Inspiring Great British Manufacturing

Report title: IUK Rain Screen Cladding removal and replacement. Discovery process presentation of final report.

Prepared for: Ministry of Housing, Communities and Local Government (MHCLG)

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Date: 19th July 2018.

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Contents

The Project

Project Brief

Project – The MTC were approached to review the use of manufacturing optimisation tools to ascertain bottlenecks, and areas for investment, to determine whether it was possible to increase the rate of removal and replacement of external cladding envelopes from high-rise buildings by adopting technology and practices commonplace in manufacturing industries.

Aims – Through various packages of work we hope to identify technology, processes and tools that can be implemented, modified or removed to increase the efficiency of replacement.

Output – By delivering a review of current processes and identifying bottlenecks and delays, The MTC would propose implementation of changes to the way of working, and delivery of new tools to increase efficiency of work. A cultural shift, in appropriate use of technology, within the construction sector will reap benefits across the board and contribute to future projects.

The Project

Work Package 1

Work Package 1 – Cladding Removal & Replacement Discovery Project

- To provide concepts and identify discrete projects and/or processes for the purpose of improving and accelerating cladding removal and replacement.
  - The primary focus was with respect to increased efficiency, with consideration of safety, cost and quality. It was considered advantageous if this could be achieved within a timescale that would yield a positive Return on Investment (ROI) for which the indicative target was within 4 years.
  - It should be noted in the context of this project, ROI is not purely financial, it also includes shortening of the total duration for completion of remedial work.

The Project

Work Package 2

Work Package 2 – **Discrete Event Simulation (DES) Model for Multi-Building Cladding Removal**

- To develop a DES model to simulate the removal and replacement of cladding (including both the planning and construction phases) for multiple buildings across the country. The model will predict the estimated completion rate of buildings as well as the overall completion time.
  - DES provides both the ability to simulate resource constraints and to stochastically represent uncertainty.

The Project

Work Package 3

Work Package 3 –Non-Destructive Inspection of Hidden Cladding Materials

- To investigate the feasibility of developing a process for detecting the presence of hidden cladding materials within the cladding envelope of high-rise buildings, without the need to remove the external layers of cladding.
  - The current inspection technique is to remove the outer layer of the cladding, typically destructively, to investigate the hidden materials. If such a process can be developed, then it is no longer necessary to remove cladding that conforms to specifications and reduces wasted time.

WP1 – Cladding Removal and Replacement Discovery Project

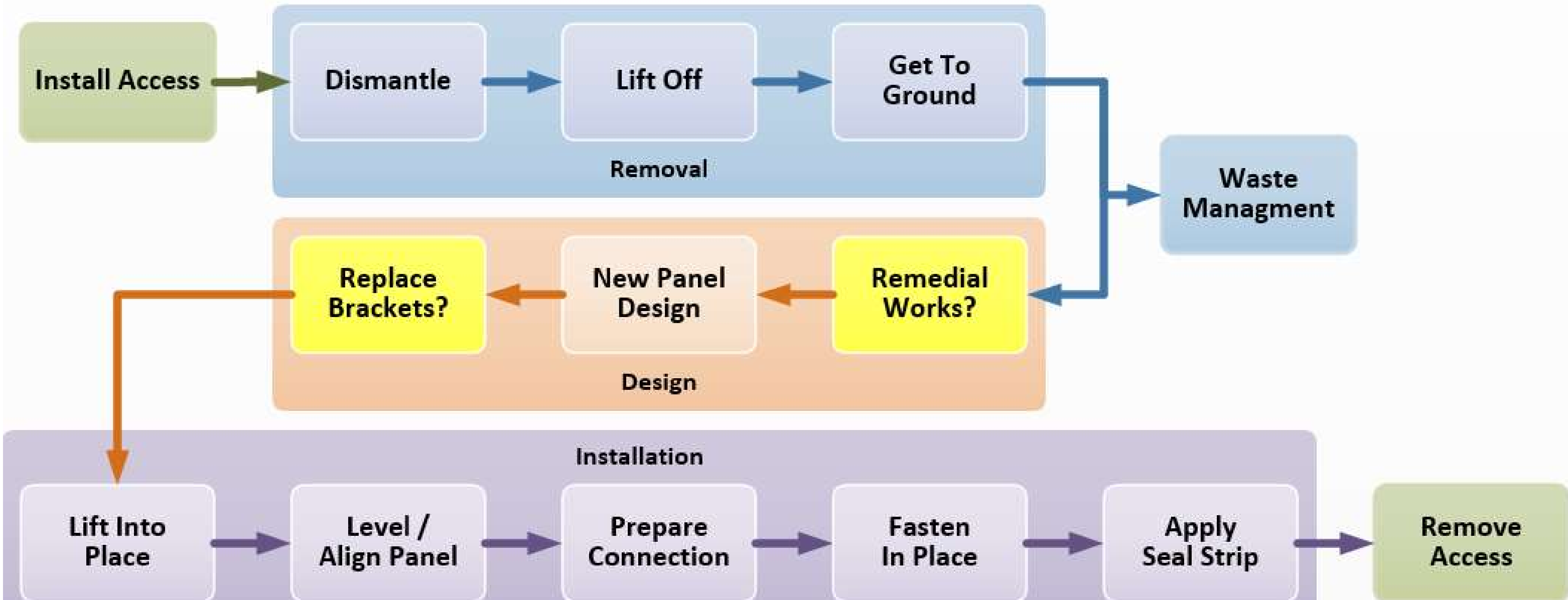
Summary

- WP1 follows the MTC's discovery process methodology for the purpose of capturing and baselining the existing current state. The intention is to provide concepts and identify discrete projects and/or processes for the purpose of improving and accelerating cladding removal and replacement.
- The MTC identified potential areas of improvement that could be adopted to directly improve the physical process of cladding removal and replacement at a local level, including but not limited to, panel handling, waste management, and automatic feed of fixings during installation.
  - The MTC has proposed eight minor changes to the existing current state process for cladding removal and replacement
- The MTC identified a future state of cladding removal and replacement based upon feedback from those in the industry and the typical challenges that have been observed.
  - The MTC has proposed an outline for a future state process for removal and replacement of cladding systems

WP1 – Cladding Removal and Replacement Discovery Project

Cladding Process Flow

A process flow of the detailed cladding removal and replacement process.



