APPENDIX

APPENDIX A: ONLINE SURVEY

Methodology

The process of data collection in this study is illustrated in figure A1.

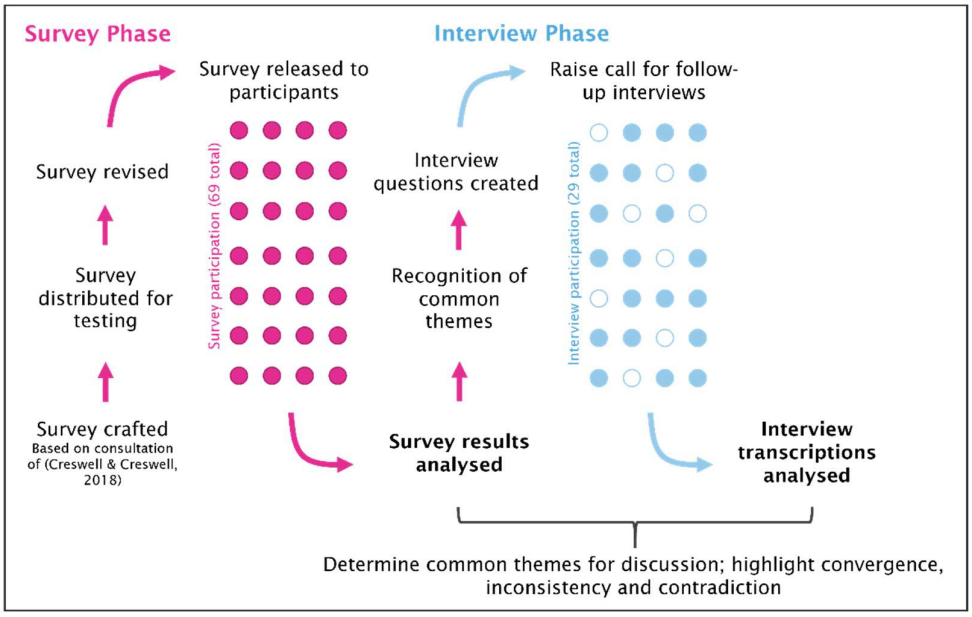

Figure A1: Process of mixed method explanatory research approach

Survey questions

Table A1: List of online survey questions

Question Number	Question	Question Type	Options
General Questions			
Q1.1	I confirm that I have read and understood the Participant Information Sheet.	Multiple Choice: Single Answer	Yes / No
Q1.2	I have had the opportunity to ask questions and had them answered.	Multiple Choice: Single Answer	Yes / No
Q1.3	I understand that all personal information will remain confidential and that all efforts will be made to ensure I cannot be identified (except as might be required by law).	Multiple Choice: Single Answer	Yes / No
Q1.4	I agree that data gathered in this study may be stored anonymously and securely, and may be used for future research.	Multiple Choice: Single Answer	Yes / No
Q1.5	I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason.	Multiple Choice: Single Answer	Yes / No
Q1.6	I agree to take part in this study.	Multiple Choice: Single Answer	Yes / No
Q1.7	How would you best describe your position in the facade supply-chain?	Multiple Choice: Single Answer	Client/Developer / Architect / Main Contractor / Façade Contractor / Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard

Question Number	Question	Question Type	Options
Q1.8	Does your company have a policy in place dealing with environmental impacts?	Multiple Choice: Single Answer	Yes / No
Q1.9	How would you estimate the typical expected service life of the following building elements?	Matrix Table (4 statements, 7 scale points: <1 year; 1-5 years; 5-10 years; 10-25 years; 25-50 years; 50-100 years; 100 years +)	Façade / Foundations / Mechanical & Electrical Services / Load-bearing structure
Q1.10	Please rank the following on perceived relative value at their respective end-of-life (10 being as new, 1 being completely redundant) - Facade	Slider Scale (1-10)	Façade / Foundations / Mechanical & Electrical Services / Load-bearing structure
Q1.1	How would you best describe existing demand of second-hand facades? Please drag slider to desired position.	Slider Scale (1-100)	
Q1.12	On average, how frequently do you believe facades are replaced during a building's service life?	Mutliple Choice	<1 year; 1-5 years; 5-10 years; 10-20 years; 20-30 years; 30-40 years; 40-50 years; 50 years +
Q1.13	Please rank the following reasons for facade demand for refurbishment purposes. Drag and drop the items to rearrange in order of most common (1) to least common (6)	Rank Order	Aesthetic / Cost / In response to legislation / Performance-related (e.g. due to component degradation) / To accommodate structural changes / To improve energy efficiency in use
Q1.14	To what extent do you believe that the benefits of facade reuse are well-understood?	Slider Scale (1-100)	Environmental / Social / Economic
Q1.15	Please rank the following components on how you perceive their existing re-use potential:	Slider Scale (1-100)	Cladding / Connections / Framework / Glazing / Insulation
Q1.16	What do you see as the main barriers/challenges to designing new facades from reclaimed material? Please list at least three most important:	Free-text	
Q1.17	What do you see as the main drivers to designing new facades from reclaimed material for your company? Please list at least three most important:	Free-text	
Q1.18	What type of facade system do you see will dominate construction in the next 20 years? What materials and jointing/construction methods will this consist of?	Free-text	
Client/Developer			
Q2.1	To what extent would you consider specifying re-use facades if you could guarantee an adequate supply?	Slider Scale (1-100)	
Q2.2	What key design criteria do you follow in facade selection and specifying facade material?	Free-text	
Q2.3	What, if anything, might limit you in specifying responsible material sourcing as key design criteria in new developments ie. specifying facades that have been re-used either as a whole system or from their constituent components?	Free-text	
Q2.4	Please rank the following criteria in terms of the relative importance to you when considering facade design for new developments:	Rank Order	Aesthetic / Adherence to Legislation / Energy Performance in Use (Energy required for heating/colling/lighting) / "Green" Credentials / Initial Cost / Maintenance Cost / Ability to Fit Structural Grid
Q2.5	What information or guidance would make it easier to specify facades for re-use purposes?	Free-text	
Q2.6	To what extent would you consider you interact with the following stakeholders of the facade supply-chain within individual projects?	Matrix Table (4 statements, 4 scale points: No Interaction; Minimal Interaction; Some Interaction; High level of Interaction)	Architect / Main Contractor / Façade Contractor / Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
	To what extent would you say the following stakeholders have an influence on your existing business operations?	Matrix Table (4 statements, 4 scale points: No Influence; Minimal Influence; Some	Architect / Main Contractor / Façade Contractor /

Question Number	Question	Question Type	Options
		Influence; High Level of Influence)	Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
Q2.8	To what extent is enabling i.) re-use and ii.) re-cycling opportunities for facades and their constituent components at the end of a life a priority in your design specification?	Matrix Table (2 statements, 6 scale points: Never a Priority in Design; Minor Priority; Somewhat of a Priority; High Priority; Very High Priority; Prefer not to say)	Enabling Re-use / Enabling Re-cyclability
Architect			
Q3.1	To what extent would you consider specifying reuse facades if you could guarantee an adequate supply?	Slider Scale (1-100)	
Q3.2	What key design criteria do you follow in facade selection?	Free-text	
Q3.3	What information or guidance would make it easier to specify facades for reuse purposes e.g. condition, size, material treatments and/or properties?	Free-text	
Q3.4	To what extent would you consider you interact with the following stakeholders of the facade supply-chain within individual projects? - Client/Developer	Matrix Table (4 statements, 4 scale points: No Interaction; Minimal Interaction; Some Interaction; High level of Interaction)	Client/Developer / Main Contractor / Façade Contractor / Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
Q3.5	To what extent would you say the following stakeholders have an influence on your existing business operations?	Matrix Table (4 statements, 4 scale points: No Influence; Minimal Influence; Some Influence; High Level of Influence)	Client/Developer / Main Contractor / Façade Contractor / Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
Q3.6	To what extent is enabling i.) re-use and ii.) re-cycling opportunities for facades and their constituent components at the end of a life a priority in your design specification?	Matrix Table (2 statements, 6 scale points: Never a Priority in Design; Minor Priority; Somewhat of a Priority; High Priority; Very High Priority; Prefer not to say)	Enabling Re-use / Enabling Re-cyclability
Main Contractor			
Q4.1	To what extent would you be flexible to working with recovered glass and other facade material if it were requested on a project?	Slider Scale (1-100)	
Q4.2	To what extent are facades likely to have a useful life remaining when removed from a building such that a firm would be able to undertake reconditioning, including performance testing if necessary?	Slider Scale (1-100)	
Q4.3	Are there tests available to assess the condition/life expectancy of facades or façade materials (includes in- and ex-situ)?	Multiple Choice: Single Answer	Yes / No
Q4.4	Do you believe the performance of reconditioned goods could be specified in ways that meet the needs of building designers and contractors?	Multiple Choice: Single Answer	Yes / No
Q4.5	What reconditioning work may be required to restore façade condition sufficiently for reuse purposes?	Free-text	
Q4.6	Are you aware of any stockists of reclaimed façades or façade elements?	Multiple Choice: Single Answer	Yes / No
Q4.7	How easy is it to transport and store façade or façade components without damage until a buyer can be found?	Slider Scale (1-100)	
Q4.8	To what extent would you consider you interact with the following stakeholders of the facade supply-chain within individual projects?	Matrix Table (4 statements, 4 scale points: No Interaction; Minimal Interaction; Some Interaction; High level of Interaction)	Client/Developer / Architect / Façade Contractor / Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard

Question Number	Question	Question Type	Options
Q4.9	To what extent would you say the following stakeholders have an influence on your existing business operations?	Matrix Table (4 statements, 4 scale points: No Influence; Minimal Influence; Some Influence; High Level of Influence)	Client/Developer / Architect / Façade Contractor / Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
Q4.10	To what extent is enabling i.) re-use and ii.) re-cycling opportunities for facades and their constituent components at the end of a life a priority within your projects?	Matrix Table (2 statements, 6 scale points: Never a Priority in Design; Minor Priority; Somewhat of a Priority; High Priority; Very High Priority; Prefer not to say)	Enabling Re-use / Enabling Re-cyclability
Façade Contractor			
Q5.1	To what extent would you be flexible to working with recovered glass and other facade material if it were requested on a project? Drag slider to desired position	Slider Scale (1-100)	
Q5.2	To what extent are facades likely to have a useful life remaining when removed from a building such that a firm would be able to undertake reconditioning, including performance testing if necessary?	Slider Scale (1-100)	
Q5.3	Are there tests available to assess the condition/life expectancy of facades or façade materials (includes in- and ex-situ)?	Multiple Choice: Single Answer	Yes / No
Q5.4	Are you also responsible for façade maintenance?	Multiple Choice: Single Answer	Yes / No
Q5.5	How do you believe the use of reuse facades would affect façade maintenance if at all?	Free-text	
Q5.6	Do you believe the performance of reconditioned goods could be specified in ways that meet the needs of building designers and contractors?	Multiple Choice: Single Answer	Yes / No
Q5.7	What reconditioning work may be required to restore façade condition sufficiently for reuse purposes?	Free-text	
Q5.8	Are you in the position to supply spare parts or; to provide a reconditioning service on demand or; to undertake reconditioning as a core service?	Multiple Choice: Single Answer	Yes / No
Q5.9	To what extent, if at all, do you specify or propose a disassembly sequence for facade units in the early design stage?	Free-text	
Q5.10	Are you aware of any stockists of reclaimed façades or façade elements?	Multiple Choice: Single Answer	Yes / No
Q5.11	How easy is it to transport and store façade or façade components without damage until a buyer can be found?	Slider Scale (1-100)	
Q5.12	To what extent would you consider you interact with the following stakeholders of the facade supply-chain within individual projects? - Client/Developer	Matrix Table (4 statements, 4 scale points: No Interaction; Minimal Interaction; Some Interaction; High level of Interaction)	Client/Developer / Architect / Main Contractor / Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
Q5.13	To what extent would you say the following stakeholders have an influence on your existing business operations?	Matrix Table (4 statements, 4 scale points: No Influence; Minimal Influence; Some Influence; High Level of Influence)	Client/Developer / Architect / Main Contractor / Manufacturer - Processor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
Q5.14	To what extent is enabling i.) re-use and ii.) re-cycling opportunities for facades and their constituent components at the end of a life a priority within your products?	Matrix Table (2 statements, 6 scale points: Never a Priority in Design; Minor Priority; Somewhat of a Priority; High Priority; Very High Priority; Prefer not to say)	Enabling Re-use / Enabling Re-cyclability
Material Processor			
Q6.1	Please list the type of materials and products that your company is responsible for processing within the facade system.	Free-text	

