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Adoption of unconventional approaches in construction: The case of cross-laminated timber

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HIGHLIGHTS

- Presents a case study exploring the adoption of novel construction materials.
- Applies a behavioural model to assess barriers to adoption.
- Locked-in actors lack the commercial opportunity to adopt new techniques.
- Lock-in limits the opportunity for those motivated to specify.
- Specific project contexts can align participants' interests allowing specification.

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ABSTRACT

Achieving sustainable development requires the decoupling of economic growth from the use of non-renewable resources. This depends on industry adopting unconventional approaches to production. This research explores the root causes of barriers to the adoption of such approaches in the construction industry, and applies a behavioural model to assess whether companies are hindered by capability, opportunity or motivation.

The long history of lowest-cost tendering in construction has led to a path-dependent lock-in to conventional market-driven objectives of cost and risk reduction; it is suggested that locked-in companies lack the commercial opportunity and hence motivation, rather than the capability, to adopt approaches perceived to increase cost or risk. Such companies will therefore tend to resist unconventional approaches, restricting the physical opportunity for other project participants. This theory is explored in a case study of first adoptions of cross-laminated timber (CLT) in UK projects, using a survey and series of semi-structured interviews.

The case study found that project contexts created market niches. This provided designers, who were motivated to use CLT, the opportunity to promote its use in the project. CLT was seen as key to successful resolution of project constraints, thereby providing motivation to other project participants to adopt the material.

1. Introduction

The global population is projected to grow to around 9.6 billion people by 2050, from approximately 7.2 billion today [1]. With this increase in population, and with each person having a legitimate aspiration for a comfortable lifestyle, the demand for homes, goods, energy and food is expected to increase. Unless economic growth can be decoupled from the use of non-renewable resources, this will, in turn, lead to increasing risks to the future supply of non-renewable resources [2,3].

The construction industry is the most resource intensive industry sector in the global economy. It is therefore exposed to the risks posed by resource scarcity, as well as changes in the availability and prices of globally traded commodities. Reducing the intensity of resource use in construction is, therefore, important for increasing industrial and economic resilience [4].

A shift to more resource efficient construction will require the adoption of novel techniques and behaviours by a traditionally conservative industry. Prior work by other researchers shows that

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attempts to introduce such approaches are often met with resistance (e.g. [5–12]). In particular, Giesekam et al. [13] undertook a meta-study of 1154 academic publications exploring barriers to the adoption of novel technologies. They analysed reported barriers under four headings – knowledge & perception; technical and performance related; economic; and institutional and habitual. Each of these types of barrier points to areas of focus and solutions that might help to reduce barriers to adoption. There is little corresponding recent work exploring the conditions under which such barriers are overcome.

However, prior work in the field of evidence-based practice has shown that interventions to change actor behaviour are more likely to be effective if they target causal determinants of behaviour [14] rather than such manifestations. Accordingly, this research aims to: increase the understanding of the systemic causes of the reported barriers in the construction industry; analyse how these systemic causes influence the adoption of unconventional approaches to construction; explore the contexts under which unconventional materials have been adopted as construction solutions; and propose further areas for study through which these barriers might be overcome.

This research project adopts a critical realist epistemology. Critical realism accepts the realist position that there is an underlying truth that can be described, but holds that attempts to describe that reality are fallible [64]. Critical realist methodologies assume that individuals display bias in responses, and triangulation of responses is encouraged.

The context dependent nature of construction projects means that quantitative approaches alone might be inadequate to identify and reflect the nuances of decision-making around materials. Accordingly, a mixed method approach was adopted to help build a deeper understanding of the problem context. Data was gathered in three phases: a literature review preceded an industry survey into cross-laminated timber (CLT) use. This was followed by a series of in-depth semi-structured interviews, which were analysed using thematic analysis.

As this work is explorative, more positivist, experimental approaches were considered inappropriate. The opportunity for more detailed case study of adoption was limited by the limited time available for the research.

The following section explores the commercial causal determinants of barriers to adoption of unconventional approaches, before Section 3 introduces a model for behaviour change, which provides a framework to analyse these causes. Sections 4–6 describe a case study of material adoption in the construction industry, which explores behavioural aspects of successful adoptions of CLT.

2. Commercial factors as the source of barriers to adoption of unconventional approaches in construction

2.1. Building purpose and value drivers

Buildings are developed for a purpose: to satisfy a need or to move towards some objective. Improvements in pursuit of these objectives add value to the client and are termed value drivers. This value may be financial, but need not necessarily be directly so [15]. For example, a new building may be procured to improve an organization's productivity. One way to achieve this increase in productivity is by improving the working environment [16]. As this increase in productivity is considered important to the client, more emphasis might then be placed on how design and construction decisions positively affect the working environment. This objective may well come into conflict with others, such as that of developing a building with low construction or operating costs.

The delivery of a construction project involves many actors, each with their own notions as to what drives value. When attempting to encourage construction project participants to approach the project differently, it is important to understand what their organizational value drivers are, and how they arose, as this can affect decision-making. The next section explores the conventional objectives of contracting businesses in the construction industry.

2.2. Avoidance of risk to commercial outcomes

The efficiency of the UK stock market means that listed companies that underperform compared to market expectations are at risk of their shares being sold [17,18]. This can lead to a fall in share prices, which, in turn, can make raising finance more difficult and increases the risk of takeover of those companies [19]. Conversely, exceeding market expectations leads to a raised share price, reduced risk of takeover and easier access to finance.

Market expectations of performance are described by a rate of return (profitability) on an asset, such as shares. This expectation is set by the trade-off between risk and return for a given asset, described by the Capital Asset Pricing Model (CAPM) [20]. Broadly, the higher the risk inherent in a share, the higher the required or expected returns. The CAPM model, despite some limitations, is widely used in the finance industry because of its simplicity, and is taught in introductory texts on investment appraisal [21].

For a given asset base, there are, therefore, two broad ways of improving market perception of a company and hence to increase share prices: to deliver lower than expected risk, or higher than expected returns. Historically, in the absence of concerns over resource depletion or global warming, delivering improvements in these areas were the primary conventional objectives of companies listed on the stock exchange. This has important implications for company processes and policies:

- profits need to be maintained (or grown) to fund a constant (or increasing) dividend per share [22];
- certainty of outcome is valued in the delivery of those dividends; and
- risk exposure should be reduced where possible for a given return.

Further, input prices – wages, materials, rents – are likely to be rising through inflation. Therefore, the maintenance of constant or increasing profits requires that either income increases at a rate higher than the rate of increase in costs, or that costs fall for a given level of income.