WP1 – Cladding Removal and Replacement Discovery Project

Manufacturing Technology Centre

Manufacturing Readiness Level (MRL)

			Research			'Valley of death'			Commercialisation			
		MRL pre-work	MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
MRL stages *3		Technology idea, unproven concept transitioning to applied scientific research and then to technology formulation.	Basic manufacturing implications identified. Technology applied research and proof of concept.	Manufacturing concepts identified. Small scale 'ugly' prototype built in lab.	Manufacturing proof of concept developed. Understanding of risk emerges. Transition to larger scale prototype tested in a relevant environment.	Manufacturing process carried out in a laboratory environment. Engineering development starts. Technology transition to pilot scale.	Prototype components created in a production relevant environment.	Prototype manufacturing system or subsystem produced in a production relevant environment.	Components, systems and subsystems produced in a production representative environment.	Pilot line capability demonstrated. Ready for Low Rate Initial Production (LRIP).	Low Rate Production demonstrated. Ready to begin Full Rate Production (FRP).	Full Rate Production demonstrated and continuous improvement systems in place.
							Demonstration system in operational environment at pre-commercial scale.		First of a kind commercial system. Manufacturing issues solved.	Transition to full commercial application i.e. technology available to consumers.		
				Initial investment				Major investment				
Risks	Top level	Technology	Technology		Technology							
				Funding	Funding			Funding				
					Manufacturability	Manufacturability	Manufacturability	Manufacturability	Manufacturability			
								Yields & Rates	Yields & Rates	Yields & Rates	Yields & Rates	
					Material supply	Material supply	Material supply	Material supply	Material supply	Material supply	Material supply	
					Equipment supply	Equipment supply	Equipment supply	Equipment supply	Equipment supply	Equipment supply	Equipment supply	
											Continuous Improvement	Continuous Improvement
	Key relationships	The inventor and those closely associated	Designers and materials specialists	Financial, project management, manufacturing expertise, modelling and simulation, risk assessor	Supply chain for both materials and equipment	Materials planning, facilities, quality and funders. Relationships with manufacturing team, production operatives & unions	Major investors Equipment suppliers	Major investors Equipment suppliers	Manufacturing team Unions Production operatives	Continuous improvement team and the sponsor	Sponsor Major investor All manufacturing	Sponsor Major investor All manufacturing

Lighter: less — **Intensity of involvement / risk** — Darker: more

MRL chart used to assess the maturity of a new manufacturing method and the associated risks for each level

WP1 – Cladding Removal and Replacement Discovery Project

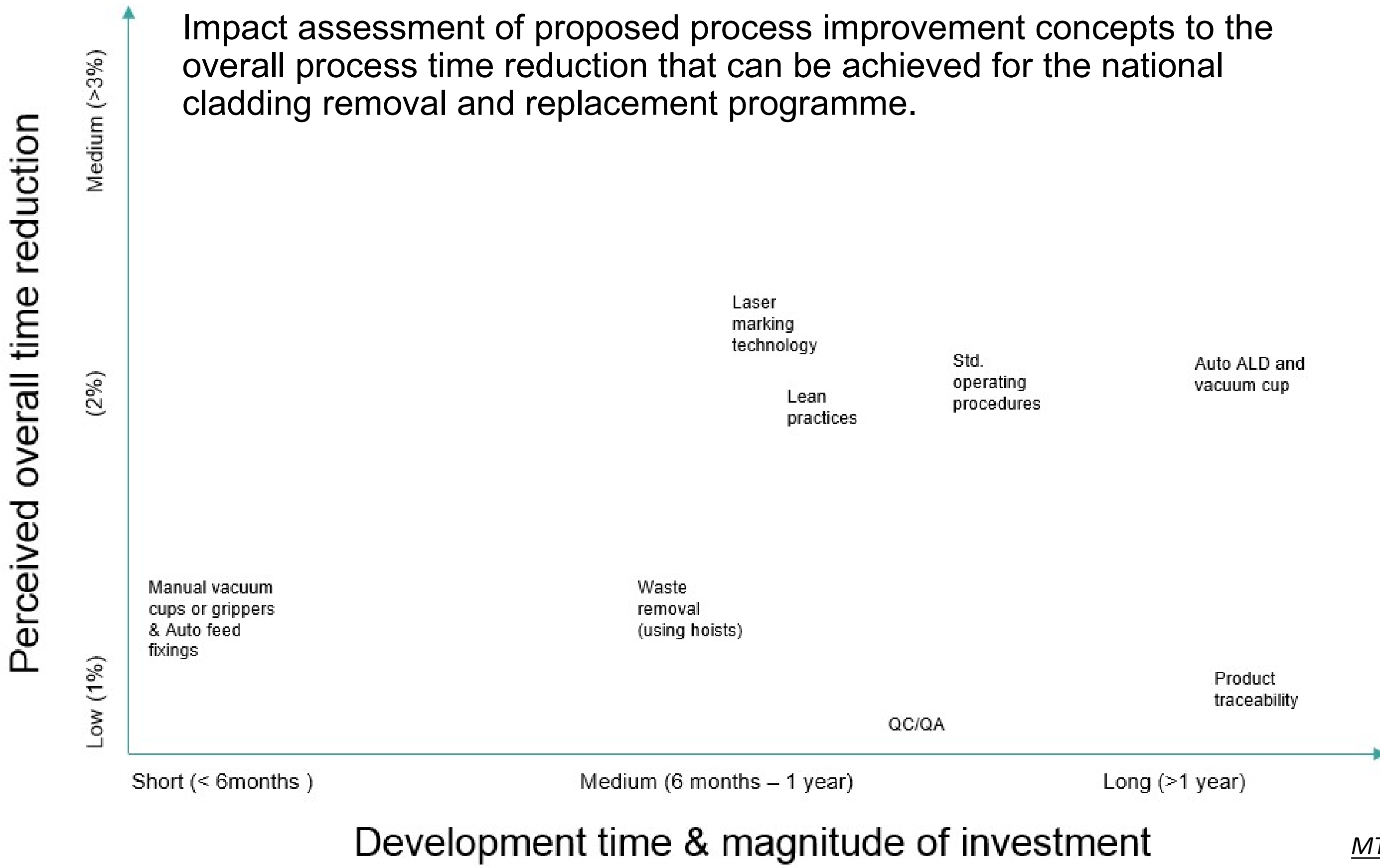
Conclusions

- The MTC captured information on the current processes, standards, legislation and practices seen in the industry.
- The MTC identified a series of improvements that could be applied to the physical process of removal and replacement of cladding.
- It was determined that the physical process is only a small element of the entire process flow associated with cladding removal and replacement, including external influences such as surveying the building, tendering, and designing the cladding.
- The MTC proposed a future state of cladding manufacture influenced by the aerospace sector, whereby the manufacture of modules of cladding, including bracketing, insulation and cladding panels, will take place off-site in a factory, and then requires only installation of the modules on-site.
- Adopting a modular manufacturing mentality can lead to increased quality and traceability of the components being used. As a part of the improved future state, technology can be implemented, including but not limited to:
  - Drone based inspection technology to accurately digitise the present condition of a building
  - Asset tracking to ensure the source of and material used in cladding is known