Question Number	Question	Question Type	Options
Q6.2	To what extent would you be flexible to working with materials recovered from facade systems if it were requested on a project?	Slider Scale (1-100)	
Q6.3	To what extent are facades likely to have a useful life remaining when removed from a building such that a firm would be able to undertake reconditioning, including performance testing if necessary?	Slider Scale (1-100)	
Q6.4	Are there tests available to assess the condition/life expectancy of facades or façade materials (includes in- and ex-situ)?	Multiple Choice: Single Answer	Yes / No
Q6.5	Do you believe the performance of reconditioned goods could be specified in ways that meet the needs of building designers and contractors?	Multiple Choice: Single Answer	Yes / No
Q6.6	What reconditioning work would be required to restore façades or facade material (e.g. glass/framework) condition sufficiently for re-use (functioning as new)? If unsure, please answer 'Unsure'	Free-text	
Q6.7	Are you in the position to supply spare parts, or to provide a reconditioning service on demand, or to undertake reconditioning as a core service?	Multiple Choice: Single Answer	Yes / No / Not Applicable
Q6.8	Are you aware of any stockists of reclaimed façades or façade elements?	Multiple Choice: Single Answer	Yes / No
Q6.9	Would you be prepared to store reclaimed façade material until a suitable project became available?	Multiple Choice: Single Answer	Yes / No / Not Applicable
Q6.10	To what extent is enabling i.) re-use and ii.) re-cycling opportunities for facades at the end of a life a priority in the design of your products?	Matrix Table (2 statements, 6 scale points: Never a Priority in Design; Minor Priority; Somewhat of a Priority; High Priority; Very High Priority; Prefer not to say)	Enabling Re-use / Enabling Re-cyclability
Q6.11	Please could you explain to what extent to which your company's current products are i.) re-usable ii.) re-cyclable? If not at all, please feel free to explain what other design factors take priority.	Free-text	
Q6.12	To what extent would you consider you interact with the following stakeholders of the facade supply-chain within individual projects? - Client/Developer	Matrix Table (4 statements, 4 scale points: No Interaction; Minimal Interaction; Some Interaction; High level of Interaction)	Client/Developer / Architect / Main Contractor / Façade Contractor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
Q6.13	To what extent would you say the following stakeholders have an influence on your existing business operations? - Client/Developer	Matrix Table (4 statements, 4 scale points: No Influence; Minimal Influence; Some Influence; High Level of Influence)	Client/Developer / Architect / Main Contractor / Façade Contractor / Demolition Contractor / Recycling Facility / Architectural Salvage Yard
Demolition Contractor			
Q7.1	At the pre-demolition/pre-refurbishment stage, are you able to report on details of the façade systems within the building e.g. type, condition, function, age? Please list any below:	Free-text	
Q7.2	Would you be willing to make this information publicly available?	Multiple Choice: Single Answer	Yes / No
Q7.3	Do you have access to information about the different facade types/design used?	Multiple Choice: Single Answer	Yes / Some / None at all
Q7.4	To what extent would you consider reclaiming façade systems from a project if you knew there was good demand for façade systems and it was commercially viable? Drag slider to desired position	Slider Scale (1-100)	
Q7.5	Are you aware of any architectural salvage yards?	Multiple Choice: Single Answer	Yes / No
Q7.6	Do you believe facades can be removed from a building and returned in a suitable condition to a firm that will undertake reconditioning, including performance testing if necessary?	Multiple Choice: Single Answer	Yes / No
Q7.7	What are the common recovery routes for the following materials on-site?	Matrix Table (6 statements, 4 scale points: Landfill Disposal; Incineration - recover energy from waste; Downcycle (crushed	Metals - e.g. Aluminium and Steel Framework, Cladding Materials / Glass - e.g.

Question Number	Question	Question Type	Options
		up and used in different product e.g. concrete in aggregate); Recycle (sold for reprocessing); Component Re-use; Direct Re-use as a System)	Glazing / Timber / Insulation Material / Polymer materials e.g. seals / Masonry Cladding
Q7.8	If cost was not an issue, please rank the following components on how you perceive their existing reuse/recyclability potential at the demolition/refurbishment stage:	Slider Scale (1-100)	Cladding / Connections / Framework / Glazing / Insulation
Q7.9	Would reclaiming facades change the typical disassembly route for buildings and/or require specialist equipment? Please detail below.	Free-text	
Q7.10	How easy is it to transport and store façade or façade components without damage until a buyer can be found? Drag slider to desired position	Slider Scale (1-100)	
Q7.11	Are you aware of any stockists of reclaimed façades or façade elements?	Multiple Choice: Single Answer	Yes / No
Q7.12	Would you be prepared to store reclaimed façade material until a suitable demand for the product was met? - Yes (Please explain if you do already store reclaimed material) - Text	Multiple Choice: Single Answer	Yes (free-text) / No
Q7.13	To what extent would you consider you interact with the following stakeholders of the facade supply-chain within individual projects? - Client/Developer	Matrix Table (4 statements, 4 scale points: No Interaction; Minimal Interaction; Some Interaction; High level of Interaction)	Client/Developer / Architect / Main Contractor / Façade Contractor / Manufacturer - Processing / Recycling Facility / Architectural Salvage Yard
Q7.14	To what extent would you say the following stakeholders have an influence on your existing business operations?	Matrix Table (4 statements, 4 scale points: No Influence; Minimal Influence; Some Influence; High Level of Influence)	Client/Developer / Architect / Main Contractor / Façade Contractor / Manufacturer - Processing / Recycling Facility / Architectural Salvage Yard
Recycling Facility			
Q8.1	Could you briefly explain how your company manages waste materials?	Free-text	
Q8.2	What of the following services do you offer? - Selected Choice	Mutliple Choice: Multiple Answers	
Q8.3	Please explain what type of products you supply/sell on? Are you able to give details on sales prices?	Free-text	
Q8.4	Do you charge a fee for collecting 'waste'? If so, what are the approximate charges for the following materials?	Multiple Choice: Multiple Answers	Building Glass (free text) / Metals (free text) / Concrete (free text) / Wood Including Timber Products (free text) / Ceramic Materials (free text) / Other (free text)
Q8.5	What sort of separation methods do you make use of on-site?	Free-text	
Q8.6	Do you perform any kind of assessment of waste materials and if so, please describe a typical assessment procedure for the use of recycled façade material including properties, performance condition and the quality of materials?	Free-text	
Q8.7	Would you be prepared to store reclaimed façade material until a suitable project became available?	Multiple Choice: Single Answer	Yes / No
Q8.8	Do you have the facilities or are you aware of any facilities to recondition facades to their as new condition?	Multiple Choice: Single Answer	Yes / No
Q8.9	How would describe the existing maturity of the market for building facade a. re-use b. re-cycling?	Slider Scale (1-100)	Re-use / Re-cycling
Q8.10	To what extent would you consider you interact with the following stakeholders of the facade supply-chain within individual projects? - Client/Developer	Matrix Table (4 statements, 4 scale points: No Interaction; Minimal Interaction; Some Interaction; High level of Interaction)	Client/Developer / Architect / Main Contractor / Façade Contractor / Manufacturer - Processing / Demolition Contractor /

Question Number	Question	Question Type	Options
			Architectural Salvage Yard
Q8.11	To what extent would you say the following stakeholders have an influence on your existing business operations? - Client/Developer	Matrix Table (4 statements, 4 scale points: No Influence; Minimal Influence; Some Influence; High Level of Influence)	Client/Developer / Architect / Main Contractor / Façade Contractor / Manufacturer - Processing / Demolition Contractor / Architectural Salvage Yard
Architectural Salvage Yard			
Q9.1	Could you briefly explain how your company operates?	Free-text	
Q9.2	What of the following services do you offer?	Multiple Choice: Multiple Answers	Collection / Storage / Reconditioning - please detail (free text) / Transport to New Site / Other (free-text)
Q9.3	Do you charge a fee for collecting 'secondary products'? If so, what are the approximate charges for the following materials? - Selected Choice	Multiple Choice: Multiple Answers	Building Glass (free text) / Metals (free text) / Concrete (free text) / Wood Including Timber Products (free text) / Ceramic Materials (free text) / Other (free text)
Q9.4	Approximately what fee do you charge for selling 'secondary products'? - Selected Choice	Multiple Choice: Multiple Answers	Building Glass (free text) / Metals (free text) / Concrete (free text) / Wood Including Timber Products (free text) / Ceramic Materials (free text) / Other (free text)
Q9.5	Do you perform any kind of assessment of waste materials and if so, please describe a typical assessment procedure for the use of recycled façade material including properties, performance condition and the quality of materials?	Free-text	
Q9.6	Would you be prepared to store reclaimed façade material until a suitable project became available?	Multiple Choice: Single Answer	Yes / No
Q9.7	Do you have the facilities or are you aware of any facilities to recondition facades to their as new condition?	Multiple Choice: Single Answer	Yes / No
Q9.8	To what extent would you consider you interact with the following stakeholders of the facade supply-chain within individual projects?		Client/Developer / Architect / Main Contractor / Façade Contractor / Manufacturer - Processing / Demolition Contractor / Recycling Facility
Q9.9	To what extent would you say the following stakeholders have an influence on your existing business operations?		Client/Developer / Architect / Main Contractor / Façade Contractor / Manufacturer - Processing / Demolition Contractor / Recycling Facility
General Questions: Experience with Façade Reuse			
Q10.1	Have you heard about the idea of reusing facades or their elements before this survey?	Multiple Choice: Single Answer	Yes / No
Q10.2	Does your company have experience of reusing (a) facade materials or (b) whole facade systems (e.g. aluminium curtain wall unit) before this survey?	Multiple Choice: Single Answer	Yes / No
Q10.3	What percentage of recovered material/new material was used in the project that you referred to in the previous question?	Slider Scale (1-100)	% of Reuse Material Used / % of Recycled Material Used / % of New Material Used
Q10.4	Where did the interest for reusing facade materials or facade systems in your latest project arise?	Free-text	

Question Number	Question	Question Type	Options
Q10.5	What were the main findings from reusing facade material in terms of ease of use and difficulties encountered?	Free-text	
Q10.6	How did the use of facade material affect costs in for your latest project? If possible, please provide details.	Free-text	
Q10.7	What was the environmental benefit of reusing facade material in your latest project, if any, and how was this quantified?	Free-text	
General Questions: Experience with Material Re-use			
Q11.1	If not facades, have you been involved with reuse of any other building elements? This involves the use of existing building elements on another site. Please detail:	Free-text	
Close			
Q12.1	How many people are employed in your company?	Multiple Choice: Single Answer	1-10 / 11-50 / 51-250 / 250+
Q12.2	We would like to keep in touch with you about this survey. If you would be willing to be contacted, please provide contact information.	Form	Name / Email Address / Contact Number / Any other suggestions?

Process of exporting and encoding free-text answers

The process of encoding the two free-text answers relating to the barriers and motivations to reuse is shown on figure A2.