However, the standard approach to letting out construction contracts, lowest cost tendering, limits the opportunities for companies to increase income for a given contract. This lowest tender approach encourages a reliance on the adoption of enhancements to existing, tested products and processes (incremental improvements) over unconventional approaches to reduce costs or risk. Incremental improvements are preferred as they are based on a technology that is better understood and carries a more certain cost and risk profile [23]. As Mahapatra & Gustavsson explain, 'most market actors prefer to further develop or use existing technology' [9]. Through the need to match the bids of listed companies, unlisted contractors are then indirectly exposed to the same cost pressures.

2.3. Path-dependency and lock-in

Organizations develop know-how when working with construction materials. This confers market advantages by reducing future costs and uncertainty. Companies are, therefore, likely to seek to further enhance that advantage over time by using the same material again [24].

Foxon [25] explores the impact of Arthur's [26] findings on this path-dependent development and improvement process, describing how the advantages gained deliver increasing returns to producers through lower costs, which allows them to secure more work. In turn, further path-dependent development occurs, leading to the domination of one (or more) product(s), in mature markets, and making it very difficult for new market entrants.

The dominant products may not necessarily be optimal from the perspective of the long-term interests of the market, consumers or society, but their dominance reflects the contingent nature of the development process [27]. In structural engineering, path-dependent development appears to be one of the key reasons behind the dominance of techniques that use reinforced concrete and structural steel in all but the simplest buildings [28].

Over time, companies' production, processes, knowledge base and structures become increasingly aligned to delivering their products or services efficiently to meet the market expectations of risk and return using these dominant technologies. Changes to these structures and processes can be expensive [28], threatening returns, so organizations become locked-in to a particular way of working. Lock-in can extend beyond the organization, to the industry, to society, policy and to the education of the next generation of specialists [29,30] as the demands of the market are internalized. However, the degree of lock-in varies by organization in an industry and is, in part, a function of its need to match the market demands of lowest cost.

3. The COM-B System as a framework for understanding barriers to the uptake of unconventional approaches in the construction industry

3.1. The COM-B system

In the face of industry lock-in, adopting unconventional approaches for resource efficiency in construction requires that construction project participants change their decision-making behaviour. This section introduces a model of behavioural preconditions, the COM-B system [31], which is then used to explore how the conventional objectives of cost and risk reduction might give rise to the barriers to adoption described by Giesekam et al. [13].

The COM-B system (Capability, Opportunity, Motivation – Behaviour) is a model of behavioural preconditions that can help diagnose why actors demonstrate resistance to changing their behaviour. The system was developed in the context of healthcare interventions, emerging from a broad analysis of behavioural models from fields including technology, environmental conservation and finance [32]. It forms part of a wider behaviour change system, the Behaviour Change Wheel [31], and has already been applied to areas outside of healthcare including facilities management. To our knowledge, the system has not yet been applied to explore decision-making on the adoption of construction innovation.

Using the COM-B system, researchers investigate the behavioural decision-making context through interview and observation to determine whether a decision-maker, representing the interests of their employing organization, has the capability, opportunity and motivation to display the desired behaviour. Capability and opportunity can both affect motivation, and all three directly affect behaviour. If any of these pre-conditions are not met, then the target behaviour is unlikely to be displayed. Each of these requirements has sub-components:

- Capability – does the decision-maker have the physical and intellectual resources to undertake the behaviour (awareness, understanding, ability)?
- Opportunity – does the social, commercial and physical environment enable the target behaviour?
- Motivation – does the decision-maker have both the reflective and automatic (sub-conscious) motivation to display the behaviour? The motivation driving the desired behaviour must be stronger than for competing behaviours [33].

The COM-B diagnostic investigation highlights which of the behavioural preconditions are limiting the desired behaviour. This data can then be used to inform appropriate interventions and policies to increase the capability, opportunity or motivation of the decision-maker through the relevant sections of the Behaviour Change Wheel [31]. In the context of the decision relating to the adoption of a particular material, a decision-maker may have deficiencies in more than one area, for example both a lack of commercial opportunity and a lack of motivation. This paper aims to explore the decision-making context. The analysis of appropriate interventions is reserved for later study.

The following sections explores how commonly reported barriers to adoption can be explained in the framework of the COM-B system and in light of the conventional objectives of companies. The intervention and policy implications of this exploration are beyond the scope of this study.

3.2. Capability impacts on motivation

'Knowledge and perceptions' was one of the four groupings of barriers in Giesekam et al. [13]. This grouping included as a barrier a 'lack of awareness and practical knowledge'. Further, Giesekam's 'Technical and performance related' heading included barriers relating to a 'lack of [..] data' and a 'lack of [..] demonstration projects'; Zhang and Canning [6] describe how a lack of awareness and uncertainty over properties are the main barriers to adoption; and a lack of technical knowledge was also the second most important barrier reported by Watson et al.'s survey on non-conventional materials [5]. Together these reports indicate a lack of capability on the part of the industry participants.

A common solution proposed to address this information deficit is to provide decision-makers with more information (e.g. [34]). Indeed, information deficit models support this approach, suggesting that providing people with the requisite information means that behaviour will change deterministically (see [35] for an early discussion regarding schizophrenia patients). The COM-B model indicates, however, that although such information, and hence capability, is necessary for the performance of the desired behaviour, it may not always be sufficient to amend behaviour [36,37].

Organizations with a locked-in knowledge base will be required to acquire the requisite skills and knowledge to work with novel technologies. Even with the fundamental ability of actors in the construction industry to grasp these skills and knowledge, training in specific new approaches will still take time and cost money, reducing the commercial desirability of a new approach. As a result, construction organizations facing cost pressures lack the motivation to invest the time or resource to develop capability. Accordingly, attempts to improve capability through information provision alone, in the absence of increasing motivation to act, will tend to fail.

3.3. Opportunity impacts on motivation

3.3.1. Physical opportunity

Each construction project offers the project team as a whole the physical opportunity to adopt unconventional approaches to construction. However, as a result of fragmentation [40] each project is delivered through a temporary coalition of organizations. This means that the adoption of unconventional approaches requires negotiation and trade-offs between the competing value drivers of these organizations [39,40].

At the outset of a project, decisions are led by the client, guided by their advisors. Their early, often high level, value drivers are captured in the contract documents. To the extent that the brief constrains the project at the time of contract, there is an increased likelihood of unconventional requirements being reflected in the final building, as project participants will retain the physical opportunity. The contractor will be in a position to reflect any uncertainty over unconventional approaches in their tender price, creating the commercial opportunity.