WP1 – Cladding Removal and Replacement Discovery Project

Impact Assessment

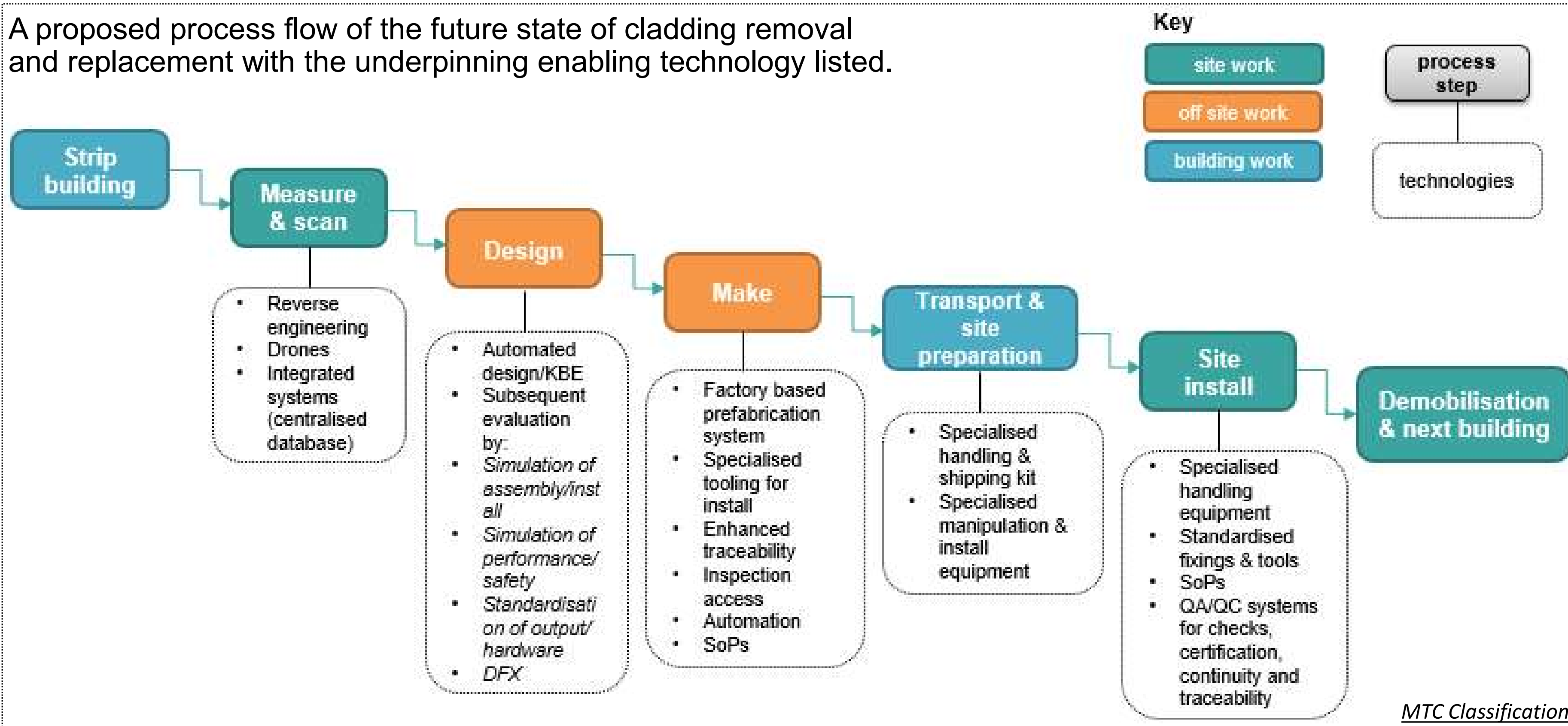
Impact assessment of proposed process improvement concepts to the overall process time reduction that can be achieved for the national cladding removal and replacement programme.



WP1 – Cladding Removal and Replacement Discovery Project

Future State Process Flow

A proposed process flow of the future state of cladding removal and replacement with the underpinning enabling technology listed.



WP1 – Cladding Removal and Replacement Discovery Project

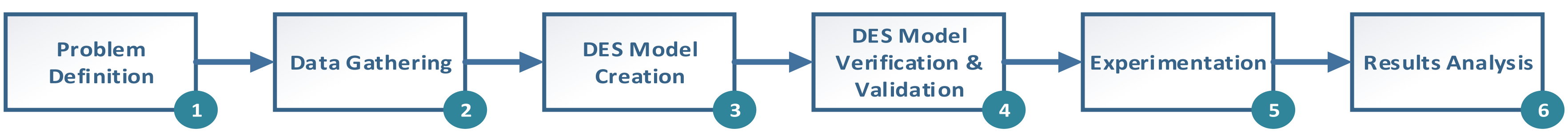
Recommendations and Further Work

- The MTC believes that it can contribute to the improvement of the industry through technology development, de-risking and standardisation. The MTC has experience of multiple industries that have encountered and resolved similar issues in the past, and this can help transfer these adopted practices to the construction industry.
  - A prime example is to look towards the aerospace industry, and how they implement traceability across multiple suppliers and sub-contractors to maintain quality, whilst ultimate accountability is still held by a single party.
- The MTC would add value by becoming part of a steering group to advise, facilitate and implement changes within the industry. The MTC can impart relevant knowledge where applicable, such as for a migration to factory based pre-assembly is preferable, or support selection and qualification of the recommended improvements to existing installation practices. Through this group the necessary research and development can be undertaken to work towards a standardised modular cladding future state.

WP2 – DES Model for Multi-Building Cladding Removal

Summary

- A DES model has been produced to simulate the removal and replacement of cladding, including both the planning and construction phases, for multiple buildings across the country.
  - The model predicts the completion rate for individual buildings as well as the overall completion time
  - DES has been selected for this task as it provides both the ability to simulate resource constraints and to stochastically represent uncertainty
- The model produced has been specifically used to simulate buildings identified as being in need of replacement in order to highlight potential capacity bottlenecks.
- Analysis of the simulation results demonstrated that in a ‘best case’ scenario, the work could be concluded in around 2 years, but that, considering delays and capacity constraints, an overall timescale of 3 years is more realistic.



The standard methodology the MTC adopts for all DES projects.