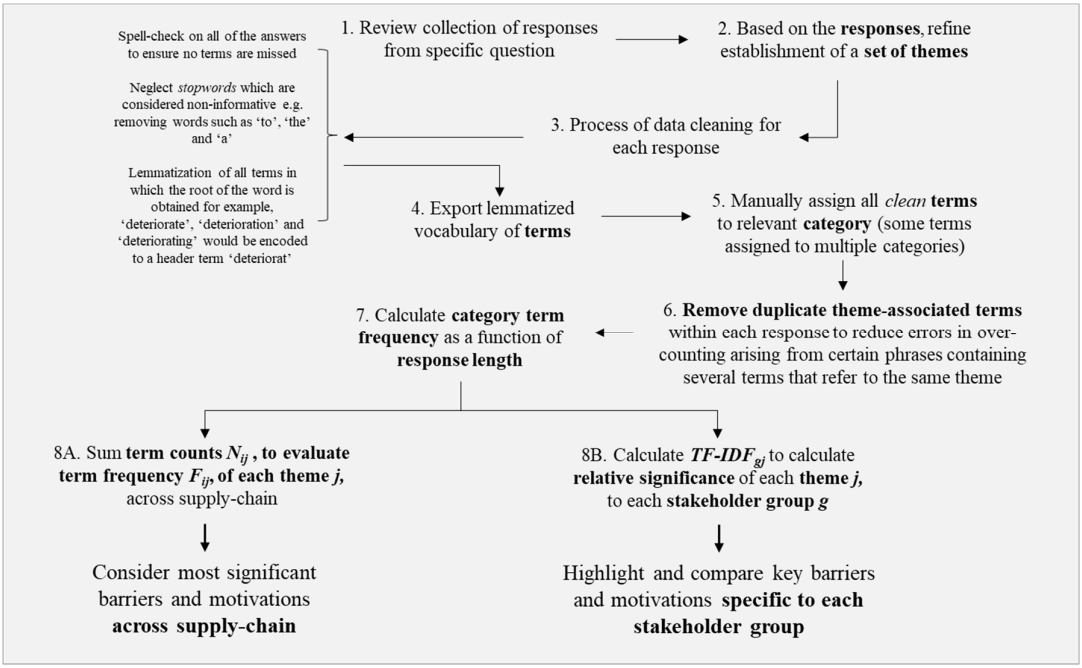

Figure A2: Data analysis process adopted for free-text survey answers relating to barriers and motivations to façade reuse

Term inventories of barrier and motivation themes

All terms within each response were cleaned and then exported and manually assigned to the relevant pre-defined themes listed in table B2. The process of manually associating terms to pre-defined themes is well suited to this study in which a small dataset consisting of 69 respondents in total for each question. Some terms were associated with multiple themes.

Table A2: List of barriers and motivations defined by the authors for text categorisation and their associated term inventories

Notation	Barriers, B_n	Term Inventory
AES	Aesthetic Compatibility	'aesthet', 'appear', 'bespok', 'chang', 'characterist', 'colour', 'compli', 'complianc', 'conform', 'damag', 'degrad', 'eye', 'fashion', 'finish', 'heritag', 'inferior', 'invalid', 'look', 'maintain', 'new', 'old', 'requir', 'restor', 'retain', 'see', 'sound', 'spec', 'suitabl', 'tast', 'visual', 'wear', 'weather'

AGE	Negative Perceptions of "Old" Material	'aesthet', 'appear', 'associ', 'condit', 'current', 'fashion', 'look', 'new', 'old', 'older', 'percept', 'prejud', 'prejudic', 'second', 'sector', 'trust', 'valu', 'valuabl', 'visual'
COS	Economic Cost	'buy', 'capit', 'cheap', 'cheaper', 'cost', 'costplan', 'effici', 'expen', 'expens', 'investor', 'lengthi', 'long', 'market', 'sell', 'time', 'valuabl', 'valu'
DEM	Lack of Demand	'accept', 'agent', 'allow', 'appetit', 'architect', 'buy', 'capit', 'client', 'commit', 'compat', 'compromi', 'consid', 'consider', 'contract', 'demand', 'desir', 'fashion', 'interest', 'investor', 'manufactur', 'market', 'sector', 'trust', 'want','wish'
DFD	Design for Disassembly/Separability	'access', 'adapt', 'aggreg', 'bespok', 'bound', 'build', 'chang', 'characterist', 'coat', 'compat', 'compon', 'conform', 'connect', 'constrain', 'construct', 'demolit', 'design', 'dismantl', 'instal', 'lamin', 'make', 'manufactur', 'modular', 'mount', 'part', 'process', 'pvb', 'reclaim', 'recov', 'recycl', 'redesign', 'remanufactur', 'remov', 'reus', 'seal', 'separ', 'silicon', 'system', 'technic', 'technolog'
DIM	Sizing/Dimensions Mismatch	'bespok', 'characterist', 'compat', 'dimen', 'dimens', 'fit', 'grid', 'match', 'requir', 'size', 'smaller', 'structur', 'suitabl'
EDU	Education: Lack of Awareness/Understanding & Negative Perceptions	'abil', 'abl', 'accept', 'achiev', 'arguabl', 'associ', 'assum', 'awar', 'build', 'care', 'commit', 'confirm', 'consider', 'content', 'data', 'demonstr', 'desir', 'determin', 'difficulti', 'educ', 'highli', 'inferior', 'inform', 'insuffici', 'interest', 'know', 'knowledg', 'known', 'lengthi', 'long', 'may', 'might', 'never', 'new', 'obstacl', 'old', 'peopl', 'percept', 'potenti', 'prejud', 'prejudic', 'probabl', 'quantif', 'think', 'trust', 'uncertain', 'understand', 'understood', 'unlik'
FUNC	Functional Compatibility: Performance Assurance/Warranty/Traceability/Obsolescence	'abil', 'accept', 'achiev', 'asbesto', 'bespok', 'certainti', 'certifi', 'chang', 'compat', 'compli', 'complianc', 'damag', 'degrad', 'durabiltiy', 'durabl', 'energi', 'fire', 'function', 'guarante', 'hazard', 'inferior', 'insur', 'invalid', 'life', 'lifespan', 'maintain', 'new', 'old', 'perfom', 'perfomr', 'perform', 'properti', 'qualiti', 'quantif', 'regul', 'regulatori', 'restor', 'safe', 'safeti', 'spec', 'standard', 'technic', 'technolog', 'test', 'thermal', 'trasnmiss', 'trust', 'uncertain', 'valu', 'verif', 'warrant', 'warranti', 'weather'
INFO	Lack of information	'avail', 'data', 'data', 'degrad', 'determin', 'durabiltiy', 'durabl', 'function', 'inform', 'know', 'knowledg', 'lack', 'perfom', 'perfomr', 'perform', 'qualiti', 'quantif', 'reliabl', 'requir', 'safe', 'traceabl', 'uncertain', 'uncertainti', 'understand', 'unlik', 'verif'
LOGI	Logistics	'access', 'avail', 'availabilti', 'capit', 'chain', 'compat', 'demolit', develop', 'effici', 'exist', 'guarante', 'infrastructur', 'lengthi', 'logist', 'programm', 'remanufactur', 'reus', 'servic', 'spare', 'time'
MATS	Material Selection	'aggreg', 'alloy', 'aluminium', 'aluminum', 'asbesto', 'bracket', 'brick', 'coat', 'compat', 'compon', 'develop', 'dismantl', 'energi', 'finish', 'gasket', 'glass', 'glaze', 'lamin', 'manufactur', 'materi', 'metal', 'process', 'properti', 'pvb', 'redesign', 'remanufactur', 'remov', 'reus', 'seal', 'silicon', 'toughen', 'virgin', 'wear'
REGS	Regulation/Standards	'aggreg', 'alloy', 'aluminium', 'aluminum', 'asbesto', 'bracket', 'brick', 'coat', 'compat', 'compon', 'develop', 'dismantl', 'energi', 'finish', 'gasket', 'glass', 'glaze', 'lamin', 'manufactur', 'materi', 'metal', 'process', 'properti', 'pvb', 'redesign', 'remanufactur', 'remov', 'reus', 'seal', 'silicon', 'toughen', 'virgin', 'wear'
RISK	Risk Aversion	'adh', 'asbesto', 'buckl', 'certainti', 'certifi', 'characterist', 'compli', 'complianc', 'compromi', 'condit', 'damag', 'degrad', 'durabiltiy', 'durabl', 'fire', 'guarant', 'guarante', 'hazard', 'indemn', 'inferior', 'insur', 'integr', 'invalid', 'liabil', 'life', 'old', 'perfom', 'perfomr', 'perform', 'quantif', 'reliabl', 'risk', 'safe', 'safeti', 'spec', 'standard', 'technic', 'technolog', 'test', 'trust', 'uncertain', 'verif', 'warrant', 'warranti'
SUPP	Material Availability and Adequate Supply	'avail', 'availabilti', 'bracket', 'compon', 'demand', 'enough', 'guarante', 'insuffici', 'logist', 'origin', 'part', 'penalti', 'readili', 'reclaim', 'secur', 'sourc', 'spare', 'suppli'
Notation	**Motivations, M_n**	**Term Inventory**
AES	Aesthetic Value	'aesthet', 'appear', 'characterist', 'compromis', 'fashion', 'finish', 'heritag', 'life', 'look', 'patina', 'preserv', 'retain', 'risk', 'rustic', 'stone', 'suitabl', 'trend', 'vintag'
COS	Economic Feasibility	'brand', 'buy', 'cashflow', 'circular', 'commerci', 'competit', 'cost', 'costplan', 'demand', 'econom', 'economi', 'expens', 'faster', 'financi', 'financi', 'fiscal', 'incent', 'market', 'offer', 'opportun', 'price', 'procur', 'save', 'termcost', 'tender', 'valu','viabil'
DEM	Increased demand	'buy', 'cashflow', 'client', 'competit', 'custom','demand', 'fashion', 'incent', 'market', 'offer', 'price', 'request', 'resal', 'specif','tender', 'vintag'
DFD	Design for Disassembly/Separability	'access', 'build', 'clad', 'compon', 'construct', 'custom', 'deconstruct', 'design', 'eas', 'easi', 'easili', 'glass', 'layer', 'manufacur', 'modular', 'process', 'product', 'reclaim', 'reclam', 'remanufactur', 'remov', 'restor', 'simplist', 'steel', 'system', 'system', 'workmanship'
EDU	Education: Increased Awareness & Understanding	'age','appear', 'assum', 'assumpt', 'astm', 'awar', 'compani', 'concern', 'educ', 'ethic', 'incent', 'know', 'messag', 'moral', 'old', 'perceiv', 'probabl', 'provid', 'research', 'resourc', 'stigma', 'uncertainti', 'uncertainti'
ENV	Environmental Drivers & Waste Reduction	'assess', 'carbon', 'circular', 'climat', 'co2', 'credenti', 'eco', 'embodi', 'emerg', 'emiss', 'energi', 'enviro', 'enviroment', 'environ', 'environment', 'footprint', 'friendli', 'green', 'measur', 'messag', 'moral', 'offer', 'raw', 'reclaim', 'reclam', 'recycl', 'sustain', 'virgin', 'wast'
FUNC	Verified Functional Compatibility: Performance Assurance	'adapt', 'age', 'assess', 'assum', 'assumpt', 'astm', 'characterist', 'compromis', 'concern', 'condit', 'contamin', 'data', 'failur', 'life', 'liabil', 'measur', 'per', 'perform', 'preserv', 'qualiti', 'risk', 'strength', 'suitabl', 'test', 'uncertainti', 'verif', 'warranti', 'weather'

INNOM	Innovation: Call for new materials	'aluminium', 'aluminium', 'choic', 'clad', 'concret', 'custom', 'design', 'durabl', 'fibr', 'finish', 'glass', 'insul', 'masonri', 'materi', 'metal', 'modular', 'option', 'polyamid', 'simplist', 'slate', 'steel', 'virgin'
INNOP	Innovation: Call for new design processes	'abil', 'adapt', 'aluminium', 'aluminium', 'choic', 'clad', 'cullit', 'custom', 'design', 'durabl', 'extrus', 'finish', 'float', 'glass', 'manufactur', 'metal', 'option', 'polyamid', 'preserv', 'process', 'product', 'remanufactur', 'remelt', 'remov', 'restor', 'simplist', 'steel'
PRESP	Producer Responsibility	'adapt', 'assess', 'assist','brand', 'compani', 'condit', 'control','custodi', 'deconstruct', 'design', 'eas', 'easi', 'easili', 'enabl', 'ethic', 'failur', 'issu', 'liabil', 'manufacur', 'perform', 'post', 'qualiti', 'remanufactur', 'remelt', 'restor', 'risk', 'system', 'test', 'uncertainti', 'uncertainti', 'warranti', 'weather'
REGS	New regulations/standards	'e1300', 'govern', 'incent', 'legisl', 'regul', 'plan', 'oblig'
SCTS	Improved Supply-chain Collaboration & Logistics	brand', 'buy', 'chain', 'circular', 'client', 'commerci', 'compani', 'competit', 'concern', 'contractor', 'cost', 'costplan', 'demand', 'eas', 'easi', 'easili', 'economi', 'ethic', 'faster', 'financi', 'fiscal', 'incent', 'market', 'model', 'option', 'plan', 'privat', 'procur', 'request', 'specif', 'tender', 'time', 'uncertainti', 'uncertainti', 'valu', 'wareh'
SUPP	Material Availability/ Adequate Supply	'avail', 'choic', 'enough', 'lack', 'option', 'quantiti', 'resourc', 'scrap', 'suppli', 'volum', 'time'

Calculations of term frequency and TF-IDF

The term count N_{ij}, was calculated as the number of occurrences of a term, assigned to associated theme *j*, by respondent *i*. Total response length T_i, is obtained by summing the N_{ij} over *j*. The term frequency F_{ij}, of any mentioned theme, *j*, to a specific respondent *i*, can therefore be calculated using equation 1. The sum of $F_{ij,}$ for each theme *j,* can then be used to identify the most significant barriers and motivations across the supply-chain.