When the contract is let for tender, the project design is often incomplete and many design criteria unsettled. At this time negotiating power switches from the client to the contractor [42]. Decisions on the adoption of unconventional approaches, post-tender, are therefore heavily influenced by the contractor's conception of value rather than the client's. Faced with near perfect competition [43], and in the absence of guidance to the contrary, locked-in contractors are likely to be concerned with cost and risk management over non-financial value drives.

3.3.2. Commercial opportunity

The 'economic barriers' described in Giesekam et al. [13] are related to the relative cost or risk of unconventional approaches. In addition to training costs (3.2), unconventional approaches are often more expensive because they have not benefitted from scale economies which have accrued to dominant solutions over the long history of their use. Further, when contractors are uncertain about innovations, they may add a risk premium in their pricing or considerations to reflect their uncertainty over use, performance and outcomes [38] (which again relates to Giesekam et al.'s 'perceptions' [13]). This tends to make an unconventional approach more expensive to the end client, even if the actual purchase price is comparable. A company that is seeking to minimise cost and risk would therefore lack the motivation to adopt such an approach due to the absence of the appropriate commercial opportunity.

Therefore, while locked-in project participants retain the physical opportunity to specify unconventional approaches on projects, they may lack the commercial opportunity, and hence, the motivation to take on the additional costs or risks inherent in unfamiliar products. Such resistance from client or contractor, in turn, restricts the physical opportunity of other project participants to recommend successfully unconventional approaches for adoption.

3.4. Motivation

Finally, Giesekam et al. [13] describe a grouping of 'institutional and habitual' barriers. Many of these barriers describe symptoms of efficiencies driven by the path-dependent development described above – e.g. 'established culture promotes preferred material palette'; 'habitual specification'; 'time constraints'. Together these reflect an internalised view of the value drivers of the wider industry. This view means that decision-makers will lack the automatic motivation to consider alternative materials and approaches.

4. The case of cross-laminated timber

4.1. Introduction

The preceding sections have described barriers to the adoption of resource efficient approaches to construction using the COM-B system. The barriers are seen to arise primarily from a lack of commercial opportunity to increase costs or risk in a cost competitive environment. This in turn reduces the motivations of some actors, and the physical opportunity of others.

Prior work by other authors has attempted to understand, classify and address the reasons why a particular material or approach has not been adopted. Little corresponding work explores why a target construction material or approach has been adopted in the face of such conservatism.

The recent increase in the use of cross-laminated timber (CLT) in UK construction projects suggests that there are contexts under which new products can be introduced to improve the resource efficiency of the construction industry in the absence of regulatory requirements. CLT consists of timber planks, stacked and glued in perpendicular layers into panels, which are manufactured in sizes up to 16.5 m by 2.95 m (see Fig. 1). These are cut to the designer's specification using computer controlled cutting equipment before being delivered and assembled on site [44].

CLT was introduced to the UK in 2001 and its use is growing at a rate of 25% per annum worldwide [45] as 'developers are waking up to the fact they can get their building up and get their money back faster' [46]. The reported relative advantages and disadvantages [47] of using CLT are shown in Fig. 2 below.

One potential disadvantage, which is omitted from this list, is the up-front (capital) cost of CLT. At the time of the research, the price of CLT was higher per square metre of completed building than steel or concrete (£240/m^2 compared to £190/m^2 [49]). However, this material cost is generally offset by the reduced programme time for buildings up to 8 storeys [50]. Financially, therefore, the adoption of CLT is considered cost-neutral when both capital costs and programme time savings are considered together.

This exploratory case study of first CLT adoptions in UK projects seeks to gain an understanding of the contexts under which such unconventional approaches are adopted. The outcomes of these proposals are explored using the COM-B system to examine the decision context for adoption and rejection outcomes.

5. Empirical study

5.1. Approach

An industry survey and semi-structured interviews were conducted to provide cross-sectional information on the conditions for the adoption or non-adoption of CLT. Confirmatory information on the barriers to and drivers of adoption of novel materials was also sought.

The target audience for the survey was 'system integrators' – designers and contractors [41] – who are primarily responsible for decisions on materials selection on construction projects. The survey was distributed electronically to known specifiers of CLT as well as the top 100 architectural practices in the UK, engineers and contractors [51–53]. The survey was also made available through social media. Of the survey respondents ($n = 49$), 55% (*27*) had used CLT on a project. Of the 45% (*22*) who had not used CLT, approximately a third (*7*) had considered using it, but had been unable to get the material adopted, most frequently on the grounds of cost ($n = 5$).

The majority of respondents in this study were architects ($n = 34$). This reflects the skewing of the sample towards architectural practices as the primary specifiers of CLT. The survey findings on barriers were triangulated with the findings of the literature review and results of similar surveys on barriers to adoption – in particular Watson et al. [5] who received responses primarily from structural engineers.

Fig. 1. CLT panel under construction. Source: Stora Enso.

Advantages

- As a renewable material, stores carbon throughout its usable lifespan
- Avoids thermal bridging (in parapet walls or flat roof solutions)
- Good delivery of airtight envelope
- Greater load distribution can reduce thickness of transfer slabs
- Light weight reduces load on foundations so less need for materials with high embodied energy (eg concrete)
- Need for robust upfront design may improve overall design and efficiency
- Robust finished wall will take sundry fixings
- Simple and fast onsite construction process
- Suitable for non-visible as well as exposed finishes
- Vapour-permeable wall construction

Limitations

- Requires accurately set out groundworks
- Requires completed designs ahead of start on site, to allow for offsite manufacture
- Requires external cladding or render to provide weatherproof envelope
- Use limited to above damp-proof course or equivalent level

Fig. 2. Advantages and disadvantages of using CLT [48] © IHS, reproduced with permission from BRE IP 17/11.

Eight interviews were arranged from the respondents to the survey who had used CLT before. Such 'typical case sampling' is considered to be useful in highlighting behaviour drivers when seeking to understand a new area [54]. A semi-structured approach to questioning was adopted to allow exploration of project specific issues raised by the interviewee in response to the pre-planned questions. The interviews were coded according to the pre-conditions to behaviour described above, and sub-categorised to reflect the cause of that impact.

5.2. Limitations and potential problems

The sampling targeted larger organizations and others that are known to have used CLT. A fully random approach would have taken the sample across all sizes of organization, irrespective of their prior experience with CLT. As such, the sampling approach is not random and generalizations of the wider population cannot be definitely inferred. Further, the small sample size for the survey ($n = 49$) relative to total employment in the industry of approximately 2.1 m [65] limits the significance of the findings. However, in the context of the critical realist approach adopted, the data are considered valid as a source of insights [55].