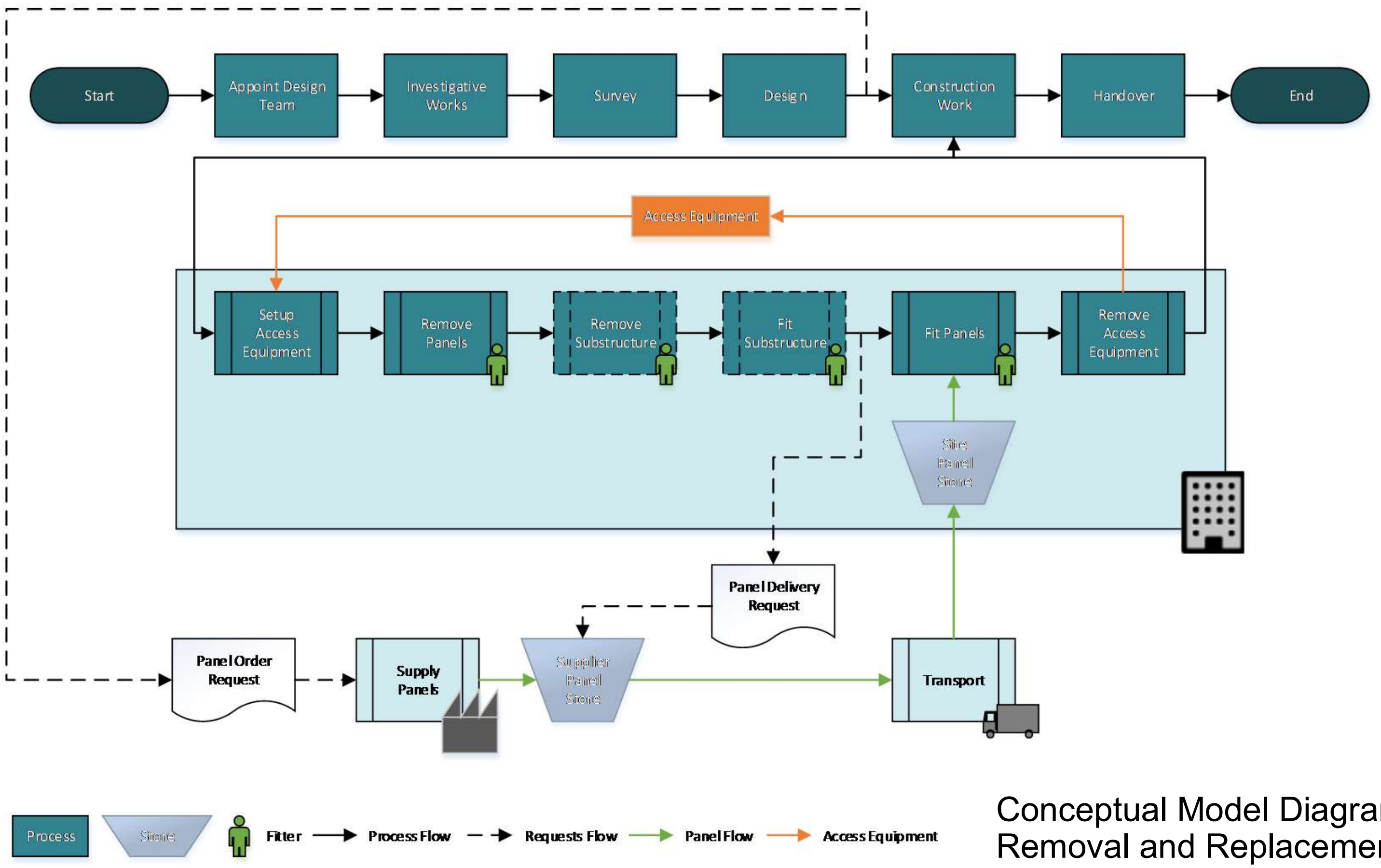
WP2 – DES Model for Multi-Building Cladding Removal

Summary

- Based on current estimates on UK supply and on the additional demand from new builds and other re-cladding projects (e.g. in the private sector), it is expected that:
  - Additional cladding material will need to be sourced from the European market.
  - Provided the existing number of installers in the UK is sustained, there is sufficient installer capacity to complete the work without major delays.
  - Scaffolding will need to be used for some buildings due to a lack of mast climbers, but that this will not significantly affect the overall completion time.
- No substantial issues have been identified from a capacity perspective for the buildings assessed. However, due to other factors (other buildings such as 'new builds' and private housing) there is a possibility that re-cladding presents a much wider issue, which has not been captured in this simulation model.
- Output data detailed in WP2 is not intended to give an indication of when the full remediation of buildings with unsafe ACM cladding will be complete. Input data is based on a small sample of buildings in the social sector and does not take into account other complications which may not have been relevant in the buildings, included in the research, but which may impact on the time it takes to fully remediate other buildings. It also does not take into account the information on the number of buildings in the private sector with ACM cladding, which was not available at the time of the research.

WP2 – DES Model for Multi-Building Cladding Removal

Conceptual Model



MTC Classification: Public

Conceptual Model Diagram for the Removal and Replacement of Cladding

WP2 – DES Model for Multi-Building Cladding Removal

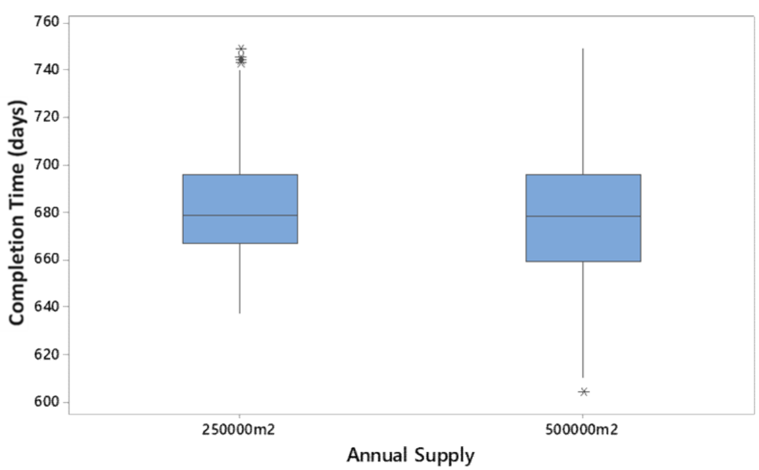
Conclusions

- Based on the assumptions made and data gathered, the simulation results imply a predicted, realistic timescale of around 3 years. The following observations have been made from the analysis of the simulation results:
  - The current estimates for capacity of cladding material, installers and access equipment appear to be sufficient to meet the expected demand without incurring major project delays, provided that these resources are managed effectively.
  - If re-cladding of all the buildings was to start simultaneously, the best case completion time is estimated to be around 2 years (678 days).
  - A reduced supply of cladding material is not expected to greatly impact the overall completion time of the project. It is, however, anticipated to significantly slow the initial rate of completion.
  - In order to entirely eliminate delays caused by material supply it is highly probable that access to the wider European market will be necessary.
  - The current capacity of installers within the UK is deemed sufficient to complete the project without delay.
  - A decrease in installer capacity by around 25% is expected to increase the timescale by more than 3 months. There are several risk factors that could contribute to such a reduction, e.g. increased demand in other construction areas.
  - A lack of mast climbers is likely to introduce a need for alternative access equipment. Using scaffolding is predicted to prolong the overall duration, but only by around a month.
  - Staggering the start dates of the buildings will have a significant effect on the overall timescale, extending the anticipated completion time to almost 3 years. However, as a consequence, the demand for resource over this longer period is expected to be significantly reduced, alleviating the potential for capacity-based delays witnessed in other scenarios.
  - Data output is based on simulation and cannot be currently used to accurately predict time frame(s) for full remediation of buildings with unsafe ACM cladding.