Equation 1:

$$\boldsymbol{F_{ij} = \frac{N_{ij}}{T_i}}$$

The term count N_{ij}, as defined by the total number of occurrences of a term assigned to associated theme *j*, by respondent *i,* was calculated and normalised for the total response length T_i, to obtain the term frequency F_{ij}, of any mentioned theme, *j*, to a specific respondent *i*. The sum of $F_{ij,}$ for each theme *j,* can then be used to identify the most significant barriers and motivations across the supply-chain. To allow for comparisons between stakeholder groups, a well-known statistical approach to information retrieval, originally developed by *Jones*, called *term frequency-inverse document frequency*, TF-IDF was used (Jones, 1972), which accounts for the rarity of terms across documents, and therefore provides a more representative measure of the term frequency to each individual document (Aizawa, 2003; Salton & Buckley, 1988). The TF-IDF for each theme *j*, for each response *i*, was calculated using equation 2:

Equation 2:

$$TF - IDF_{ij} = F_{ij} \times \ln\left(\frac{R}{R_j}\right),$$

where R denotes the total number of responses and $R_{j,}$ the total number of responses containing j. The sum of TF-IDF for each stakeholder group *g,* was then calculated and normalised to account for differences in the total number of respondents within each stakeholder group, to offer an insight into the relative priority of each barrier and motivation theme to each stakeholder group. The recognition of these key themes helped to guide interpretation of the survey findings, and provide direction for the interview phase.

APPENDIX B: INTERVIEWEE BACKGROUND

Brief description of interviewees

Some interviewees were involved with the design of more standardised products; others involved in more high-end bespoke architecture; and yet others involved in the refurbishment and extensions of existing buildings. These included commercial, residential and mixed-used development projects. A short description of each interviewee is described below.

Table B1: List of barriers and motivations defined by the authors for text categorisation

Reference	**Details**	**Interview Date**
Client_1 (CL1)	Listed property group specialising in project management and construction, real estate and development. International portfolio.	Aug-2019
Client_2 (CL2)	Environmental manager at major British property development and investment company. Commercial, residential and mixed-used developments.	May-2020
Client_3 (CL3)	Project manager at major British property development and investment company. Commercial, residential and mixed-used developments.	May-2020
Client_4 (CL4)	International property business that develops, manages and invests in property. Portfolio largely consists of masonry and brick facades with solid-wall construction.	Jun-2020
Client_5 (CL5)	Manage large scale developments of many different kinds including office, residential and mixed-used. The company also continues to own some of their properties.	Jun-2020
Client_6 (CL6)	Large international investor in real estate. Buy, develop, manage and sell properties. Properties include offices, retail and residential,. Also act as building owner.	Jul-2020
Architect_1 (ARCH1)	UK-based architectural practice with a portfolio that includes cultural, educational, public and housing projects.	Aug-2018
Architect_2 (ARCH2)	Asian-based architectural practice mainly focused on low-cost products and design.	Jun-2019
Architect_3 (ARCH3)	British structural engineering company with collaborations in architecture largely involved in bespoke one-off architectural projects.	Apr-2020
Architect_4 (ARCH4)	Small architectural practice that actively looks to source re-use materials and be resourceful on-site. Work with a mix of heritage and contemporary builds.	May-2020
Architect_5 (ARCH5)	Large UK-based architectural firm committed to sustainability. Wide range of projects including mixed-used, residential and commercial properties.	Jul-2020
Main_Contractor_1 (MC1)	Large UK-based construction and civil engineering company with range of projects.	Aug-2018
Main_Contractor_2 (MC2)	Large international construction contractor with range of projects.	Aug-2019
Main_Contractor_3 (MC3)	Large international construction contractor with range of projects.	Sept-2019
Façade_Contractor_1 (FC1)	Engineering design façade consultancy involved in the design of high-end bespoke projects.	Aug-2018
Façade_Contractor_2 (FC2)	International façade consultancy involved in the design of high-end bespoke projects.	Jun-2019
Façade_Contractor_3 (FC3)	UK-based façade consultancy involved in a mix of low- and medium-cost projects.	Oct-2018
Façade_Contractor_4 (FC4)	Façade contractor involved in the development of design drawings and subsequent manufacturer of facades. UK-based projects including commercial, residential and public.	May-2020
Façade_Contractor_5 (FC5)	International façade contractor and consultancy. Largely bespoke system designs.	May-2020
Material_Processor_1 (MP1)	Senior technologist at UK-based flat glass manufacturer.	Sept-2019
Material_Processor_2 (MP2)	Technical advisor at UK-based flat glass manufacturer.	Dec-2019
Material_Processor_3 (MP3)	European based glass manufacturer involved in the manufacture of the secondary processes for glass manufacture.	Apr-2020
Material_Processor_4 (MP4)	Aluminium material processor and façade systems consultant.	May-2020
Material_Processor_5 (MP5)	Production manager at UK-based flat glass manufacturer.	Jun-2020
Material_Processor_6 (MP6)	Glass specifier at UK-based flat glass manufacturer.	Jul-2020
Demolition_Contractor_1 (DC1)	UK-based demolition contractor with a portfolio spanning a large range of construction projects.	Jul-2018
Demolition_Contractor_2 (DC2)	Representative of the UK demolition federation.	Apr-2020
Demolition_Contractor_3 (DC3)	UK-based demolition contractor with a portfolio spanning a large range of construction projects.	Jun-2020
Demolition_Contractor_4 (DC4)	UK-based demolition contractor with a portfolio spanning a large range of construction projects.	Jul-2020

APPENDIX C: SURVEY RESULTS

Table C1: Reasons for façade replacement shown below in tabular format shows average across each stakeholder group +/- 1 std.

	Aesthetic	Cost	Energy Efficiency	Legislation	Performance	Structural
CLDEVMean	3.89 +/- 1.54	2.56 +/- 1.33	2.55 +/- 1.24	1.33 +/- 1.66	3.67 +/- 1.22	1.00 +/- 1.41
ARCHMean	3.53 +/- 1.55	1.80 +/- 1.57	32.93 +/- 1.5	1.93 +/- 1.39	3.33 +/- 1.76	1.47 +/- 1.55
MCMean	4.00 +/- 1.41	2.00 +/- 1.31	2.25 +/- 1.83	1.75 +/- 1.83	3.375 +/- 1.41	1.63 +/- 1.51
FCMean	3.69 +/- 1.40	1.56 +/- 1.41	2.44 +/- 1.79	2.38 +/- 1.63	3.50 +/- 1.37	1.44 +/- 1.50
MMEMean	4.50 +/- 0.71	1.00 +/- 1.41	2.00 +/- 1.41	1.50 +/- 0.71	4.50 +/- 0.71	1.50 +/- 2.12
MMPMean	2.80 +/- 1.87	1.60 +/- 1.50	3.20 +/- 1.23	2.50 +/- 1.58	3.90 +/- 1.29	1.00 +/- 1.33
DCMean	3.38 +/- 2.07	3.75 +/- 1.16	2.125 +/- 2.03	2.00 +/- 1.31	2.25 +/- 1.75	1.50 +/- 1.07
RFMean	3.00 +/- 0.00	4.00 +/- 0.00	0.00 +/- 0.00	5.00 +/- 0.00	2.00 +/- 0.00	1.00 +/- 0.00
Average across all stakeholder groups	3.60	2.28	2.19	2.30	3.32	1.32

APPENDIX D: INTERVIEW RESULTS

Existing priorities relating to sustainability

Stakeholders exhibited varying levels of influence in the design process and sustainability-related design priorities. CLs are looking to create an asset that can appeal to investors and tenants in terms of aesthetic, performance and sustainability, and offer differentiation amongst competitors. Sustainability factors in the client brief were described to be driven by compliance with regulation and existing environmental certification schemes such as BREEAM and LEED. To date, sustainable designs have been focused on improving operational energy use. Many CLs expressed an awareness of embodied carbon however, they provided few examples of its application in project work. Many CLs identified a lack of quantitative measures for justifying design for disassembly (DfD). ARCH3 and ARCH4 described the early design process as being primarily centred around aesthetic and finishes. Designing for re-use and re-cycling was considered of low priority. In some circumstances, "sustainable" design options were described to be 'designed out' by the MC in favour of a lower cost option. ARCH4 highlighted competing factors between sustainability and other design constraints, suggesting that 'some of the building regulations seems to be dancing around each other at the moment.' MCs emerged as being largely driven by minimising cost and risk in system performance, client direction, logistics and availability of supply. One MC described their level of influence in responsible material sourcing 'limited by their later role in the design stage'. FCs and MPs are largely driven by competition and supply-chain pressure and seek to minimise risk and assure product durability in terms of functional and aesthetic design intent, whilst minimising cost of material resources manufacturing processes. Some FCs and MPs felt that they held little agency in material selection. This was exemplified by FC2's comment that 'we are not in the position to lead the design team in a different direction'. FC5 emphasised that to promote re-use, 'you have got to incentivise the CL and the ultimate building owner to come up with the idea and pass it through the procurement chain.' FCs and MPs highlighted some uncertainty in the best approach for reducing whole-life carbon. FC4 questioned 'should we actually be replacing it and making it more thermally efficient because that in turn reduces its carbon factor during lifetime, or do you do we take an old facade and put it on another building?' DCs were found to be predominantly driven by the client brief, project location and maximising profit margins by balancing time and labour costs to remove components with their market demand/value, whilst ensuring health and safety in the completion of projects.

Behavioural: Tables D1-D3 are an extension of table 3 in main paper

Table D1: Existing willingness to stimulate demand for reuse design strategies

Stakeholder Group						
General	**Client/Developer**	**Architect**	**Main Contractor**	**Façade Contractor/Consultant**	**Material Processor**	**Demolition Contractor**
• Varied willingness across supply-chain • Change in approach required from CLs and ARCHs • Some FCs and MPs felt that meeting the ARCH's visual intent was already challenging with high standards, expectations and limited flexibility in requests, which would create a barrier to re-cycling efforts.	• Some CLs felt that specifying re-cycled products would be restrictive on design process. • CL3 described current re-use strategies as rare 'unless there is something quirky or special about what is taken down.' • Some enthusiasm to deploy re-use design strategies to reduce the embodied carbon of new designs in future. • Existing standards offer incentives for responsible material sourcing but not for designing for future re-use. • CL1: 'if it is client-led and client-driven, it is likely to happen, driven by cost and sustainability.'	• Expressed mixed desires to specifying re-use design strategies: specifications for re-use were described as highly dependent on the cultural, age value and longevity of the façade elements; material type and availability; and expected functional performance. • Highlighted a 'negative social stigma' and 'negative perceptions' around the use of re-use and re-cycled materials. • ARCH2: 'ARCHs are not in the position to change, it is mainly client-led who wants it to be problem free.' • Idea of re-use 'slightly like pushing at an open door'	• MC1 proposed that 'there are no true barriers (to re-use) there just exists no current drive for it.' • MC2 and MC3 highlighted that recent project work has shown that there are some customers that are not looking for re-use, but 'some percentage of recycled content.'	• FC5: 'existing demand (for re-use) is minimal.' • Concerns over take-back and reconditioning schemes due to them necessitating a 'significant change to existing operations' and existing business models.	• MP4: 'a client now, wouldn't accept 30-year old standards of weather-tightness, security and thermal performance.' • Acceptance of recycled materials was perceived to be more difficult by respondents in the glass industry for which 'unlike a lot of other materials, there is an issue around technical **and** visual quality assurance'. • MP3 stated that architects seek glass to be 'perfect… we are talking about spots of 1mm, if you sell glass with more spots like that, because we say "but it's recycled", I think no one will accept this, because everyone knows how clear and transparent and not disturbed glass can be.'	• Existing operations are driven by client-dictated program, time and labour costs to remove the components for re-use, and their market demand/value. • Dismantling existing façade systems necessitates scaffolding and a costly manual removal process and therefore was considered as unfeasible within existing CL-dictated timescales. • Limited access to original drawings • Some DCs feared future skill shortages for manual deconstruction methods and predicted that demountable fixings may corrode during their lifetime which could add additional complications to deconstruction. • In contrast, DC3 argued that 'the skill set is there it is just a case of who wants the material? Where will it be re-used?' A lot of time we get asked to save certain elements of things on site – put aside to re-use at a later date but it always ends up in the bin. The client changes their mind, we thought that would be re-used, doesn't actually fit - get rid of it.'

