Building energy efficiency: a value approach for modelling retrofit materials supply chains

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Energy Efficiency Retrofit (EER) forms a critical component of strategies to reduce energy demand and is increasingly a source of investment and added economic value. While there is a growing body of literature on the technical aspects of EER, research to date has typically focused on the project or component level, to the detriment of system-wide studies. Understanding the materials and monetary flows within supply chains and the value interactions between stakeholders is vital in optimising the long-term capacity of the sector, and increasing the uptake of EER solutions. This chapter forwards a value approach to modelling retrofit activities, providing an analysis of typical EER materials in construction project supply chains. The reported research demonstrates a novel application of value analysis in the construction industry.

Keywords: energy efficiency; buildings; retrofit; value analysis; models

1. Introduction

The built environment accounts for 30-40\% of global energy consumption and associated greenhouse gas (GHG) emissions [1], offering the greatest potential of any domain for energy savings and avoidance of GHG emissions [2, 3] and at high benefit-cost ratios. Accordingly, reducing the energy intensity of buildings is increasingly a priority in energy and environmental policies in European countries [4]. Retrofitting energy efficiency improvements to existing building stock represents an important part of this, without which, OECD nations would have used approximately 49\% more energy than was actually consumed over the 30 year period to 1998 [5]. In this context, retrofit projects represent a significant and growing sector of the construction industry, and a major source of investment and added value. Eight of ten European buildings existing today will still be in use in 2030 [6] emphasising the importance of encouraging building Energy Efficiency Retrofit (EER) initiatives.

Additionally, as buildings become more energy efficient, the relative importance of non-operational energy components so-called embodied energy, such as that involved in the extraction, processing and manufacture of construction materials grows and the need to consider energy, and energy efficiency on a lifecycle basis increases. Within this context, developing optimal energy retrofit strategies involves many external uncertainties (\textit{e.g.} climate change, human behaviour, public policy [7]), multi-dimensional performance metrics (\textit{e.g.} energy, financial return, GHG emissions [8]) and varying constraints (\textit{e.g.} structural limitations, climatic locations, supplier capacity).

Designing policy instruments to increase the uptake of EER solutions also requires ‘satisficing’ the needs of multiple actors involved at various junctures in the lifecycle of buildings [9]. Understanding the material and monetary flows within this ‘sector’ and the value interactions between stakeholders is vital in optimising long-term capacity [10] and thereby increasing uptake. To date there has been a dearth of research into value creation activities across the dynamic inter-firm networks characteristic of retrofit projects. This chapter presents a value approach to modelling retrofit supply chains and associated activities.

2. Construction project supply chains

The construction industry is highly heterogeneous, and its components are not conducive to easy characterisation and analysis. In considering the EER ‘sector’ in particular, care should be taken not to misinterpret this as being necessarily a group distinct from the rest of the construction industry. There is a great deal of fluidity among companies involved in EER activities, many of whom may be involved in the provision of both ‘conventional’ and energy-efficient solutions to meet the needs of different projects and who therefore move in and out of the sector depending on the specific project on which they are working [9]. Businesses delivering building energy retrofit projects should therefore not be viewed as separate from the construction industry, but rather as those companies within the existing industry who are working towards a new goal of energy efficiency. Building upon Goldman \textit{et al.} [11], Genovese \textit{et al.} [12] see these activities as forming a multi-faceted ‘Energy Efficiency Retrofitting Services Sector’ that addresses the design and construction of homes and buildings, and the installation, use, and maintenance of high-efficiency equipment.

Construction processes, both conventional and energy efficiency focused, are not standardised in the same way as those associated with manufactured goods because of the unique characteristics of each building project [13]; these projects do not involve combinations of otherwise standardised details as found in modern car production, for example, but result in products that differ significantly in their individual specifications and details [14]. Whereas manufacturing identifies the market’s value parameters and develops the product accordingly, construction integrates product...
development with the actual production process [15]. Construction supply chains illustrate the complexity of construction projects and processes, as well as the difficulty with cross-project comparisons. Construction supply chains include all business and other organisations which are involved in the process, from the extraction of raw materials to the eventual demolition of the building and disposal of its components [16]. Individual supply chains may have been established for a multitude of commercial and practical reasons, resulting in a whole that is extremely complex, characterised by complicated individual processes in-and-of themselves, and by interactions between processes, disciplines, and organisations, all subject to effects of dependence and variation [17].