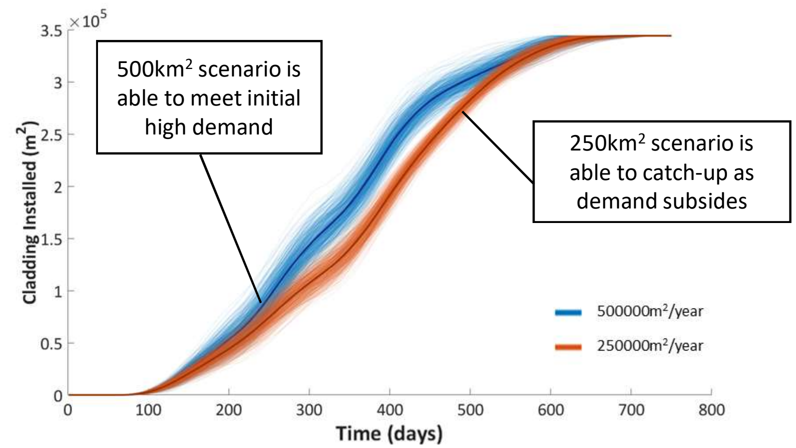
WP2 – DES Model for Multi-Building Cladding Removal

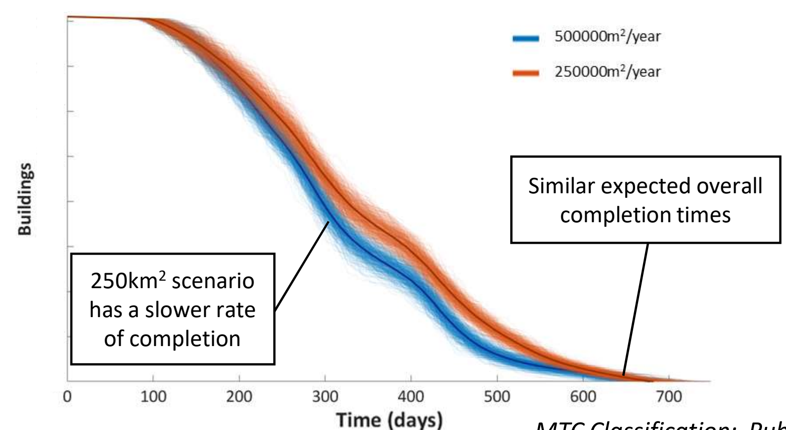
Results for Restricted Cladding Supply

Time-series of completed buildings (bottom right) and cladding installed (top left) across replications with mean fit for cladding supply restricted scenarios.



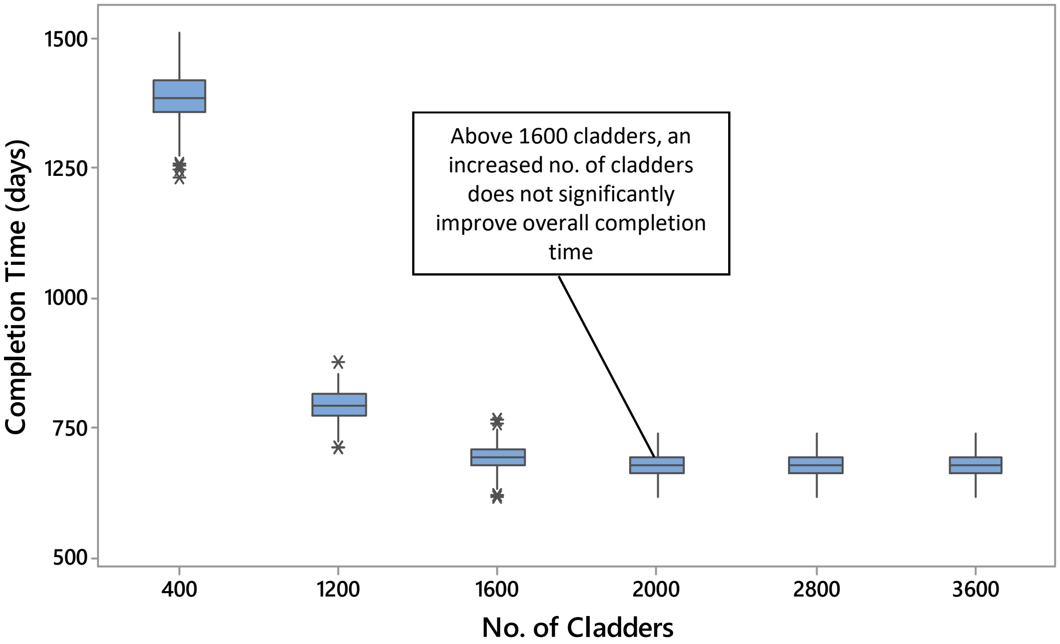
Boxplot diagram of completion times for cladding supply restricted scenarios.



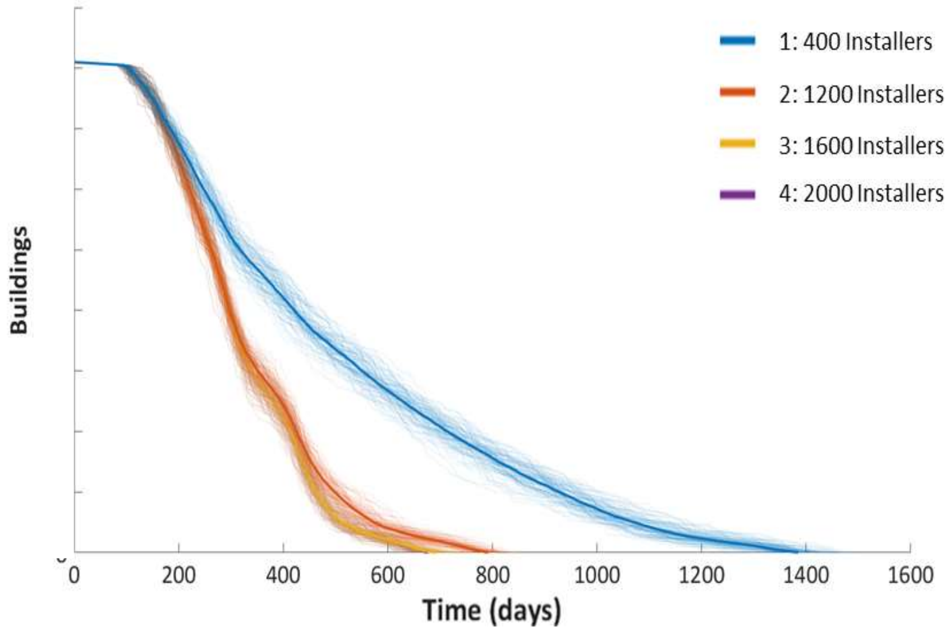


WP2 – DES Model for Multi-Building Cladding Removal

Results for Restricted Cladding Installers



Boxplot diagram of completion times for cladding installer restricted scenarios.