Table D2: Reputation and recognition

Stakeholder Group	
General	**Architect**
• The drivers for greater focus on sustainability were described by some clients as coming through: changes in certification schemes, differentiation amongst competitors and recognition by investors, as well as wider social and cultural pressures. • It emerged from many interviewees that building end-of-life and re-cyclability do not currently receive the recognition that other parts of the life-cycle achieve. • Many interviewees felt that better quantification of environmental savings related to re-use design strategies would help to push desirable 'green credentials' and outward reputation. • Some MPs described their efforts to increase the recycled content of their products as increasing marketability.	• ARCH4 highlighted the influence of awards and other forms of recognition focused on sustainability and environmental impacts. They expressed that clients are becoming increasingly aware of the commercial value of sustainability, 'which then becomes a useful lever to justify greater capital expenditure within the project.' The same architect spoke of some experience with structural elements that had been selected at a premium cost, partly for environmental reasons.

Table D3: Value of façade and aesthetic obsolescence

Stakeholder Group			
Clients/Developer	**Main Contractor**	**Façade Contractor/Consultant**	**Demolition Contractor**
• The building envelope was described as an integral building element for CLs; forming the building aesthetic, defining the building performance, and ensuring robustness and longevity. These factors, considered together with: planning restrictions and existing age value, were mentioned as key factors that would influence the ability to specify re-use and re-cycled products. These factors affect the value of the client's asset and ultimately the building 'has to be a sellable commodity.' • The high perceived value of the façade was found to be a key factor that might inhibit circular strategies because the CL, wants a new aesthetic, sometimes as frequently as every 10-years. • The general perception from CLs was that new materials and products would increase the asset value.	• MC3 emphasised that old systems 'can start to look old and tired.' • MC2 highlighted that 'the envelope is the aesthetic; it is the one element that needs to be bespoke.'	• Some facade contractors expressed that incorporating re-use materials would create constraints in achieving the desired aesthetic. • FC2 highlighted that 'the envelope is what you see and that is why it is perceived as the most valuable component apart from timber frames… the client sees a benefit to invest in a "high-end" façade… the envelope can be described as a commercial product.' • Façade retention schemes were described as uncommon, unless driven by planning, 'because usually… the retained facade just doesn't suit the (new) building.' • Fashion trends and tastes in design for the building envelope can change over a 20-30 year period. • FC3 proclaimed that 'everyone wants new.' The high perceived value of the façade was found to be a key factor that might inhibit the use of re-use or re-cycled products because the client, whom can change as frequently as every 10-years in big cities, wants a new aesthetic. • Expressed that in rare circumstances, CLs accept a compromise in the aesthetic in favour of perceived age value or personal taste, provided the façade system is still functionally performing.	• Some DCs found façade systems may still meet functional performance but due to fast-changing design trends, systems from the 1950s-1990s do not fit the CL design intent and have limited resale value. • DC3 referenced an architectural trend in the 80s involving blue reflective glass which is now considered outdated. • DC1 highlighted notable visible degradation in façade products at their end-of-life, particularly if they are the product of poor construction detailing. • The general perception from clients was that new materials and products would result in increased asset value. DC2 claimed that obsolescence was often a perception and that systems often exhibit few functional issues.

Knowledge Gap: Tables D4-D5 are an extension of table 4 in main paper

Table D4: Lack of information and awareness of material availability

Stakeholder Group				
General	**Clients/Developer & Architect**	**Main Contractor**	**Façade Contractor/Consultant**	**Demolition Contractor**
• Interviewees expressed a limited awareness of materials derived from re-cycled or re-use products due to: a lack of available information surrounding the re-cycled content; lack of communication of any associated trade-offs; and assumed limited availability to meet the demands of large-scale projects. • Main contractors, façade contractors and material processors, expressed that they would then be incentivised to improve their own knowledge of alternative options. • Accessibility to re-cycled products can be subject to market fluctuations in supply.	• Accessibility to recycled materials varies; 'recycled post-consumer glass is very premature and lagging behind other materials such as aluminium.' • Some CLs and ARCHs called for better communication from MPs on the trade-offs of recycled products in terms of aesthetic, function, embodied carbon and cost, to enable a well-informed project consideration. Some CLs and ARCHs expressed willingness to adjust their acceptability criteria and accept a compromise in visual quality, with the right knowledge available and assured performance. • Some CLs recognised that glazing specifications can be 'too onerous' - it was suggested that the clarity of the glass should be more project-specific. • ARCH5 was highly supportive of a change in aesthetic of re-cycled products due to a shift in the mindset of their own practice towards the environmental impact of products. They expressed disappointment with high percentage recycled content aluminium, which has the same finish as virgin aluminium, and felt that manufacturers had not yet understood this new demand. 'We almost want it to look recycled - an imperfection or a pattern that comes from it, to tell that it looks recycled… Information needs to be available as to what differences could be expected and may be good and celebrated - they can be part of the charm… If they look different, sometimes you can justify them costing more.' • Most architects expressed that they have a low awareness of the re-cycled content of façade products, largely because they feel that this information is not readily available. ARCH4 mentioned that they would benefit from the contractors and material processors making suggestions on different material options based on the environmental credentials. • ARCH4 mentioned that 'there needs to be an understanding over what can be compromised, if the manufacturing processors were able to quantify to what degree existing level of post-consumer glass could go back into the float glass tank and what effect this would have on optical quality, clients could make a more well-informed decision.'	• MC1 recognised 'sustainability and environmental benefits' as 'key opportunities' but questioned their accurate quantification. • Seeking materials with high re-cycled content was considered as high on some clients' agendas, 'especially if there is no impact on performance.'	• FC2 acknowledged the need to increase their own awareness of re-use products and recycled materials to be able to better advise the design team away from virign material. • A few FCs called for support from MPs to provide better information to clients on recycled content and availability. • FC5 emphasised that 'manufacturers are most responsible for increasing their own re-cycled content of products.' • Some FCs expected a compromise in performance by using re-cycled products. • Previous experiences of masonry façade retention projects driven by planning constraints had led to a compromise in the building performance. Some clients recognised that glazing specifications can be 'too onerous' and it was suggested that the clarity of the glass should be more project specific. • Some clients felt that specifying re-cycled products may be restrictive on the design process. Some common façade materials were described as easier to access than others; 'recycled post-consumer glass is very premature at the moment and lagging behind other materials such as aluminium.' It was felt by some architects and façade contractors that the existing availability of re-cycled and re-use products would be insufficient to meet the demands of large-scale projects.	• DC2 referenced of an 'online database that was set up 10 years ago to list re-cycling and re-use facilities' but at the time 'it could not be financed and required a lot of resource to make it work.'

Table D5: Awareness of impact of design decisions on end-of-life design criteria

Stakeholder Group				
Client	**Architect**	**Façade Contractor/Consultant**	**Material Processor**	**Demolition Contractor**
• Some clients mentioned that although some standards are starting to consider responsible material sourcing, few standards incentivise designs that can be re-cycled or re-used. • CLs generally expressed low motivation to specify end-of-life design criteria in the client brief • Feared technical limitations, time-lags in the realisation of the benefits of re-use capability, and unknown economic feasibility. • CL3 suggested that prioritising design for end-of-life would necessitate an attributable incentive 'that somehow assisted the idea of reduced carbon footprint.'	• Future end-of-life opportunities are rarely considered as am early-stage design parameter. • ARCH4 recently specified low-iron glass specifically for the 'clarity of the glazing not knowing if that has any impact on its manufacture or environmental credentials'. • Despite not specifically designing with end-of-life in mind, some architects expressed an understanding of the recyclability potential of the materials as constituent elements and considered the façade to have 'relatively high-value at the end-of-life due to recyclability potential.' There was an understanding that the way components are connected may inhibit recyclability potential. • ARCH1 explained his awareness of a pilot project named 'Circular House' delivered by Ove Arup and Partners which included the use of a 'window system with an air separated cavity that was clamped together' mechanically that enabled better separation of systems for component re-use. • ARCH3 described their experience in working on the design for a short-term development project with the obligations to remove the building after a 5-year period where 'everything from the foundations (pile foundations) up to the cladding/envelope will have to be designed to be lightweight and demountable, to then be moved elsewhere around Europe.' In this instance, the main challenges for facilitating re-use lay in the design of connection types, standardisation, considerations on dimensions, weight and transport, to allow for the direct removal, transportation and re-use of the façade systems on a new project. The architect emphasised that the collaborative iterative nature of this design process was different to the typical day-to-day practice. • ARCH5 had a preference for masonry, timber or brick materials, and façade systems based around one material, in the interest of designing for longevity and therefore reducing the whole-life carbon. They expressed that 'materials can be re-used but components and products are more difficult. Re-using stone, timber or bricks is easy to understand. Re-use of composite products is more difficult. Buildings built in the 1960s to 90s are difficult to re-use.' The same architect suggested that the UK is driven by 'cheap' construction methods which can be short-sighted in the context of end-of-life and adaptability. A few other architects echoed this sentiment suggesting that 'there is a trade-off in the advancement of technological systems and opportunity to take back' and that designing for adaptability 'is often compromised by the drive for building efficiencies.' ARCH4 mentioned that in contemporary practice there seemed to be a more 'short-term design approach' which incorporated curtain walling with a reduced re-use capacity and shorter lifespan than those 'buildings which have survived 200 years.' • ARCH1 and ARCH4 called better assessment methods and quantitative information to be able to make well-informed decisions on whole-life environmental impacts. They called for supply-chain upskilling to better understand embodied carbon and end-of-life design criteria. ARCH4 mentioned that 'at the moment, the tools that are available feel like slightly blunt instruments – with BREEAM for example.'	• Varying awareness of the recyclability potential of façade products and ability to disassemble systems for re-use. • Deconstruction not considered a key priority in the original design process which is led by the CL brief.	• It was expressed that deconstruction was beyond the responsibility of the façade contractor and not within existing company policies, because it was not a key consideration in the original design process which is led by the client brief and the supply-chain. • MP3: 'People are more informed and interested in addressing environmental issues. We see are a lot of things popping up, including re-cycling etc. but it is not yet a complete system fitting to each other yet.'	• Highlighted a disconnect between the design process and demolition and described a high level of short-sightedness amongst ARCHs on the influence of material selection on the ability to deconstruct. DC4 expressed that they have been unable to successfully engage with architects over the use of potentially hazardous materials. • DC4 claimed that there is a lack of education and willingness to understand the demolition process. DC4 expressed that in the past, they have been unable to successfully engage with architects over the use of potentially hazardous materials and 'insulation materials that can't be re-cycled' reducing their end value. DC4 further highlighted the disconnect between design and deconstruction was due to a lack of education and willingness to understand the demolition process. They urged ARCHs and designers 'to look at the end use criteria rather than just the new build element and the fact that you are achieving A+ environmental ratings.' • It was mentioned that FCs 'design for buildability and maintenance but not for disassembly'. DCs called for different types of fixings that would make it easier to remove façade products at their end-of-life. • A few demolition contractors believed that re-use strategies would in some way limit the design freedom of new builds due to the lack of interchangeability in components between buildings in terms of aesthetic and dimensions. Demolition contractors suggested that designers and manufacturers would resist the idea of standardisation, due to the perception of an associated lack of design freedom.