Architecture practices make up a large part of the survey sample set. As such, the views of architects may be over-represented in comparison to structural engineers and contractors. While architects were also over-represented in the interviews, the messages arising from contractors ($n = 2$) and architects ($n = 6$) were consistent. Further, the focus of the survey distribution on system integrators may lead to the views of other industry participants being omitted.

Interviews with and surveys of individuals, by their nature, involve the revealing of opinion. This means that the results are necessarily subjective, as recognised within the literature on critical realism [64]. There is also the possibility for inaccurate reporting of events. This risk was mitigated by asking primarily factual questions rather than seeking opinion during the interviews.

6. Results & discussion

The following sections describe the relevant findings of the survey and interviews. Full details of the study are presented in Jones [unpublished 56].

6.1. Capability limiting behaviour

The most significant barrier to adoption of more sustainable approaches, 'uncertainty over the technical performance' (Fig. 3 and 53% of respondents) demonstrates that a lack of

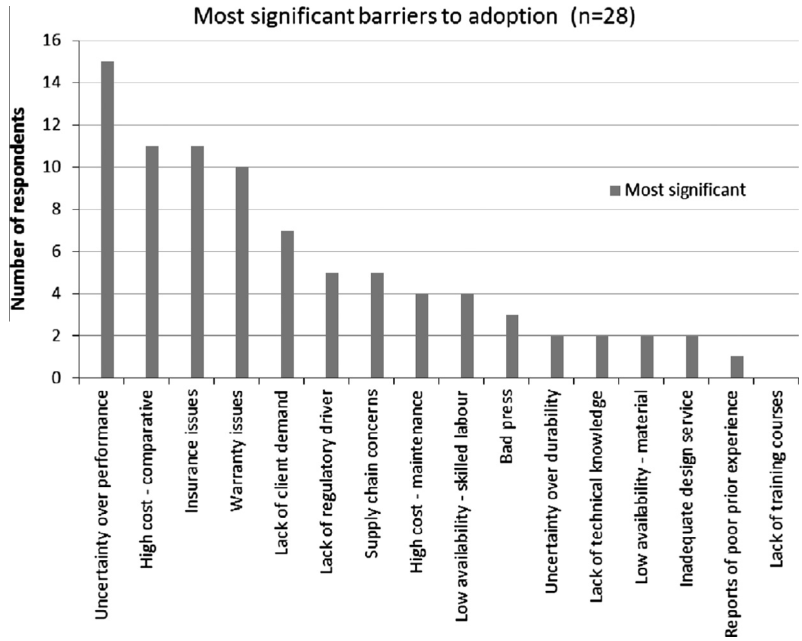

Fig. 3. Most significant barriers to adoption of novel, more sustainable, approaches, products and materials.

awareness of materials and their properties – a capability deficit – might be limiting the adoption of unconventional approaches.

However, the fact that a 'lack of training courses' is the least significant barrier (Fig. 4) and 75% of respondents) suggests that organizations in construction believe they have or can access the capability to use these unfamiliar materials as the need arises. This supports findings in Watson et al.'s study (2013) with an emphasis on attitudes of structural engineers rather than architects [5].

The majority of survey respondents (85%) also agreed strongly or somewhat strongly that their organizations were technically excellent. This suggests that this lack of current capability does not hinder adoption of unconventional approaches, perhaps due

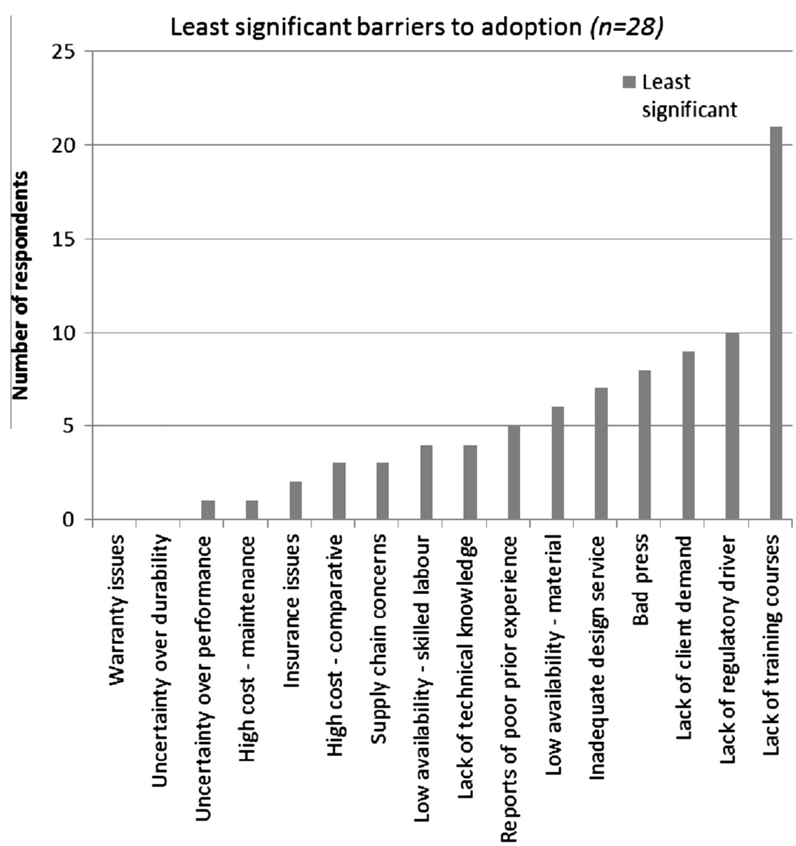

Fig. 4. Least significant barriers to adoption of novel, more sustainable, approaches, products and materials.

to a confidence in the respondents' abilities to develop capabilities as required.

Supporting this view, interviewees presented very few comments indicating a lack of capability in the use of CLT, notwithstanding the lack of calculation rules in Eurocode 5. This suggests that designers and contractors rely on the information provided by suppliers to undertake initial design and on specialist engineers for more detailed construction calculations. Some calculation guidance is provided by TRADA [76] which can be helpful to suppliers and designers undertaking construction calculations. Such reliance is common in the construction industry, with detailed design being undertaken by specialist sub-contractors in the construction supply chain. This approach can sometimes lead to construction materials being wrongly used or applied. This in turn may lead to future barriers to adoption being erected to that or other novel materials, manifesting through a lack of social or commercial opportunity, or an absence of sub-conscious motivation to adopt new materials.