The principal material supply companies are likely to be dependent on many other firms who provide various inputs to their production. Similarly, the main trade contractors will have their own supply chains and many of these will further subcontract out smaller work packages [18]. The specialist construction subcontractors will usually be much smaller firms and several of these may be providing labour-only services. The composition of the overall project supply chain or network will tend to be unique to a specific contract, although some favoured suppliers are likely to be used repeatedly by individual main contractors [18].

The large number of participants working on a project-specific, temporary basis in construction ensures that the planning and management of supply chains is particularly challenging [19]. This network of companies can often be extremely complex, particularly on larger projects where the number of separate supplying organisations may run into hundreds, if not thousands [18]. Furthermore, characterising these project as networks is complicated because ‘like-for-like’ construction projects, which would facilitate such characterisation and the cross-network evaluation of contractor performance attributes [20], do not exist. Even where similar construction products are found, other vagaries such as site conditions, geographical location and project timing all make generalisation and comparison difficult, and suspect if not carefully designed. The complexities of international comparisons are further compounded by, for example, the different cultures, languages, regulations, standards and customs of the countries involved [21].

Due to the unpredictability of both the market and the construction process, building projects are frequently a ‘make-to-order’ business, with no overall production schedule [21]. Construction therefore demonstrates many of the characteristics of a project industry. Projects are often carried out in a context of high complexity and uncertainty, which call for organic organisational structural characteristics [22]. A typical characteristic of project industries is the frequent lack of a continuing relationship between the main actors, which complicates attempts to coordinate interdependent activities [22].

An agile and flexible supply chain is a way of coping with the high levels of uncertainty manifest in the construction industry [23]. The planning and management of supply chains requires, in the first instance, a full and comprehensive analysis to properly identify the participating members and to characterise the relationships among them [19]. Furthermore such understanding contributes to the development of a policy context that facilitates and promotes business models in which all actors can see benefit, resulting in increased capacity and ultimately greater uptake of building energy efficient solutions in the marketplace.

3. Characterising materials supply chains - a value approach

3.1 Methodological Approach

The conventional means to understanding markets is through value chains, a concept that has emerged from the business management literature. Porter’s [24, 25] conceptualisation of value chains, consists of five primary activities: inbound logistics; operations; outbound logistics; marketing and sales; and services, as well as supporting activities. Typically, value chain analysis (VCA) deconstructs the stages that a product follows from the very beginning of its production to its final sale, and beyond. Suppliers or distributors of the product may also be considered in the analysis, especially where there are critically important linkages between the various organisations in the chain [26]. The value chain concept maintains a central role as a framework for the analysis of company-level competitive strengths and weaknesses [27]. In its most common application, VCA is a strategic management or cost accounting tool used to diagnose and enhance a company’s competitive advantage as well as the efficiency of the operations of several actors in an industry-wide value chain [10].

The traditional view of value creation as based on value chains has changed and the focus is increasingly on more broadly defined value-creating configurations [28]. These can include value chains, value networks and value constellations. A value network can be defined as any set of roles and interactions through which people engage in both tangible and intangible exchanges to achieve economic or social good [29]. The value network paradigm therefore models companies that create value by facilitating a network relationship between their customers, typically through application of mediating technology [27]. A network perspective is increasingly necessary as few companies are involved in only one ‘chain’, and the conditions for efficiency in a single chain are largely determined in terms of how the activities and resources are related to those in other chains [28, 30].

