ahead of construction. The process of coordination through unique digital replicas of the building has become an established industry norm. As a consequence of the proven benefits to cost and schedule certainty, clients or end-users of the building expect a high standard of BIM from their specialist supply chain partners as standard.

Although the use of BIM is an established practice, the level of detail

and accuracy required to leverage the benefits of BIM at a pre-construction stage vary from project to project, and, furthermore, from component to component. Equally, reliance on competent specialist fire-stopping has become increasingly important to clients for the safety of personnel and the protection of assets. Herein lies the challenge for providers of specialist interior architectural partitions, and inter-dependent service providers needing to pass piping, ducting, cable-trays, and other sector-specific building components through the partitions from one internal space to another. This case study describes how a Lean initiative developed and utilised by Ardmac leverages a technology-based process to apply an innovative digital construction process, namely "Service Penetration Management".

Lean Initiative Undertaken – Lean Thinking, Tools, Techniques

Challenges in Service Integration

Where services interface with or pass through internal partitions, a tertiary construction element is created and upon which multiple stakeholders depend. This interdependency is represented in model form by a penetration in a partition, allowing services to pass from room to room clash-free. The sum total of penetrations can be costly to clients, with varying commercial impacts based on quantity, size, height above floor level, location, and type. Often, the true cost of the penetrations is unclear and can remain largely undefined until well into the construction programme. Additionally, service penetrations require specific and often expensive firestopping materials to maintain the integrity of fire rated partitions and to conform with building standards. However, at the time Ardmac developed the Service Penetration Management Process, there did not exist any one end-to-end dedicated sectoral standard or defined BIM process for the modelling and management of service penetrations. The existing standard management procedure for this element of works was limited in most cases.

Figure 1. Example of Complex Service & Partition Integration within BIM Model

Typically, service providers identify physical openings through marking and cutting openings through in-situ marking and cutting, sometimes in error or out of sequence, and at scales or locations that can impact schedule and cost. This unstructured format is untraceable as the openings are not recorded as individual elements and therefore do not leverage the potential Lean Construction benefits made possible through BIM. Without an established BEP (BIM Execution Plan) to define the processual sequence of works required for interdependent contractors to model and track openings, clients do not have full visibility of the quantity, potential cost, or impact on the construction schedule, thus elevating the project's overall risk profile. Furthermore, without adequate modelling of openings through an established, controlled, and agreed process, the openings marked or cut in error are typically unidentifiable from those which are genuinely required. As a consequence, clients do not have visibility of what they should or, arguably, should not be paying for. For contractors, the risks are equally high as seeking commercial recovery for untraceable service openings within the partitions is difficult and more likely to become a source of conflict.

BIM Execution Plan & Best Practice

Ardmac's BIM-led Service Penetration Management Process is fully coordinated from modelling through to site install, giving our clients full visibility of project progress through the use of a tailored BEP, software, and live progress tracking to keep all stakeholders informed on project coordination and commercial outcome.

The ECI (Early Contractor Engagement) stage of the programme is utilised in this case to insert Ardmac's tailored BEP as a supplementary guide for service providers and the project BIM team. The step-by-step process outlines the most efficient and impactful methods for identifying service penetration locations, generating penetration models with unique identifiers and freezing penetration models before construction commences.

The model freeze is a key milestone in the BEP and creates the opportunity to evaluate the impacts of the penetrations on the structural stability and passive fire protection required at each interface. Where the structural stability of partitions may be compromised due to large openings, or where clusters of openings occur, identifying long-lead, high-risk elements such as secondary support steel becomes possible at a much earlier stage in the programme. A bespoke master tracker tool provides instant feedback to the site teams, clearly identifying the quantity, locations, sizes, and types of openings. In turn, this sequence of works forms the basis of the interlinked fire-stopping register handed over to clients at project completion stage. The master tracker can forecast the true extent of the works to be carried out in a particular area of the building ahead of commencement dates, feeding directly into the weekly work plans and project production plans. From a safety perspective, the frozen models create an opportunity for the site safety teams to review and understand the extent of works to be carried out at height ahead of time, and sequence the works in a way that reduces constraints.

Using BIM, and a plug-in software for Autodesk Revit, all openings can be auto-formed around services penetrating partition models.