While some respondents indicated that learning needed to happen for the adoption of unconventional approaches, a lack of capability was not presented in interview as a barrier to the adoption of CLT by system integrators [41]. The use of specialist sub-contractors and material producers with the requisite detailed technical and design capability was also described in interview as a way of overcoming an organization's own capability deficits and risk concerns.

6.2. Opportunity

6.2.1. Lack of commercial opportunity affecting motivation to adopt

Earlier sections have described how locked-in organizations are likely to resist construction approaches that they perceive to increase risk and costs, without a corresponding increase in income [see also 9]. This restricts the commercial opportunity and thereby reduces motivation to act.

The survey results indicated that high costs were the second most common cause of barriers to the adoption of unconventional approaches (Fig. 3). This supports the findings in the literature review (Section 3.3.2) [5–12] and reflects the commercial imperative in construction [75]. The survey responses indicate that perceived risk to costs is a key barrier to the adoption of CLT (Fig. 6), with most resistance coming from the quantity surveyor (QS) (Fig. 5). Given the limited nature of the role of the QS, this result is unsurprising.

The impacts of perceived cost on the chances of adoption are reinforced by the responses from companies that have neither used nor considered using CLT ($n = 23$). Of these, a significant proportion decided against using it because of perceived costs (86%) and in the expectation of cost cutting (77%). Murtagh et al. describe this effect in smaller architectural practices [66]. Interviewees also highlighted the perceptions of increased cost as being a significant barrier to adoption of CLT, describing an overemphasis on 'the bottom line' (cost constraints) of the project as preventing adoption.

However, the adoption of CLT is described by many interviewees and the literature as being cost neutral overall [68]. This is because the nature of the CLT innovation allows for project savings to be made, having a positive impact on the construction system, with process changes being delivered by subcontractors who are already skilled in the use of the new technology [70]. Interviewees suggested that the elemental approach to costing adopted by the QS, under which they simply substitute the capital cost of CLT for that of steel or concrete, may be the reason for their presentation of barriers. This suggests that one of the relative advantages of the use of CLT highlighted in Fig. 2 – speed of construction – may be being omitted in the QS's reckoning. This in turn may influence those members of the project team strongly concerned with cost to lack the motivation to specify CLT through a lack of commercial opportunity.

6.2.2. Physical opportunities for the successful adoption of CLT

This empirical study sought to explore the circumstances under which CLT was successfully adopted. Accordingly, this section explores the contexts that provided the opportunity for the use of CLT.

The survey found that CLT use in projects was mostly due to client concerns for the environment (Fig. 7). However, a significant number of respondents indicated that there was no particular client driver for adoption [7]. Subsequent interviews suggested, however, that the question leading to these responses might have limited respondents as interviewees often cited multiple reasons given for adopting a particular material.

Prior work by others in the field of technology transitions describes how early adoptions are likely to take place in niches, or protected spaces [58,59]. Niches can be conceived of as formative markets in which participants perceive value in areas that may be different from those of an organization locked-in to cost and risk reduction [60,61]. Such niches might arise naturally through a number of constraining project characteristics. The

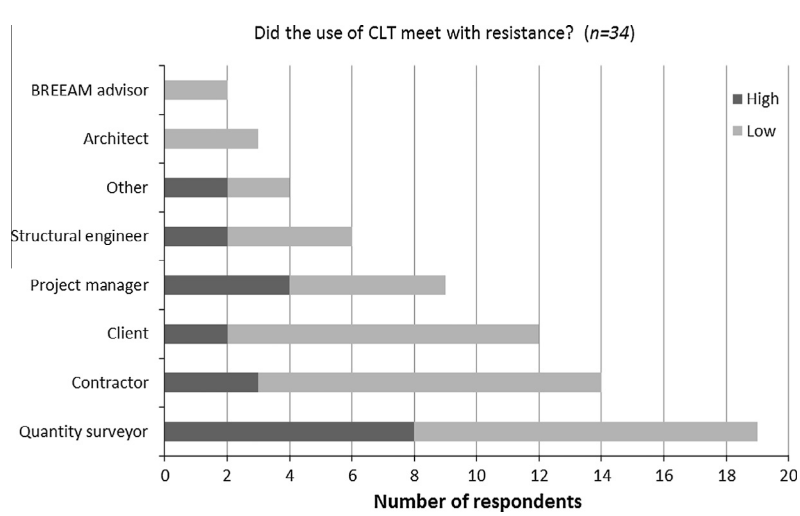

Fig. 5. Strength of barriers presented in projects for which CLT was proposed by source.

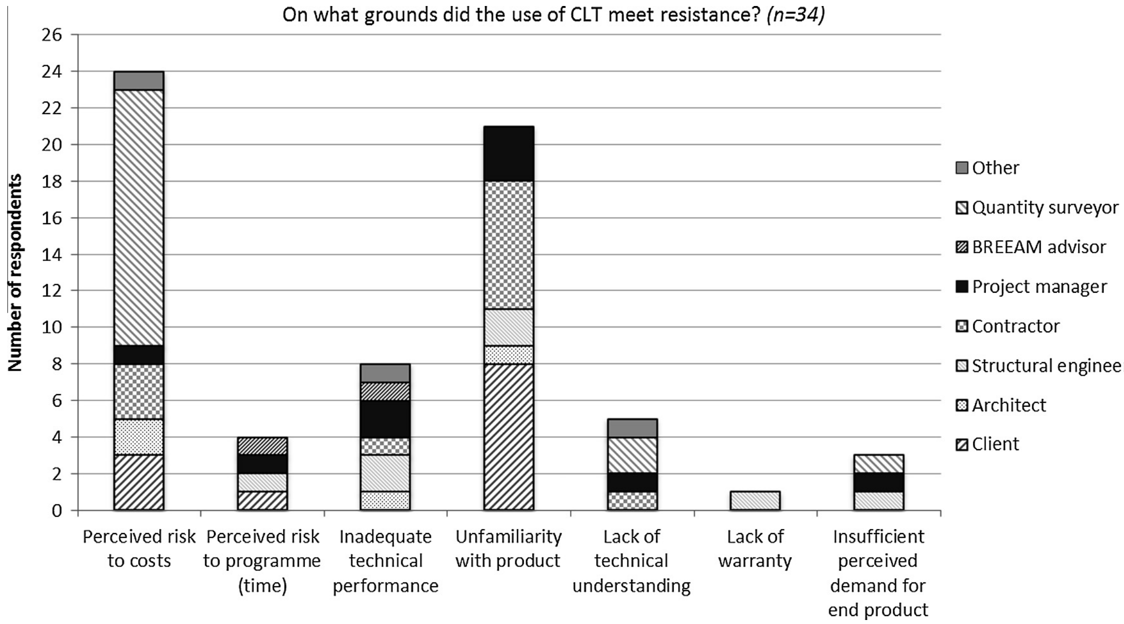

Fig. 6. Resistance to project use of CLT by reason for resistance.