Supply-chain Factors: Tables D6-D9 are an extension of table 5 in main paper

Table D6: Existing recycling infrastructure

Stakeholder Group		
General	**Clients/Developer**	**Material Processor**
• Existing levels of re-cycling varied between materials and manufacturers. • A clear distinction must be made between pre-consumer and post-consumer re-cycling; these terms are sometimes used interchangeably by the supply-chain. Pre-consumer re-cycling refers to the recycling of waste offcuts that have been provided by downstream suppliers before it has been incorporated into a façade unit and/or fitted to a building. Post-consumer re-cycling refers to the re-cycling of products after they have spent a period of time in use.	• CL1 expressed that they would be 'delighted to push the agenda to use post-consumer re-cycled glass. It is a niche industry that has the chance to take off rapidly once the motivationscc across the supply-chain are established'.	• MP4 referenced pre-consumer re-cycling in terms of the collection of aluminium production scrap from downstream customers and upstream waste produced during extrusion process, which is re-melted to produce new aluminium billet to be extruded and produced from low-carbon energy sources. This was upscaled to post-consumer re-cycling with technological advancements that were justified through the savings in operational energy, marketability and environmental factors. It was expressed that evidence of reduced embodied carbon helps the marketability of re-cycled product. The material composition of the aluminium alloy is controlled to ensure that the newly produced billets are not inferior in any way to a billet that is produced from virgin materials and therefore no depreciation in value. The costs associated with scrap collection, separation and reprocessing are balanced by the reduced raw material costs and internal savings in energy consumption from the smelting process. This has allowed the aluminium manufacturer to retail the post-consumer re-cycled product at the same output price level as the standard product. However, they emphasised that they are limited in their current collection of post-consumer material to meeting demand. The process is limited to collecting scrap from a certain geographical radius. The aluminium manufacturer emphasised that a key enabler in the success of the retail of the re-cycled product was developing acceptance criteria and the provision of quality assurance to their customers to remove any pre-conceptions of inferior quality products. • Some glass manufacturers highlighted the method of collection of glass cullet from their own customers where they have clear traceability on the sources of the product to return to the float glass tank for processing. In terms of post-consumer re-cycling of curtain walling materials, one manufacturer mentioned that at the façade end-of-life metallic and PVC-window frames are being re-cycled, but glass cullet is not always recovered. Experience of post-consumer glass re-cycling varied with some manufacturers providing no experience with reclaiming from 'installed' glass and others expressing that there are some processes being researched for post-consumer glass but not back for re-cycling back to flat glass. Whilst it was suggested that there is an 'upper limit for the amount of cullet in new glass', values for existing levels of re-cycled content incorporated in new glass production, suggested that there is an opportunity for replacing a large percentage of raw materials with cullet in new glass production. The main fear in re-cycling post-consumer glass resulted from potential contamination with other materials that could set back production in the glass-making process. The ability to detect different glass types to then suggest the best recovery option was bought into question and MP2 mentioned that 'testing for coating and interlayers used is currently possible but would be best undertaken by a third-party for inspection and analysis.' Achieving the required glass composition from post-consumer cullet and managing different iron contents was mentioned as an additional challenge to consider in the recovery and re-cycling of post-consumer glass. MP5 explained that different manufacturers use different iron contents of glass within the same insulated glazing unit which can also make it more challenging to manage the composition of the cullet in the furnace. 'The chemical composition of the new glass you are producing is governed by the chemical composition of the cullet you are putting in and the raw material batch you are producing.' Altered compositions can take many days for glass manufacturers to manage, in which time they are producing a glass of non-standard composition. MP5 explained recent efforts to recycle post-consumer glass from domestic glazing which was described as more simple than commercial builds because 'the age is roughly known, therefore we have an idea of what the composition will be and we can also test it.' In this vein, they concluded that it would be better to have a standardised composition for all individual glass panes manufactured across industry. MP2, MP3, MP5 and MP6 expressed high willingness develop the technical capacity to recycle post-consumer glass if the infill glass could be recovered without contamination. MP3 emphasised that achieving re-cycled contents 'is more of a must than a yes or no.'

Table D7: Demand for reuse products

Demolition Contractor
• Demolition contractors receive finance through the service fee associated with the demolition or deconstruction and the sales of materials that arise from the demolition process itself. As such, beyond client influence, disposal methods, and in some cases the demolition process itself, are largely driven by the available market opportunities of the recovered materials. • The landfill tax, introduced in 1999 at £90/tonne, creates an immediate financial incentive to seek alternative recovery routes that go beyond landfill in the recovery hierarchy. Besides the landfill tax, a mindset of seeking monetary value for recovered materials is engrained in the demolition industry. The salvaging of materials creates an additional revenue stream, for materials that have a market value, in which an additional '25% on top of the project value itself' can be obtained. • Different materials hold different value when taken off site, whilst contractors incur a cost for some materials, others have an economic value which can make it 'worthwhile' to separate on-site. As an example, DC3 proclaimed that the best-case scenario for a building with high recovery potential would be 'a metal sheet clad warehouse made of steel, concrete slab - every single item in that building can be recycled.' • Owing to a well-established global re-cycling market for steel, including sites in Poland and China, it has 'historically been a valuable commodity; three to four years ago, contractors were paying the client to demolish the project to be able to retain the steel.' 'Prices of metal scrap can fluctuate from £200 - £240/tonne, depending on the market, including copper pipework, lead flashings and aluminium.' Existing market conditions have stimulated demolition contractors to demonstrate a 'highly-precise removal of metals, in which they are pried out from the building using a grab-pincer attachment.' 'Metals are separated into one skip and sent off site to be melted down for re-cycling.' • Segregating materials on site enables the materials to have a higher value. Plastic, timber, wood, brick, plasterboard, carpet tiles, waste electrical equipment and fluorescent light tubes are segregated for re-use or re-cycling. 'Timber usually goes off for shredding and goes back into the wood industry.' • Most demolition contractors mentioned that glass is rarely separated from inert material such as concrete and frequently sold on with the mixed inert material for aggregate production. Crushed up inert waste material is generally considered valuable as it can be retained and re-cycled on site for piling mats and enabling works section, reducing the transportation of material on and off site. At this stage, the inert waste as a value of around '£60/20-tonne load'. However, DC4 mentioned that they look to separate glass from other materials on-site if it is large quantities. They would then pay a fee for it to be collected and re-cycled in some way. Some contractors mentioned that unless externally pushed, the ability to separate glass for re-cycling is currently economically unfeasible due the efforts to separate it outweighing the quantity of material recovered. However, some demolition contractors envisaged that the future of demolition would involve a larger number of projects that contain total glazed facades. DC4 mentioned that the nature of newer façade designs that are load-bearing and consist of glazing and steel work will need to be 'dismantled the way they were constructed rather than demolished' which would allow materials and products to retain a higher value. • Market demand emerged as the main driver for encouraging a greater level of deconstruction for high-value product recovery. It was emphasised that in general, if the façade, components or materials has a value and functioning market that will make separation economic, most demolition contractors would be inclined to separate them and/or to store to re-use later.

Table D8: Lack of reuse supply-chain, traceability and suitable logistics

General						
General	**Client/ Developer**	**Architect**	**Main Contractor**	**Façade Contractor**	**Material Processor**	**Demolition Contractor**
• Interviewees expressed apprehension in directly reusing façade systems in new projects due to reservations with regards to the level of maturity of the existing re-use supply-chain. • The practicality of transporting systems and components was considered by several stakeholders. Existing façade re-use experiences were described as very material-specific such as traditional stone- or brick-work but rarely multi-component systems. Building components that are currently recovered for re-use have a high monetary value and can be sold directly to architectural salvage yards. • Issues with the cost of storage and transportation to a suitable buyer in an undamaged state for approval from designers were mentioned by several contractors • Lack of existing examples of façade re-use.	• CL1 mentioned that despite aspiring to see high percentages on the amount of façade re-used in refurbishment projects, the main barrier in specifying re-use strategies that 'the maturity of the industry is just not there. Not just the supply-chain in terms of industry being able to re-cycle materials but also the façade contractors and main contractors to complete the refurbishment itself.'	• Several ARCHs mentioned that they were not aware of any 'existing take-back infrastructure' or 'organised second-hand market/collection scheme'. • ARCH2: 'there is one market available and that is for new components and products.'	• Experience of masonry re-use projects were described as highly labour-intensive and expensive often involving a hand-refurbishment process and found that due to the 'limited supply-chain for restoration', the transportation, protection, storage costs were high relative to new façade renovation projects. • MC1 detailed their experience of re-using the stone cladding of a building driven by planning constraints, client and architect motivations; 'it was taken off and put into storage and then put back onto the building, everything on the building except for the façade was demolished.' Transportation, protection, storage and a hand refurbishment process meant that costs associated with re-use were relatively much higher in comparison with new façade renovation projects. • The logistical challenges in re-use were recognised as being dependent on the type of façade system: 'stone cladding or modular frameworks might have an opportunity for (direct system) re-use', similarly 'unitised systems are mechanically bolted to the structural grid and therefore could technically be removed easily whole through reverse engineering', however it was suggested that they would be more costly to transport to a suitable location without some form of on-site disassembly 'because you are transporting a lot of fresh air.' MC1 mentioned that 'stick systems are multi-component systems which could lead to damage in handling and transportation, some of which damage might be irreparable.' Some contractors and manufacturers called for on-site construction sites to allow for maintenance, deconstruction, sorting of materials and then transportation to re-cycling. • MC2: 'industry is not sympathetic to re-use strategies at present'.	• FC2 evaluated new logistics that would need to be developed to enable re-use: 'products would have to be refinished, transported, adapted, stored and well-catalogued for the supply-chain to work efficiently.' • Some contractors and manufacturers called for on-site construction sites to allow for maintenance, deconstruction, sorting of materials and then transportation to re-cycling.	• MP2 mentioned that the construction process could be reversed by sending the system and its constituent components back through the supply-chain with the same logistics. Such a process does not currently exist and therefore would require a 'whole new industry to be developed to bridge the construction and demolition site back to façade contractors and material processors.' • MP4 described the process that might be necessary to recondition a glazed curtain walling system: 'you could leave the internal framework in, re-use the glass, replace the gaskets, respray external framework, replace cover caps, use new structural silicone if it is an silicone-sealant glazing system, replace rain screen panels, renew the insulation.' MP4 had doubts over whether this process would be cheaper or more effective than replacing the façade as new. Additionally, any reverse logistics process would have some form of associated transport costs which were considered prohibitive with existing business models. Façade contractors can be placed in a variety of different locations globally and linked with a procurement supply-chain that covers many different places globally which could result in high transportation costs. The 're-use value of the façade starts becoming dependent on what you're building and the cost of taking it out of one building, storing it somewhere and bringing it back to put into the new building and the potential for it to be damaged - if it gets damaged, can you still match it.' 'The process (of dismantle for re-use) would not be possible without effective new logistics put in place; it was stated by one main contractor that the 'industry is not sympathetic to re-use strategies at present'. They emphasised that there is 'a lack of existing data and examples of it being done before.' • The global nature of the procurement supply-chain and existing business models were suggested to inhibit the feasibility of any reverse logistics process.	• DCs have limited access to construction drawings of original buildings and fixing details that inform the demolition and deconstruction process. DC4 mentioned that the development of 3D cloud-point surveys in the early design stages could help to recognise opportunities for re-use in the early design stages with better understanding of the size and material type. • DC2 emphasised that the 'industry can salvage the materials, they can be re-used, but it needs to be a combined effort – someone needs to bring them all together.'