Openings are formed as per recommended sizing and deflection limits. Opening information is inputted using the naming conventions outlined with the BIM Execution Plan. All trade contractors have the ability to move and change the size of openings up until the builders' work freeze date. Following the freeze date, Ardmac can consult with relevant supply chain partners, including partition panel manufacturers and the fire-stopping material suppliers, for review and comment. Should comments be received, requests for openings to be adjusted to comply with the structural and fire integrity of the wall are addressed and models are updated where necessary. Once the review process is completed, the openings become frozen within the federated model. Builders Work Elevations for the frozen area will be issued to all project teams, and any change or additional penetrations can be communicated through the Service Penetrations Change Process, thus creating a level of flexibility to account for error or change.
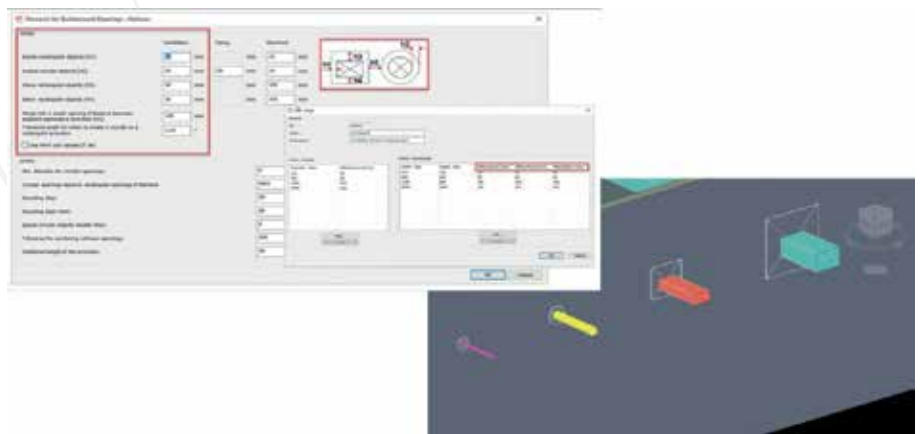
Figure 2. BIM Software Parameter Input Creates Auto-generated Service Penetrations within the Partition Models when Interfacing with Services

**Figure 3.** Example Partition Elevation showing Service Penetrations with Unique ID Tags

Certified Fire-Stopping

Ardmac is certified, based on a stringent evaluation program, as a Competent Fire-stopping Contractor with UL® who are widely recognised as leading experts in the testing, inspection, and certification of building materials as well as fire-stopping contractors. This gives clients and building owners confidence knowing that our installation processes have been reviewed and management

system certified through passing of UL Fire-stopping Examinations, maintenance of a prescribed 10-element management system evaluated through an annual audit, and the designation of a DRI (Direct Responsible Individual) within the organisation.

In line with operational quality plans, the Service Penetration Management Process results in a detailed combined system of records for fire-stopping including a register, location plans, details, product data sheets, and installation records. The BEP has been created to manage and track service openings through reliable real-time, reportable data, giving clarity on detailed costs and reduced risks for all stakeholders. As each of the penetrations is modelled and given a unique ID reference within the model, the tracking and commissioning of the building fabric becomes much clearer from a passive fire-stopping perspective. Coupled with competent installation of the fire-stopping systems in line with manufacturer's recommendations and project

specification, dedicated install teams carry out and record their works in line with competent fire-stopping contractor guidelines under the supervision of quality inspection plans and guidance from a fire-stopping DRI.
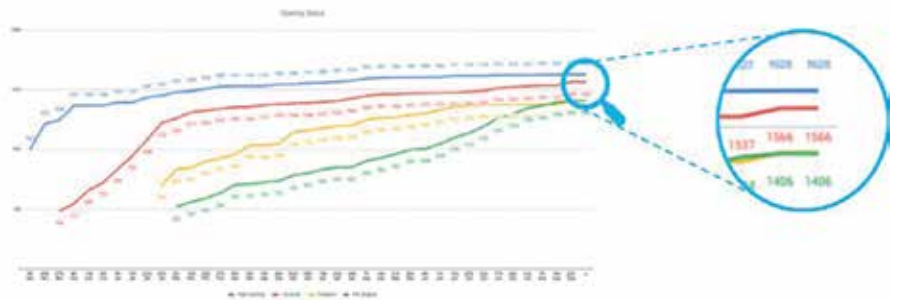
Figure 4. Live Tracker Extracts Model Data to Monitor Quantity & Status of Service Penetrations under each Service Provider along the Project Timeline
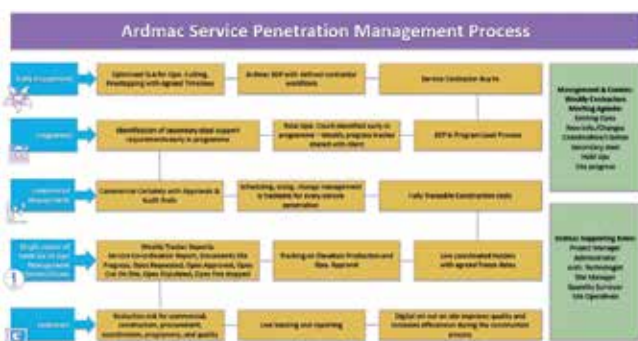
Lean Initiative Improvements & Impact