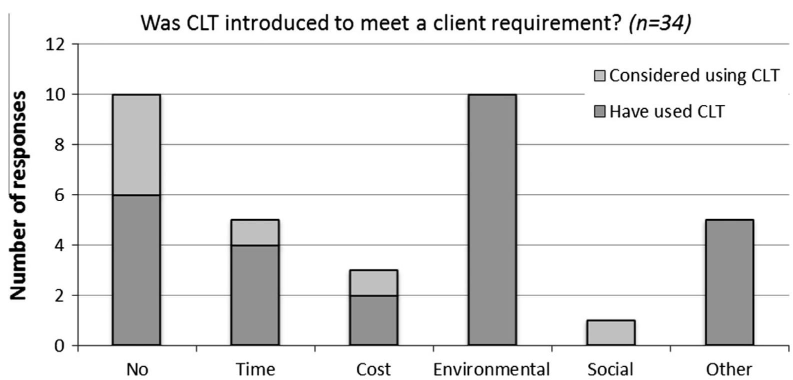

Fig. 7. Client requirements driving adoption of CLT.

potential niches providing a contextual opportunity for the adoption of CLT are explored below.

- Client type. Clients have a key role in the promotion of the adoption of innovations in construction, with experienced clients more likely to be demanding [67,69]. However, two thirds ($n = 20$) of the clients with whom CLT buildings were first developed fell into the categories of private client, public body and charity. This should be compared with the responses for commercial enterprises for which only three projects (9%) were undertaken in this study. Whilst there are no directly comparable figures, construction industry statistics indicate that, on average from 1997 to 2013, private residential and public non-residential schemes account for 36% of the market, with private industrial and commercial ventures making up 50% of the total industry new-build output [62]. This suggests that commercially (i.e. profit) focused client organizations may be considered less likely to be relatively early adopters of unconventional approaches.

One interviewee explored why this might be the case:

'Organizations which don't build regularly have different risk attitudes to those that build frequently. Because they are already doing something that they perceive as risky, it is easier to sell them something different because everything is new to them.'

This position can be contrasted with the attitude to novelty exhibited by more experienced builders who discussed how adopting unconventional approaches required organizations to develop new ways of thinking and to solve different problems. In this context, risk perception increases and concerns arise over the certainty of profit outcomes.

- Future occupants: The majority of projects for which CLT was first considered were for known occupants ($n = 20$, 59%) and 78% of completed projects in the survey were for client occupation or known end-users. This suggests that owners of buildings with known occupants might be open to innovation in those buildings, or have different value drivers from speculative developers. Further, known occupiers are also more likely to be interested in the lifetime cost (and impacts) of their buildings, and so may be more receptive to a trade-off between capital (up-front) and operating costs (perceived or real). They are also more likely to be interested in the selection of materials as a manifestation of the values they wish to project to the world. The nature of the construction client and the client's future relationship with the building is, therefore, considered to influence

perceptions of how buildings add value and hence the likelihood of adoption.
- Building type: The largest number of first adoptions reported is on schools (27%). The nature of these projects is that work is required to be completed to very short programmes and to fixed term-based deadlines to accommodate new students. This means that solutions to construction projects that reduce the risk of over-run will be considered to have a relative advantage and be valued.
- Project value: 65% of projects were valued below £5m, with project values concentrated in the region of £1m-5m (35%). Given that the average cost of a school project at the time was in the region of £25m [63], the values of the projects on which CLT was first adopted by respondents can be considered to be relatively small. While this doesn't mean that the projects are low-risk for the project participants, it suggests that the project might be used for limited experimentation, a factor in the diffusion of innovations [47].
- Project or planning requirements: Planning requirements, design contexts and site constraints were amongst other project context factors acting as constraints on material selection. It was notable that approximately half of the respondents listed impact on project duration, client requirements and off-site manufacture as very important factors in the decisions. Several of the adoptions discussed by the interviewees were driven by time constraints. The ability to deliver a completed building more quickly than in in-situ concrete or steel elements is one of CLT's primary relative advantages over the UK's typical construction solutions [47].

Whilst it is recognised that materials are adopted for more than one factor, the opportunity for first adoptions of CLT was described in interview as being presented fundamentally by: site constraints ($n = 1$); project time delivery requirements ($n = 3$); client business activities ($n = 1$); and the desire to display sustainability ($n = 3$). Other CLT projects discussed during the interviews used CLT for time, cost and planning reasons.

Together, these constraints meant that the 'typical' construction approaches of steel, in-situ concrete or masonry were not appropriate for a particular project. As a result, a different material solution was required. This presented those designers who were motivated to use CLT with the physical opportunity to do so, and to validate the commercial opportunity. Further, the same constraints also provided motivation to others to explore beyond their normal palate of materials so that they could satisfy the project constraints.

6.3. Motivating factors for the use of CLT

Survey respondents were asked to highlight the importance of various factors in their decision to adopt materials (Fig. 8). Technical performance is seen to be key to material choice for the respondent group (96% important or very important). If a material is found not to meet technical constraints, it is highly unlikely to be adopted.

However, almost all other surveyed criteria, apart from end of life options and novelty, were also rated over 50% important or very important. This highlights the fact that a number of reasons can interact for construction material selection, with different actors placing importance on different aspects of those materials.

Designers are the primary group of actors to have proposed the use of CLT (61.7%). This could be a reflection of the make-up of the respondents to the survey or reflect the fact that designers are usually responsible for making the initial decision on project material.

Given the predominance of architects responding to the survey, it is perhaps unsurprising that the highest number of respondents strongly agreed to being design-led (Fig. 10, $n = 13$). The next three categories ranking highest in terms of 'strong agreement' were socially engaged; sustainable; and innovative. This suggests that the bulk of respondents felt that drivers other than their own profits were important in decision-making. This indicates that these respondents may not be fully locked-in to the short-term optimization of cost and risk.