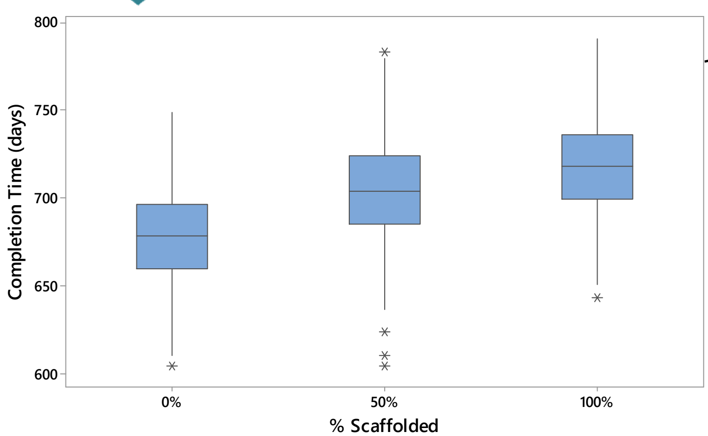


Time-series of completed buildings across replications with mean fit for cladding installer restricted scenarios.

MTC Classification: Public

WP2 – DES Model for Multi-Building Cladding Removal

Results for Restricted Access Equipment

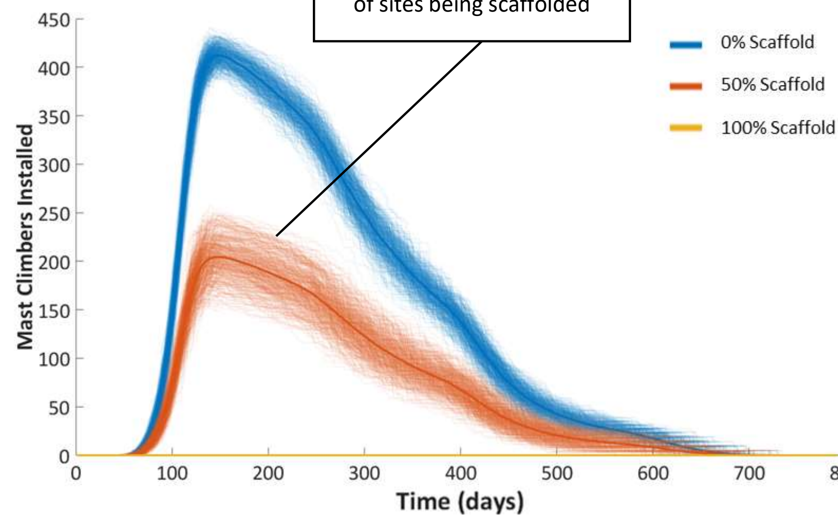


Extended installation and removal time for scaffolding causes the average completion time to increase across scenarios

Scenario	% Scaffolded	Completion Time (days)			
		Mean	Std. Dev.	Minimum	Maximum
1	0%	677.81	26.16	603.81	748.68
2	50%	703.93	29.25	603.81	782.92
3	100%	717.46	26.81	642.72	790.35

Boxplot diagram and statistics summary table of completion times for different access equipment scenarios.

High variance in the 50% case is caused by probabilistic determination of sites being scaffolded

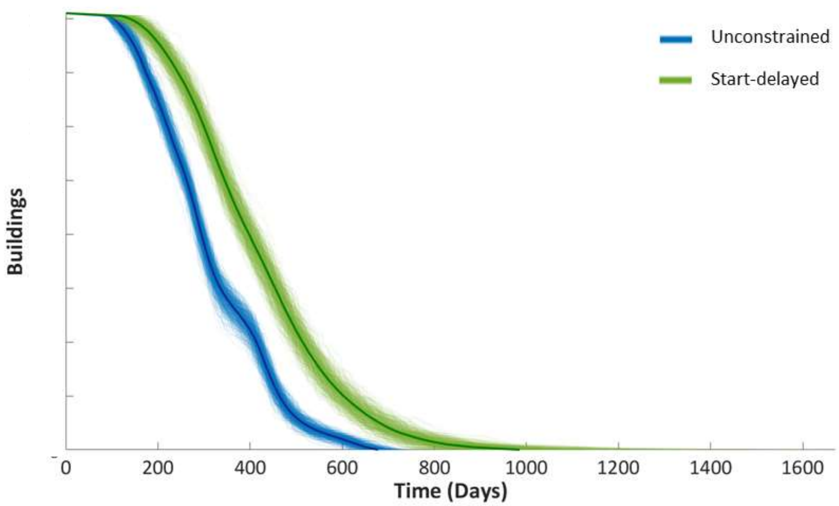


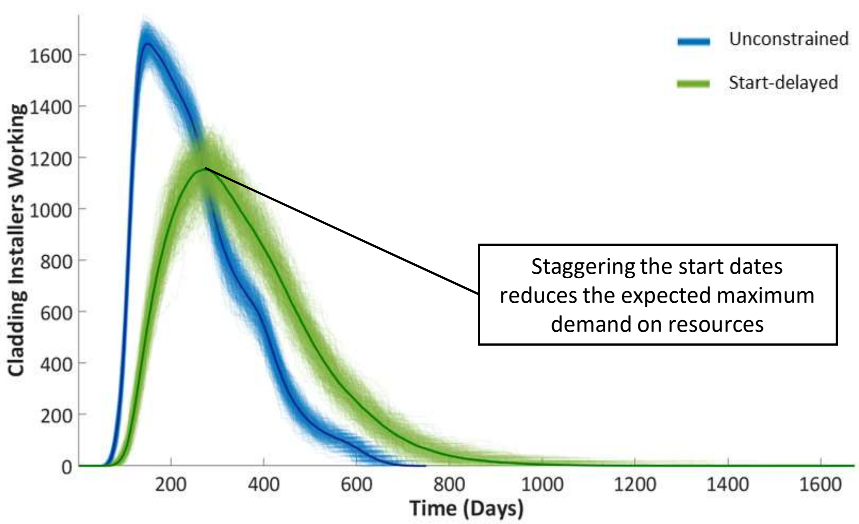
Time-series of mast climbers installed across replications with mean fit for different access equipment scenarios.