Table D9: Existing influence on the demolition/deconstruction process and existing market for reuse or recycled products

Stakeholder Group			
Clients/Developer	**Architect**	**Main Contractor and Façade Contractor / Consultant**	**Demolition Contractor**
• Predominantly interested in the new build; the motivation to re-use and re-cycle existing products from old buildings was described to fall out of the scope of the initial client brief. • Most CLs suggested the DC was responsible for selecting the best recovery route. • CL2: could be 'better at articulating and specifying (recovery routes)' in future by tracking the recovery routes of various materials.	• Most architects mentioned that it was not generally within the client brief to examine the potential of re-using existing products on-site for refurbishments or searching for the best recovery method for each product. • ARCH4 mentioned that re-use was more engrained within their current practice to 'where there is good fabric to be found, we will look for it.' The nature of this style of design thinking means that as a practice, they frequently look for re-use opportunities and where they are available will work with demolition contractors to establish the demolition sequence and effective recovery of materials. This process of design was somewhat unfamiliar to the other architects interviewed. However, it was felt that there is growing interest from clients to start looking into re-use opportunities. ARCH4 described a shift in the architectural profession to looking at circular economy and considerations for embodied carbon in existing designs that incentivise efforts to look at ways to upgrade, re-use and adapt them to a new use so that they carry a cultural value of 'what has gone before.'	• MC2 mentioned that 'some existing design specifications specify what will happen at the end-of-life in terms of re-cycling but not yet re-use.' • MC1 expressed that there is currently a 'lack of appetite for dismantling and re-use materials.' • 'By the time the MC gets involved, they do not have much say in the planning for recovery - components that 'can' be recycled will be recycled' but there is 'no specific focus on façade itself. Recovery is set out in more of a material basis: are they (currently) recyclable? It is not commonly done on a building element basis.'' • Dismantling was described as not currently being undertaken in a way that would favour re-use and was also described as lacking expertise. The process itself was described by MC3 as 'highly labour-intensive and there is a limited supply-chain for restoration, tends to end up more expensive, depending on the condition of the original façade.' • MC1 felt that the 'fragmented' nature of the construction supply-chain provided some limitation for the opportunities in better recovery methods from being realised. Every stakeholder has the 'the same objective but different priorities; in the case of the main contractor it is cost and risk, whereas for the client/developer it is cost.' The 'the current cost for deconstruction is not present in the client/developer's budget'. Under the existing supply-chain, MC2 remarked that the client/developer can 'often receive higher returns by knocking down and starting again.' Façade materials were considered to be 'low value relative to other building elements based on existing practices' and 'costs could become prohibitive under the existing supply-chain.' • FC4 believed that the responsibility for identifying value and managing recovering products from façade systems would lie in the responsibility of the demolition contractor who would 'build into their project brief what he can get for the scrap value of the materials in that project, then the driver of recycling every component out of that design comes from cost.'	• The brief as set by the CL; planning restrictions; geographical location; and available market were highlighted as the main influences on the DC's operations and material recovery routes. Options at the demolition/refurbishment stage include facade retention, full strip out, full demolition, floor-by-floor demolition and cut and carve demolition. Each process can open different opportunities for the recovery route of the façade systems and their constituent materials. • Detailed experiences of façade retention where the original façade was retained whilst the rest of the building was demolished or refurbished were driven by local authorities and planning departments often with appealing visual outcomes. Façade retention projects usually consist of architectural stone, masonry or old brick design. The retention process was detailed by most contractors as involving a large amount of planning, with each project possessing unique challenges which can add time and costs to the project. • Demolition in city-centre projects was described as a careful process, often conducted in a floor-by-floor manner with some materials segregated at source, if considered valuable enough through manual separation or small machinery. Under this careful process, DC4 identified that there may be more opportunities to salvage façade materials and products at high value. • DC4 mentioned that they lacked support from the client/developer in terms of flexibility in specification, time and program to deliver high-quality recovery options. Demolition contractors were aware of the external certifications such as BREEAM which can influence the client or developer brief to achieve credit points. Influenced by BREEAM targets, demolition contractors often conduct a pre-demolition survey, where all the different types of waste streams from a project will be estimated and converted into re-cycling opportunities on a monthly basis. Influenced by BREEAM targets, DCs record re-cycling rates; typically at 96 - 98.5 wt% of each project. There is no requirement to specify the type of re-cycling. • Some demolition contractors spoke of experiences of salvaging building components for reasons predominantly associated with architectural trends/importance, historic value and heritage. These included: 'marble, plaques, bricks and certain parts of the components of Victorian builds', 'chimney pots, natural slate and roofing tiles, butt roof, certain types of brick, London yellow stock brick - we would salvage those if you could clean them, if the mortar is nice and soft it will chip off and you can clean the bricks and they can be reused - red rubbers', 'masonry products', 'certain large bulk timbers', 'foundation stone or a key component of the façade' which would frequently be sold to an architectural salvage yard. • DC3 mentioned that some clients occasionally specify re-use of certain components in a superficial manner. • The demolition contractors interviewed did not detail any experience with quantifying the environmental impacts of project and material recovery routes, however, felt that it would be necessary to better quantify them to create additional incentives.

Technical Constraints from Original Design: Tables D10-D12 are an extension of table 6 in main paper

Table D10: Incompatibility in sizing

Stakeholder Group		
General	**Architect**	**Main Contractors & Façade Contractors / Consultants**
• Compatibility between projects and new designs in terms dimensions and fit was mentioned as an additional barrier to the realisation of re-use opportunities.	• ARCH3 highlighted that the nature of their practice delivering 'bespoke systems' would create challenges for re-use. Re-use was considered as necessitating 'modular' sizes and 'generic' designs. • ARCH1 suggested opportunities for re-use for 'monotonous architecture' in international locations.	• Some of the contractors mentioned that there are challenges in system and component re-use which are a consequence of the bespoke nature of each façade system, lack of standardisation and changing low-tolerance requirements for fit, configuration and functionality. • FC3 and MC1 concluded that the bespoke nature of facades would mean that matching a project with repeated dimensions would be 'very unlikely'. Over the lifespan of the façade, building design trends can change such as storey heights, mechanical and electrical services, leading to changing requirements for the façade dimensions and potentially inhibiting re-use options. • FC5 described current experience of working with new components that had initially been pre-manufactured for a project that had changed geographical location. 'Despite setting the building out identically, and that the product is new and has not been used yet, it is a difficult project, at the moment they can only use a certain percentage (of the new components). Therefore, thinking about the constraints to re-use from an existing building are going to make it very difficult, if not, impossible to use.'

Table D11: Experience and perceptions of functional obsolescence

General	**Client/Developer**	**Architect**	**Main Contractor, Façade Contractor/Consultant and Material Processor**	**Demolition Contractor**
• Re-use design strategies were perceived as 'unconventional' by many interviewees. For many stakeholders, apprehension in the re-use of façade products stemmed from uncertainty in the ability for systems and components to meet their original functional performance within a given time period, the ability for systems to meet standards and legislation through the building lifetime and the consequential effects on marketability. • The complex nature of façade design encompassing permanently connected components with varied service lives was considered as a limiting factor in façade system re-use. Some components can have service lives that exceed their parent system. If the elements cannot be readily disassembled, there is potential for forced functional obsolescence to the nearest permanently connected neighbour with the	• Suggested obsolescence and incompatibility of old façade systems stemming from new regulations and performance standards. • CL2 described the re-use of modern façade systems as posing 'so many challenges around cost, buildability, warranties, insurance and risk.' • Many clients expected that at the stage of refurbishment, 'typically 30-years of age', façade elements would have invalid warranties, which is particularly important for 'investment type buildings', where there needs to be a clear responsibility for potential failure. Beyond the warranty period, maintenance and repair will be a liability of the building owner. • Valid warranties and performance assurance were considered as high priority in stimulating re-use design strategies.	• Some typical performance failures noted by architects in terms of curtain walling performance degradation were suggested as 'ironmongery on windows, EPDM gaskets starting to relax, 'leaking' facades, silicone-bonded glass failure, corrosion resistance behind closed areas, molecular loss mapping, slow degradation of cavity barriers.' 'Glass will often "fail" because of IGU seal failure or leakage of Argon, resulting in them failing in real terms as thermal performance is reduced.' 'Seals and gaskets tend to fail first - due to either incorrect fitting or seals failing early' due to them stiffening, which can lead to a loss of the weatherproof seal and result in 'fogging in (the glass) pane or condensation.'	• MC3 added that 'bespoke projects can entail components being pushed further than they should.' • FC5 highlighted their surprise when they were approached by a client for a 20-year old project with a structural silicone glazing system with a design life of 60-years old. In this instance, the contractor felt that the drive to replace was not driven by aesthetic degradation, but due to 'the perceived idea that it is old', having previously identified fully functioning silicone glazing from the 1980s. • Main contractors and façade contractors typically offer a 12-year warranty for typical modern façade systems, with a design life of 30-years. Within the 12-year warranty period, the main contractor is responsible for any failures and subsequent unit replacement. The mismatch between the warranty lifetime and design life are a consequence of the multi-component nature of the corresponding façade systems; 'gaskets, ironmongery, handles have a 10-12-year lifetime whilst glass, steel, aluminium and cladding components can be up to 30 years.' Beyond the warranty period, maintenance and repair will be a liability of the building owner. Therefore, the provision of a valid warranty and performance assurance on all re-use components and systems were considered as high priority in stimulating re-use design strategies. • FC2 mentioned that through inspection work, they often see that 'components can last a lot longer than their warranty states.' 'You tend to find the most problems happen within the first 12 years of the facade and not much after that.' MP3 had found that on assessment of insulated glazing units (IGUs) with a typical mentioned an assessment that they performed on systems that were at 25-30 years service life and found that 'they were still OK, not only OK, still really in a good shape.' FC4 referenced 25-30 year old buildings where 'the insulating unit is half full of water and their seals have perished… the aluminium polyester powder coating can start to fade… aluminium framework materials can have a lot of surface damage internally which would need to be re-finished.' • MC3 called to formalise the 'process of checking the materials and create new standards that define any testing for the contractor to be able to demonstrate that the materials are fit for purpose' and understand performance degradation. Assessments of existing performance were described by façade contractors and material processors as 'not impossible but just not in existence.' Existing tests for performance validation which could be used as standard protocol in the future were described as basic verification assessments with PASS/FAIL outcomes and no quantitative information on the level of deterioration in performance, if any. Beyond this,	• DC2 described how uncertainty in performance has been overcome to some extent in the steel industry with framework materials that 'can be directly recovered for re-use' through re-certification. DC4 felt that the option to find an engineer to provide validation and redistribute products back to the architects was not currently available for façade components. Façade contractors and material processors echoed this sentiment and implied that testing and reconditioning units to validate their use for an additional time period beyond their typical service life would be difficult. • DC1 highlighted notable visible degradation in some façade products at their end-of-life, particularly if they are the product of poor construction detailing. Common issues included water ingress, mould in sealing areas and degradation of steel profile panels after 25-30 years. FC4 referenced 25-30 year old buildings where 'the insulating unit is half full of water and their seals have perished… the aluminium polyester powder coating can start to fade… aluminium framework materials can have a lot of surface damage internally which would need to be re-finished.'

General	Client/Developer	Architect	Main Contractor, Façade Contractor/Consultant and Material Processor	Demolition Contractor
shortest service life. Some contractors and processors felt that disassembling for component re-use and re-cycling held more opportunities than extending the system service life through reconditioning to enable system re-use.			'there are ways of assessing system performance' such as the thermal transmission. It was suggested that performance assurance / testing could then be provided, in a similar manner to new systems. Some IGU reconditioning methods were mentioned such as flushing them with air to extend the service life. However, these were considered as high-risk in terms of finding insurance and guaranteeing an extended lifetime • FC5 detailed difficulties in managing CL perceptions of functional obsolescence • Some FCs' experiences of façade retention projects driven by planning constraints led to a compromise in performance. • MP3 highlighted that service life was 'unpredictable and dependent on environmental conditions and maintenance.' • Some FCs and MPs believed that disassembling for component re-use and re-cycling held more opportunities than extending the system service life through reconditioning to enable system re-use. MP1 felt that direct component re-use could be made possible if there was a 'way to separate and reseal systems and could have energy-saving benefits but it has never been looked at yet.' Some components were described as limited to their original functional performance and material composition. • Bespoke recovery routes for specific components were proposed, whilst balancing the costs of functional validation with the benefits of re-use. MP3 mentioned that 'monolithic glazing without anything can work for 50 years', making it suitable for re-use in that time period, however MP5 emphasised that once produced, 'you can't do anything to glass to increase its performance' therefore 'glass elements could be taken out and reprocessed to be taken back to glass manufacturers.' Metal components were considered to present opportunities in re-use, 'however, some components would have to be tested to see whether they're a fatigued or corroded, in which case, some contractors suggested it would be unviable financially.'	• DC1 found common issues included water ingress, mould in sealing areas and degradation of steel profile panels after 25-30 years.