Managing labour can present significant challenges when applied to more complex non-sequential construction programmes. The Ardmac Service Penetration Management Process defines the critical path for the formation of service penetrations within partition systems and informs the LPS, thus creating opportunity to effectively sequence and track productivity against targets and timelines. This reduces the risk of production area revisits and out of sequence works when compared to more traditional service integration, and it delivers excellent results by linking multiple platforms together through custom built integrations, thus achieving even greater benefits for safety, quality, and cost certainty.

Given that the model and supporting data is accessible through mobile technology on tablets, site management can devote time to site-based activities and communicate with the tracking system through the FMS (Field Management Software) and live tracker rather than physically moving between the production area and site office to communicate issues with coordinators. An FMS introduced on all Ardmac projects in February 2019 provides a central cloud-based platform to share and manage project information. The in-built inspection, quality, and safety management aspects of the platform enables the completion of inspections, audits, and reporting using any mobile device. Project performance data captured in real time gives insight into the progress and proactive problem solving rather than reflective analysis.

In summary, the coordination and management of service penetrations within the internal partitions is a sectoral issue creating challenges for contractors and clients. Resolving this issue through the application of a robust, well-defined, and controlled BIM process introduces value to projects as a unique service offering with value generation potential for multiple interdependent stakeholders. Where the Service Penetration Management Strategy is applied as an agreed processual BIM approach to managing and tracking service openings, it results in reliable quantitative and reportable data, clarity can be given on detailed costs, and it reduces risks for all stakeholders. It has been observed on large-scale data centre projects that application of the process results in leaner outcomes, including over 50% reduction in site production hours required to mobilise, mark, and cut service penetrations throughout the construction phase.

Following initial project implementation in 2019, customer insight interviews have been carried out with key collaborators from amongst client teams. Resulting data has allowed further exploration into the performance of the initiative, and offers insight into how the Service Penetrations Management Process can contribute to value generation for multiple stakeholders. Interviews reveal the initiative as processual in nature, combining several established Lean tools and practices such as BIM, productivity tracking, and LPS, along with other digital communication tools, FMS, and software. It has been described by clients as "the most effective service penetration management strategy seen to date". It is Ardmac's goal, as an early adopter, to contribute to the Lean performance of the sector and to promote the likely eventual wider adoption of this approach to Service Penetration Management.

Figure 5. Service Penetration Management Process Map

Effective implementation of the initiative presents some challenges that must be overcome if Service Penetration Management is to be effective on complex construction projects. The collaborative nature of the process and the reliance on multiple contractors to each contribute to the defined workflow means that a collaborative ECI period must be leveraged. Stakeholder buy-in, with a desire to understand roles and responsibilities in line with the published BEP, is essential to the success of the process and a positive outcome. When

combined with other digital technologies to streamline workflow and improve productivity, the Service Penetration Management Process aligns with Lean Construction Principles and the Building SMART initiative underpinning Ardmac's approach.

Deploying Innovative Technology throughout Ardmac to Empower our People, Drive Performance, and Delight our Customers

We place our customer at the centre and apply Lean Construction principles and technology to everything we do at Ardmac. Our goal is to maximise value for our customers, allowing access to project information and performance in real time on any mobile device. These digital processes not only improve efficiencies for Ardmac, but also for our customers. They enable us to deliver projects faster whilst enhancing safety and quality. Working Smart allows

us to consistently deliver excellence across multiple sectors and geographic regions. Technology has the power to drastically change the face of the construction sector, and Ardmac is committed to staying ahead of the curve.

Figure 6. Building SMART