MTC Classification: Public

WP2 – DES Model for Multi-Building Cladding Removal

Results for Start-Delayed Scenario





Time-series of completion time (left) and cladding installer demand (right) across replications with mean fit for the best case scenario and a scenario where the building start dates are staggered

WP2 – DES Model for Multi-Building Cladding Removal

Recommendations and Further Work

- The results provide Rough Order of Magnitude (ROM) estimates. To make further use of this model, it is recommended that the modelling and analysis are refreshed and revised once additional data is available.
  - To further enhance analysis, newly obtained data from the sites could be used to improve duration estimates and to better qualify the assumptions in use
- The model focuses only on simulating the consequences of restricting resources that were initially flagged as potential constraints. As understanding of the process matures and the importance of other constraints and resources becomes more apparent, it is recommended to incorporate these in the simulation and to conduct an updated analysis.
- The model generated in this work package could be adapted to quantitatively assess the impact of adopting changes recommended in WP1, from a time and resource perspective.
  - This assessment could then be used to support investment decision making. Furthermore, the model could be updated throughout the development process to de-risk technical decisions.
- To maximise the model effectiveness, it is recommended that it is maintained and updated periodically as new data emerges that is more accurate and detailed than is currently available, allowing more accurate predictions to be made to support planning.

WP3 – Non-Destructive Inspection of Hidden Cladding Materials

Summary

- WP3 focuses on the identification of a Non-Destructive Testing (NDT) technique or system that is capable of assessing the presence of different materials within the external cladding envelope of a high-rise building without the need to remove the outermost layer of the cladding.
- WP3 consists of three phases of work:
  - Problem Definition: Understanding the inspection challenges that any new inspection system must address, this includes defining the materials, geometries, and compositions of cladding in high-rise buildings.
  - Downselection: Identifying the most appropriate inspection system using the MTC Inspection System Downselection process. Technology is filtered based upon criteria created through understanding the inspection challenges in the problem definition.
  - Feasibility trials: Undertaking inspection trials with the identified NDT technologies to confirm whether they are capable of detecting different materials within external cladding envelopes. If any NDT technologies prove capable, then a development route will be identified to ensure the technology can be deployed for industrial applications in order to inspect entire high-rise buildings.

Problem Definition	•Observation of current process and or collection of information about components to be inspected with new inspection system.
Technical Specification	•Highlights the important criteria by which the inspection systems will be assessed and ranked. Weighting should be decided with an appropriate panel. This will result in a numerical matrix of criteria being created.
First Stage Downselection	•A preliminary downselection stage based upon the critical criteria of the inspection process to remove inappropriate systems. This will utilise the numerical matrix to filter inappropriate systems.
Second Stage Downselection	•Perform trials on the selected inspection systems in order to populate the remaining fields of the numerical matrix and determine the most appropriate inspection system. Representative artefacts are required for performance analysis of the selected inspection systems.
System Validation	•A series of trials to validate the performance of the inspection system to ensure it can fulfil all the criteria set in the technical specification and all the inspection requirements relevant to the specific application.
System Procurement	•Purchasing the most appropriate system for the application and ensuring the system can perform within the required specifications.

A flowchart showing the downselection process that was followed

WP3 – Non-Destructive Inspection of Hidden Cladding Materials

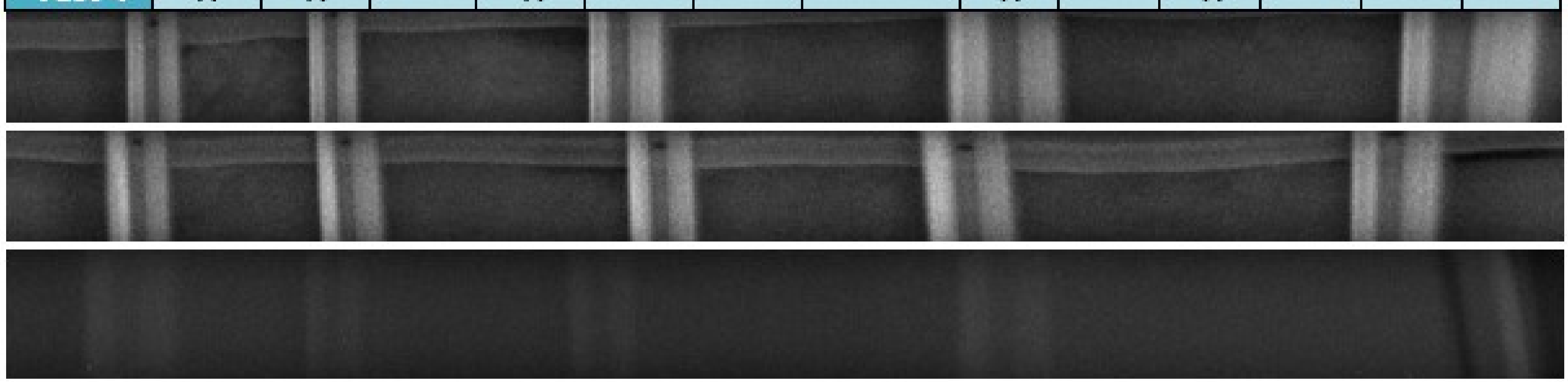
Results

Top. An image from the scan results on metal bracketry and insulation obtained directly onto the assembly.

Middle. An image from the scan results on metal bracketry and insulation with intumescent strips mounted onto the bracketry. The intumescent strips are visible as the whiter pixels on the left hand side of each bracket.

Bottom. An image of the same assembly of bracketry, intumescent strips and insulation as obtained from the scan results captured through an ACM panel. The ACM panel attenuated some of the energy, but sufficient remained to detect the intumescent strips.