Sustainability credentials were considered very important or quite important (100%, Fig. 9) in deciding to use CLT for a project. This was also the third most discussed topic in the interviews after cost and risk and was mentioned by many interviewees as being an important driver for their organization's adoption of CLT. However, the interviews uncovered that sustainability was a lucky adjunct, rather than the primary driver for adoption. This secondary nature of the sustainability credentials to those of cost were frequently expressed in interview. This relative prioritisation of sustainability by stakeholders reflects findings elsewhere [7,8].

This paper proposes, therefore, that sustainability considerations alone do not provide sufficient motivation to adopt unconventional approaches, when balanced against the demotivation brought about by a lack of commercial opportunity (see also [57]). While the next section explores the positive motivators of adoption highlighted by the study, it is noted that the motivations of actors in construction will vary from project to project and so identifying sufficient conditions is beyond the scope of this paper.

6.4. Value drivers providing opportunity or motivation

Buildings can be designed to minimise cost and risk of construction through the selection of known materials and processes. These materials are known to meet the typical planning and regulatory requirements and to ensure the minimal functional requirements of the end user are met, no more [7].

Interviews described how, in order to take advantage of learning by doing, locked-in contractors would prefer to replicate what has already been done and for the same price or less. This standardization can lead to the economies of learning, scale and expectations [25], increasing understanding, certainty and reducing costs for the contractor.

There are, however, organizations that place value on aspects other than financial and risk management. Designers, for example, may be concerned with the aesthetics of a project; the future occupant might be concerned with the daylighting levels; and a conservationist may be concerned to ensure that the construction did not disturb local species.

CLT was proposed primarily by architects, and at all times before the tender was let. Architects were seen to be likely to agree or strongly agree that they were socially engaged (94%) and sustainable (89%). This indicates that the responding architects might value social and environmental concerns over financial returns – only 17% of respondents agreed or strongly agreed that their organizations are profit focused. This may be a reflection of the nature of architecture practices, which tend to be small and subject to the influence of owners as opposed to disparate shareholders. The fact that the innovation is included early in considerations is also important for two reasons: the first is that it allows the project team to have time to consider the innovation more fully [70]; second it allows the project to be developed around the use of CLT as the 'highest context factor', forming the basis for subsequent decisions (interview 2).

In light of the sustainability benefits of CLT, the architects appear to value the relative advantages offered by CLT and thereby are motivated to specify it. The data gathered by survey did not indicate a consistent picture for contractors ($n = 6$).

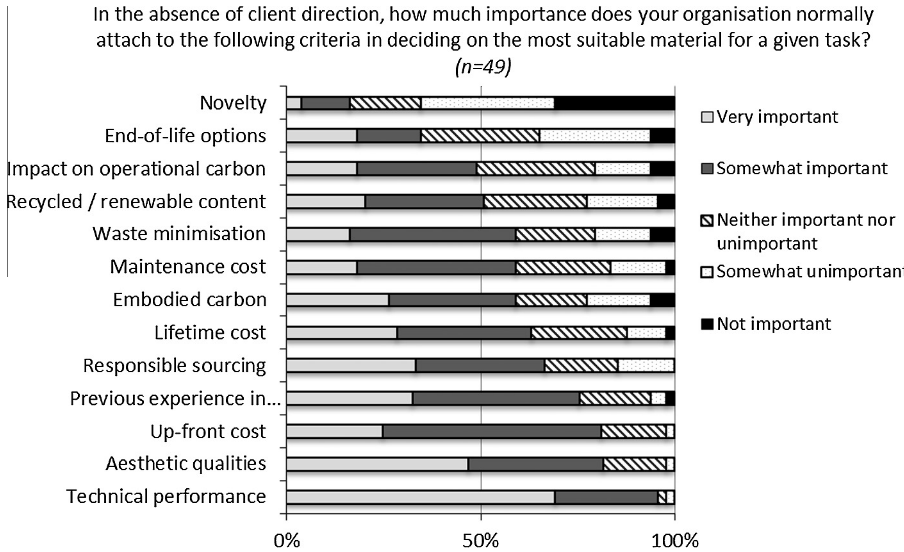

Fig. 8. Reasons for material selection.

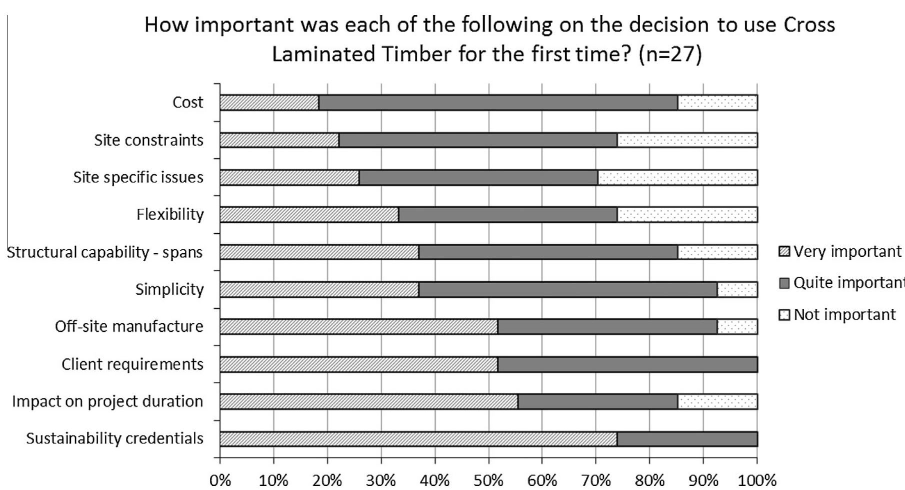

Fig. 9. Importance of factors driving first adoption of CLT.

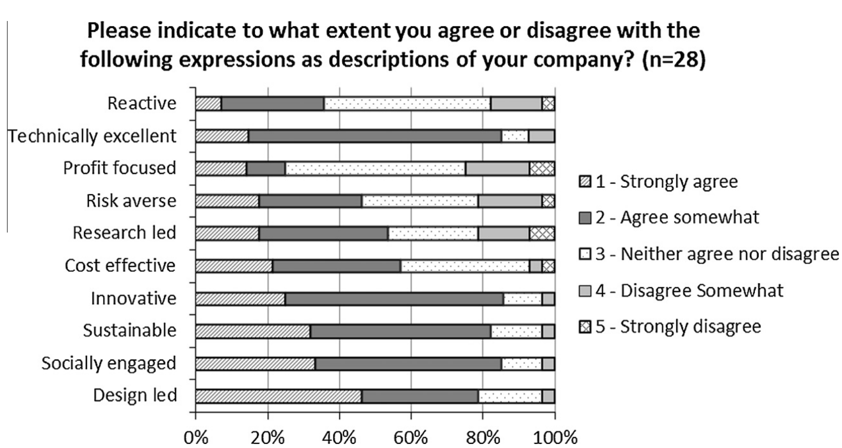

Fig. 10. Company characteristics.