Table D12: Original design methods & lack of traceability

Façade Contractor/Consultant	Material Processor	Demolition Contractor
• The evolution in the design of facades in terms of connections, material selection and service life of components was mentioned by some contractors as creating barriers in terms of disassembly and re-use or re-cycling. FC1 stated that 'facades at the moment are inferior in terms of recyclability through the existence of a mix of materials and use of resins and adhesives.' Despite considerations being made for maintenance, these processes are 'not necessarily scale-able for demolition and refurbishment.' Existing systems are not designed for 'rapid removal' to enable the recovery of components 'as would be needed for demolition.' • FC1 emphasised that 'all materials that can be recycled should be. They should be disassembled as they are assembled.' Many changes to the modern multi-component façade systems such as: improvements to the fire-rated core by incorporating polymeric materials; reduced redundancies for adaptation in aluminium profile systems to meet changing regulation in thermal performance; the use of laminated glass; attachments within the IGU; bonded composite timber curtain-walling systems and; the use of silicone sealant glazing instead of dry-fit systems for a 'crisper finish' and reduced labour costs in assembly, were all identified by different interviewees, as potential limitations in disassembly for component re-use. Polymeric materials were described as having very limited re-use or re-cycling potential. • One contractor mentioned that 'wet seals offer poor recyclability potential' and 'mechanical fixings are much better.' Different glass products were identified as having different re-cyclability potential. • FC5 that 'in terms of removing the glass from the frame' in silicone sealant glazing units, 'it can not be done easily. The dry-fit system 'would be easier to dismantle however, by releasing the glazing bead and pulling the four gaskets out, the glass would be released.'	• MP4 summarised the correlation between façade design and ability to re-use as 'the more 'high-tech' a facade, the…less re-usable it is.' MP3 highlighted that 'the complexity of facades is greater than in the past' and existing design focus has been on creating a long-lasting curtain walling unit, not for disassembly. MP3 proposed that evolving design could yet bring about more challenges in re-cycling methods. Further, it was expressed that deconstruction was beyond the responsibility of the façade contractor and not within existing company policies, because it was not a key consideration in the original design process which is led by the client brief and the supply-chain. • MP3 described recent pushes for cradle-to-cradle certifications were described as 'real challenge to get to work with the product range.' Other MPs are working towards environmental product declarations. • MPs expressed different views on the suitability of recycling glass products. MP2 stated that 'laminated glass back into float glass process would not be possible, PVB interlayer, an organic material - would have to be burnt off before going back into float glass process.' 'If you could, separate the PVB it would be good, but a lot of companies that tried to separate the PVB from the glass and it is very difficult.' 'Toughened (glass) is very recyclable.' It was stated that 'coated glass can be directly re-cycled back to the float glass tank. It doesn't cause any problems', 'the coatings are nano-metres thick and therefore do not affect production.' However, several manufacturers felt that the costs and risks for post-consumer glass re-cycling for new architectural glass were too high. MP5 mentioned that the inclusion of more post-consumer glass would be associated with more defects and result in production losses which would have to be managed by the material processor. They felt that 'the correct infrastructure and government funding' would need to be developed to ensure that 'recovered glass could be fed back into the stream that is most appropriate. • Evolving design could yet bring about more challenges in re-cycling methods, with MP3 proposing that the future of the glazing industry would involve 'electrochromic glazing, more coatings, different	• It was commonly mentioned that demolition contractors have limited access to construction drawings of original buildings with fixing details that might help inform the demolition and deconstruction process. DC4 mentioned that the development of 3D cloud-point surveys in the early design stages could help to recognise opportunities for re-use in the early design stages with better understanding of the size and material type. A few demolition contractors mentioned that issues surrounding functional performance validation could be improved using existing technology such as embedded barcodes, to improve the traceability of parts, material grades, stress factors and life expectancy. 'men trying to find fixings without any details.'

Façade Contractor/Consultant	Material Processor	Demolition Contractor
	colours of solar control coating types more float glass types, more laminated and multiple-laminated glass products.'	

Financial Factors: Table D13 is an extension of table 7 in main paper

Table D13: Financial influence

General	Clients/Developer & Architects	Main Contractors	Façade Contractors / Consultants	Material Processors
• Financial feasibility was recognised as a key leverage point in stimulating re-use and high-value re-cycling projects. • Limited understanding in the economics of re-use strategies and associated financial viability of recovery routes due to a lack of example projects that showcase the costs involved in deconstruction and re-use or re-cycling. • Several calls to 'consider the economics and cost model' for different recovery options, including the necessary 'upfront capital investment in order to create a re-use / re-cycling supply-chain' and associated to help justify the business case and/or make recommendations for external government funding.	• CL1: supply-chain is 'mainly driven by cost and not considering the holistic approach/wider impact'. • CL6: 'a significant percentage of the overall construction cost is cladding-related', therefore there is an incentive to look into the economics of re-use'. • CL3 proclaimed that they could be in the position to support and drive the demand re-cycled or re-use projects if the products were made more available, by providing 'a financial bonus for over exceeding certain embodied carbon targets.' • ARCH4 emphasised that 'it is always easier to convince someone to use a reclaimed or re-used material if it is cheaper and available.'	• Some MCs believed that time and labour associated with material recovery would outweigh their economic value in the existing market. • MCs are largely driven by liabilities and therefore re-use projects would require the 'client, design team and contractor to work together to share the risk'. • MC1 felt that the 'fragmented' nature of the construction supply-chain provided some limitation for the opportunities in better recovery methods from being realised. Each stakeholder has 'different priorities: in the case of the MC it is cost and risk; whereas for the CL it is cost.' The 'the current cost for deconstruction is not present in the CL's budget'. • MC2 remarked that the CL can 'often receive higher returns by knocking down and starting again.'	• Façade contractors did not provide examples of the application of re-use and re-cycling design strategies, however there was an assumption that shifting to using high re-cycled content materials and re-use products would involve an increase in costs which 'needs to be addressed' and would otherwise create one of the main barriers to implementing higher value recovery strategies. They felt that in the existing market, they did not have the financial flexibility to request products from manufacturers at higher re-cycled contents if they came at a higher cost. • FC3 felt they would benefit from a 'cost viability spreadsheet that assesses recyclability and deconstruction' to evaluate the trade-off between systems. Higher costs associated with recovery would 'have to be calculated into the original design and supported by the CL.' • The business model of leasing facades emerged from FC3 who felt that despite providing more incentive to re-use and recycle, they would struggle to survive as a company: 'It would be a relatively small amount of money over a very long period.'	• MP5 mentioned that there were no real barriers to using re-cycled quantities of material in new glass production however it was necessary to convince the industry and look at the investment options to realise the opportunity. As with aluminium, the internal benefits of using pre-consumer scrap within the glass manufacturing process have been established in terms of a 'saving on energy and raw material costs', which can create 'huge drivers to use recycled cullet in the early manufacturing process.' Further, the ability to use recycled cullet in new production was heralded as a good selling point for new products. • MP1 proposed one remedy to incentivising re-use would be a leasing business model to 'give more incentive to manufacturers and downstream companies to know more about the quality of products once it leaves first-hand, and their potential for future use.'

Regulatory Factors: Table D14 is an extension of table 8 in main paper

Table D14: Government and external certification

Stakeholder Group					
General	**Architect**	**Main Contractor**	**Façade Contractor / Consultant**	**Material Processor**	**Demolition Contractor**
• External influence in the form of government legislation and/or building standards was mentioned by several interviewees to increase the financial viability of re-use projects. • Many stakeholders associated re-use design strategies with more time and expense and therefore called for legislation to guide the supply-chain away from opting for the option that is currently less expensive. • Suggestions for external influences included: certification schemes that better account for embodied carbon; specific regulations to restrict facades to incorporating only a certain amount of virgin material; effective implementation of a design for disassembly policy; legislative incentives and tax breaks through soft regulation for re-use products; hard regulation on clients to demand re-use material; higher costs for low-value re-cycling; or legislation on quantities of virgin material allowed to market annually and 'credits through tax incentives that might help the client in early stages when commissioning their building at the start'.	• ARCH4 emphasised that 'it is always easier to convince someone to use a reclaimed or re-used material if it is cheaper and available.'	• The effectiveness of other existing certifications was questioned by one main contractor; 'BREEAM and other policies can help to assign credits for innovating - are they good enough? Are there specific counts for re-use?' 'Until we are given more power, guidance or legislation at our level, everything that is decided earlier on is never going to change.' • 'Few CLs would include specifications within the brief unless pushed.'	• FC3: 'unfortunately the drivers for design are cost rather than environmental. As companies look towards their bottom line, they are looking only to build to regulations.' • FC4 felt that 'until it becomes legislation, we're always going to be under pressure cost-wise.'	• Several processors felt that the advancement to a take-back supply-chain would not be possible without some sort of government-incentive to set-up a recovery infrastructure. • Some material processors were highly supportive of legislation to incorporate higher proportions of re-cycled content would help to put pressure on customers to re-cycle post-consumer materials. 'Once it is a legislation, people have got to do it, the cost will end up on the cost of the new building. While it's not legislation then there's no real motivation to do it.' • MP5 commented that current legislation has led to energy transmission rates competing with the ability to re-cycle glass products and 'making the closed loop of recycling more difficult.' • MP2 suggested that 'embodied carbon should be considered more readily in the revision to Part L of regulations to consider the risk of negating the trade-off between meeting performance with higher embodied carbon products. At some stage in the future, there should be more legislation around the topic to consider the whole life-cycle of products.' It was anticipated by the same manufacturer that 'subjects such as recycling and responsible sourcing/other sustainability issues are becoming more prominent and therefore 'more legislation surrounding circular economy at national and EU level likely to affect future regulations.' • MP5 proposed that 'there needs to be a push from local authorities which are granting the planning permission. They need to start stating recycling rates when they're giving contracts out.'	• DC2 proposed a reduced tax incentive associated with a quantitative evaluation of embodied carbon or ability to disassemble products that would add a monetary value to façade elements at the end-of-life.

APPENDIX E: DEFINITIONS

Embodied carbon: provides a measure of the greenhouse gas emissions associated with the extraction, processing, fabrication and transportation of the materials and products used in buildings.

Operational carbon: provides a measure of the greenhouse gas emissions associated with the in-use operation of a building. This usually includes carbon emissions associated with heating, hot water, cooling, ventilation and lighting,

Circular economy: the concept of a closed-loop system of consumption that aims to eliminate waste through the continual use of resources through reuse, sharing, repair, refurbishment, remanufacturing and recycling, minimising the use of resource inputs and the creation of waste, pollution and carbon emissions.

Pre-consumer recycling: the reprocessing of waste materials that arise during the process of manufacturing products to be used in new production.

Post-consumer recycling: the reprocessing of waste materials that have been collected after they have spent a period of time in use.

Design for disassembly (DfD): a design principle that calls for the end-of-life options of how the product, components and materials can be deconstructed.

APPENDIX F: LIMITATIONS OF THIS STUDY

There is some natural bias in this study, in that the respondents that were willing to dedicate their time to a follow-up interview, may have naturally been more interested in the topic itself. It would be beneficial to extend the interviews to additional respondents from each stakeholder group, as well as external stakeholder groups such as existing reprocessing facilities, architectural salvage yards, building owners, and regulatory bodies. Many respondents switched between discussing existing practice and speculative future scenarios. Where possible, the authors have highlighted this difference when presenting the results. It was made aware to the authors that some respondents were unsure about the differentiation between reuse and recycling which may alter some of the survey findings when evaluating reuse potential. The interviewer clearly distinguished the difference between these two strategies in the interview process.