Material	ACM Panel	Aluminium Bracketry	Foil Covered Mineral Wool	Intumescent Strips	Mineral Fibre Insulation Dual Density	Mineral Fibre Insulation Mono Density	Mineral Wool Fire Break with Integrated Intumescent Strip	Mineral Wool	Recycled Glass Panels	Stainless Steel Cavity Barriers	Stainless Steel Threading With Plastic Fixtures	Tempered Glass Panels	Timber
Test 1		X						X		X			
Test 2		X		X				X		X			
Test 4	X	X		X				X		X			



WP3 – Non-Destructive Inspection of Hidden Cladding Materials

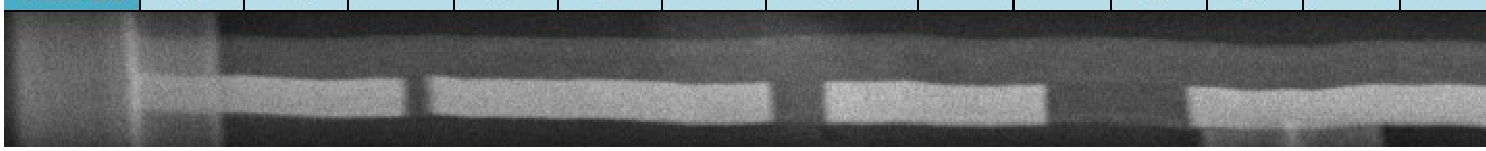
Results

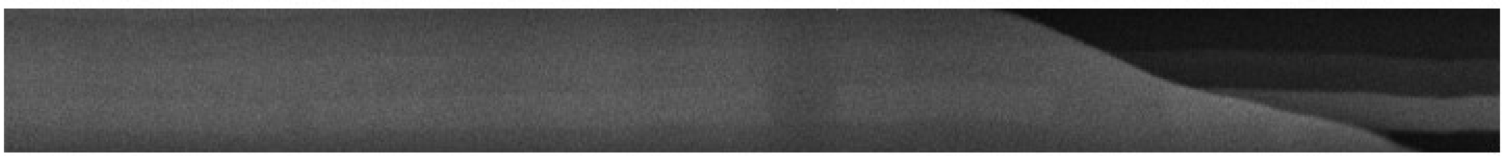
Top. An image taken by the scan results of an intumescent strip and firebreak with deliberate holes cut into to replicate gaps seen at the end of intumescent strips in industry.

Mid. The same assembly as viewed behind a recycled glass panel by the scan results.

Bottom. The same assembly as viewed behind an ACM panel by the scan results.

Material	ACM Panel	Aluminium Bracketry	Foil Covered Mineral Wool	Intumescent Strips	Mineral Fibre Insulation Dual Density	Mineral Fibre Insulation Mono Density	Mineral Wool Fire Break with Integrated Intumescent Strip	Mineral Wool	Recycled Glass Panels	Stainless Steel Cavity Barriers	Stainless Steel Threading With Plastic Fixtures	Tempered Glass Panels	Timber
Test 19		X		X	X		X			X	X		
Test 20		X		X	X		X		X	X	X		
Test 21	X	X		X	X		X			X	X		





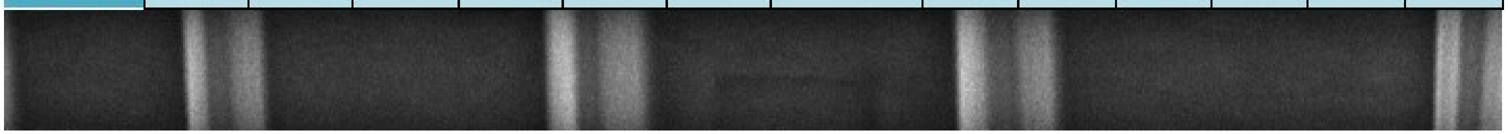
WP3 – Non-Destructive Inspection of Hidden Cladding Materials

Results

Top. An image from the scan results inspecting a hole in insulation through an ACM panel.

Bottom. An image from the scan results of a metallic screw and load bearing plastic fixture in the middle of insulation.

Material	ACM Panel	Aluminium Bracketry	Foil Covered Mineral Wool	Intumescent Strips	Mineral Fibre Insulation Dual Density	Mineral Fibre Insulation Mono Density	Mineral Wool Fire Break with Integrated Intumescent Strip	Mineral Wool	Recycled Glass Panels	Stainless Steel Cavity Barriers	Stainless Steel Threading With Plastic Fixtures	Tempered Glass Panels	Timber
Test 7	X	X		X				X		X			



Material	ACM Panel	Aluminium Bracketry	Foil Covered Mineral Wool	Intumescent Strips	Mineral Fibre Insulation Dual Density	Mineral Fibre Insulation Mono Density	Mineral Wool Fire Break with Integrated Intumescent Strip	Mineral Wool	Recycled Glass Panels	Stainless Steel Cavity Barriers	Stainless Steel Threading With Plastic Fixtures	Tempered Glass Panels	Timber
Test 12		X		X		X				X	X		
Test 17	X	X		X	X					X	X		

WP3 – Non-Destructive Inspection of Hidden Cladding Materials

Recommendations and Further Work

- The validation scan results trials identified the limitations of the system, which would present barriers to deployment in an industrial application. All of the identified limitations can be resolved through further development. The following areas are recommended for further development:
  - The MTC to develop the data collection method. This will enable determination of the optimum stand-off distance, speed, approach angle, and orientation required for optimal data collection.
  - The MTC to develop an external localiser that will allow the collected data accurately over large volumes.
  - The MTC to develop image processing, such that the system can automatically identify and detect the composition of materials within a scan image from the NDT device.
  - Following the completion of the other three development areas, the MTC to develop the NDT solution into a turnkey product such that it is ready to be used on construction sites. This will involve developing a full process that includes:
    - Scanning the building for an accurate 3D representation.
    - Automatic generation of drone paths from the scan data.
    - Stitching of the data and presentation in 3D space.
    - An automated, software-driven assessment of the cladding envelope in terms of fitness-for-purpose.

Recommendations and Further Work

Cladding Removal and Replacement

- The recommended next steps for work in the area of cladding removal and replacement are as follows:

1. The MTC to become part of a steering group to advise, facilitate and implement changes within the industry. The MTC can impart relevant knowledge where applicable; such as for a migration to factory based pre-assembly; or support selection and qualification of the recommended improvements to existing installation practices. Through this group the necessary research and development can be undertaken to work towards a standardised modular cladding future state.
2. The MTC has produced a model that can serve as a platform for evaluation of scenarios regarding remedial removal and replacement of cladding. To maximise effectiveness, it is recommended that the model is maintained and updated periodically as new data emerges that is more accurate and detailed than is currently available; allowing more accurate predictions to be made to support planning.
3. The MTC to develop the data collection method; through the ability to move the NDT device in a controlled movement over a target surface, This will enable determination of the optimum stand-off distance, speed, approach angle, and orientation required for optimal data collection;
4. The MTC to develop an external localiser that will allow the NDT device to collect data accurately over large volumes;
5. The MTC to develop image processing, such that the system can automatically identify and detect the composition of materials within a scan image from the NDT device.

Version Control

Version	Date	Author	Status	Change Description
1.0	18.04.2018	MTC IUK Cladding Project Team	Issued	Document Issued – Final

MTC Endorsement

This report has been reviewed and accepted by the following

Reviewed By	Signature	Date
Robert Crook. **Senior Programme Manager**		16th April 2018
Susan Hone-Brookes. **BEng(Hons),MSc, CEng, FCIBSE** **Chief Engineer Construction and Infrastructure**		18th April 2018