The interviews highlighted the differing value drivers of the design practices, with each designer having a particular approach underpinning their decision-making process. Some practices selected CLT based on the material itself – choosing to work primarily in timber. Others are led by the building and context, choosing CLT as an 'appropriate' material for a given site, or to create a particular spatial effect. Still others chose CLT because of its sustainable credentials, or decisions about resource efficiency.

The complete list of parameters that stakeholders might value is potentially infinite and may, or may not, be articulated during a construction project. Actors can display different value drivers over time as well as conflicting value drivers at a given time. Motivating value drivers will be project, project participant and time specific. As a result, defining universal criteria sufficient to motivate adoption consistently is considered impractical.

Returning to the standardised building described above as being preferred by a locked-in contractor; such a building may well meet the 'locked-in' value drivers of optimized cost and risk, but might ignore the variant value drivers of 'beauty', 'daylighting levels', or 'impact on land use', which may provide value to other project stakeholders.

Stakeholders whose value drivers are not addressed in the development of a project will lack the motivation to approve decisions surrounding the building, presenting barriers against aspects of it that are not in accordance with their value drivers. The effectiveness of these barriers, though, is dependent on the relative negotiating power of the actor at the time of material proposal.

These findings contributed to the small but growing number of studies that conclude that motivation is a key barrier to adoption of unconventional materials [71–74].

6.5. Synthesis

The conventional objectives of listed UK contractors are the reduction of risk, cost reduction and revenue maximization. All other things being equal, listed organizations will seek to optimize these parameters, setting their objectives as risk and cost reduction or revenue increase. Path-dependent lock-in occurs through a long-term focus on cost and risk reduction.

For a particular behaviour to be displayed in a construction project, actors must have the capability, opportunity and motivation to display that behaviour. This study suggests that, while contractors have the physical opportunity to improve resource efficiency through the specification of unconventional approaches, uncertainty over the commercial opportunity means that they lack the motivation to specify them. Designers, who may be motivated to adopt an unconventional material in line with their own drivers of value, are often constrained by other, more influential, project participants and therefore lack physical opportunity to adopt the unconventional approach. Some designers, with an eye to reducing their own costs, internalize the contractors' requirements and thereby tread along the pathway towards becoming locked-in themselves.

While resource efficient solutions are perceived as more costly or risky than standard construction materials, there will remain a tension between the value drivers of those seeking to adopt unconventional approaches to enhance resource efficiency and those more focused on the delivery of cost and risk certainty. In the absence of mitigating client, site or regulatory constraints, a proposal to adopt an unconventional solution may be perceived as adding unnecessary cost or risk. This is likely to be met with resistance by those sensitive to cost and risk, as their conceptions of value drivers are being threatened.

However, project contexts can create niche-like conditions, which rule out the dominant technological solution to a particular construction problem. This might arise from these same client, site, technical, or regulatory constraints. These constraints provide project participants with the commercial opportunity and hence motivation to explore and adopt unconventional approaches to address these constraints. Those designers, who already have the requisite motivation, by the same means, are presented with the opportunity to use the novel material.

7. Conclusion & further work

7.1. Conclusion

This paper has investigated the systemic factors limiting the adoption of unconventional approaches in construction. These were found to be the conventional objectives of risk and cost minimization arising from the long-term use of lowest cost tendering for construction contracts, and the need to meet market expectations of risk and return.

Barriers to adoption presented in research have been described as arising from path-dependent development processes, which result in a lock-in to the use of dominant technologies to deliver these expected returns. In the absence of enabling project contexts or regulation, unconventional approaches that are perceived to increase costs and/or risk are unlikely to be adopted by locked-in organizations, as they are perceived to threaten value.

The research has also explored the role that the COM-B system can play in understanding how barriers to adoption arise, studying the adoption of CLT as an example of an unconventional material that has been adopted successfully. This is a new application for the system, and points towards ways in which the barriers might be overcome.

The COM-B assessment found that designers with values promoting CLT use (eg sustainability, aesthetics) were motivated to use the material, and then developed sufficient capability and sought the opportunity to specify the product. Contractors and quantity surveyors, however, were seen to have the physical opportunity to propose novel solutions on projects, but lack the commercial opportunity and hence motivation to do so. They were confident in their capability to adopt should the need arise, in part using specialist sub-contractors.

A key contribution of this paper arises from the COM-B diagnosis of the CLT adoption study: future attempts to encourage adoption of unconventional materials should explore the commercial opportunities of adoption or non-adoption, rather than the capability deficits. Such a view directs study towards the demonstration of commercial opportunity through value generation.

To increase the likelihood of adoption, participants should identify the unique project constraints and value drivers that might allow the motivations of the participants to be aligned. Any unconventional approach proposed to address the identified constraints and deliver value must demonstrate a relative advantage over the typical construction solutions without jeopardizing cost and risk outcomes.

It is clear that regulation on resource efficiency would effectively align the motivations of all project participants and lead to increased adoption of resource efficient techniques. However, in the absence of such regulation or aligned motivations, those project team members who are motivated to adopt unconventional approaches in pursuit of resource efficient construction are likely to continue to be frustrated by the lack of physical opportunity to adopt unconventional approaches.

7.2. Further work

Further work is proposed to increase the likelihood of the consistent adoption of unconventional approaches on a project-by-project basis to deliver resource efficiency. Future areas for research highlighted by this project are set out below.

- Validation of the COM-B diagnosis. This project has developed an understanding of the drivers of adoption of CLT in the context of the COM-B system. The results presented, whilst informative, cannot be considered as fully representative due to the limited sample size. Further work would validate the inferences developed. Such work could also begin to identify circumstances under which CLT might have a higher chance of adoption and to test the intervention recommendations of the Behaviour Change Wheel.

- Organization non-financial value drivers and the impact on material choice. Organizations may be motivated by value from outcomes other than simple cost and risk reduction. These unconventional value drivers represent objectives that can have a bearing on the decision to adopt an unconventional solution. Further work should explore any link between these objectives and material choice.
- Improving capability – Material selection processes. This research project has highlighted the importance of an unconventional material's relative advantages and visibility in the market place (observability) in enhancing the chances of adoption. As such, techniques for developing awareness of these factors would aid in overcoming barriers to adoption and would represent a useful avenue of research.

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