There is a scarcity of value chain and value network literature specific to the construction industry and to building construction. The limited literature available generally focuses on the perspective of large construction companies, and emphasises issues of market share and profit generation [9]. A lack of systematic investigation has to date made it
difficult to evaluate value creation across the business relationships characteristic of the construction industry [31]. In addition, clearly defined producer and consumer roles are not forthcoming in the construction industry and the use of the building as a product is likely to be far more complex, multi-dimensional and contested than that of the single manufactured products typically addressed by VCA (e.g. fabrics, shoes, mobile phones) [9]. However, the value concept is now assuming greater importance in the study of construction projects, particularly as triple-bottom-line aspects are increasingly important in project outcomes. In the past, value in construction was defined primarily in monetary terms, but recently, customers have attached greater priority to previously marginal dimensions, such as the ecological sustainability of supply chains [32]. Value has also come to be defined in terms such as function, quality, aesthetics and environmental performance [33]. For the energy efficiency sector, there is a need for clarity on the contribution of various measures across multiple criteria, time-spans and boundaries of responsibility, including cost, emissions and energy use, all of which can be encompassed by a value concept [9]. Value approaches therefore provide a useful conceptual framework through which to manage, assess and analyse complexity in the construction sector.

For the value approach applied in this chapter, value is identified across the system though application of a ‘value chain network’ model, in recognition of the more fluid and networked supply chains of the construction industry. This approach is applied for a number of reasons. Mapping the value chain network and constituent business models for each link in the chain could also allow for comparisons across the various sub-sectors in the value chain [34]. A holistic view of supply chain interactions allows for the evaluation of overall performance of material handling, distribution, and information flow through every link of the chain [35]. The selection of the supply chain as the unit of analysis enables a focus on the wider functioning of the construction and energy efficiency sector, in contrast to a more project specific focus. This focus enables consideration of the best means to promote the overall viability of the temporary multi-firm value-generating activities at that stage, with a particular focus on stakeholder roles and positions within wider supply chains and on value configurations and the interactions between stakeholders.

### 3.2 Defining lifecycle Hubs of Activity

The initial stage of analysis considers the various activities that are associated with the delivery of EER solutions across the expanded lifecycle of EER materials and material combinations in retrofit projects. Six lifecycle stages, or Hubs of Activity are described in Table 1, derived in Dunph et al. [9] after work reported in the literature [36-39].

<table>
<thead>
<tr>
<th>Hub</th>
<th>Example of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Upstream activities</td>
<td>Extraction of raw materials, manufacture, transport, etc.</td>
</tr>
<tr>
<td>(2) Initiation &amp; viability check</td>
<td>Original proposal, making business case, etc.</td>
</tr>
<tr>
<td>(3) Design &amp; planning</td>
<td>Designs, building plans, project plans, etc.</td>
</tr>
<tr>
<td>(4) Construction and/or installation</td>
<td>All site activities</td>
</tr>
<tr>
<td>(5) Operation and maintenance</td>
<td>Use and upkeep</td>
</tr>
<tr>
<td>(6) End of life and downstream activities</td>
<td>Deconstruction, reuse, recycling, disposal, etc.</td>
</tr>
</tbody>
</table>

The activities outlined in Table 1 may be distanced by significant timespans. Raw materials may be extracted many years before the idea to construct the building has even been conceived, or many years after in the case of a refurbishment of an historic building. Likewise, materials and components removed from the building, during or after its occupation may be reused within the building, or elsewhere. For any given construction project, life cycle impacts are also highly inter-dependent, as one phase can influence one or more of the others. Categorising activities into six Hubs of Activity in this manner assists in the deconstruction of the lifecycle, enables mapping of the EER marketplace and facilitates identification of key stakeholders [9]. This analysis is performed in a generic manner in this chapter from which project-specific models may then be developed.

### 3.3 Identifying stakeholders

A descriptive approach is taken to identify stakeholders involved in the energy efficiency and retrofit industry, as is commonly applied in the literature [40], utilising the lifecycle Hubs of Activity model as a means of identifying key groups of stakeholders. This follows the suggestion by Mathur et al. [41] of initiating stakeholder identification by looking at the generic stakeholders and identifying those categories and types of actors for the particular context under study.
Initial stakeholder groupings are derived through a literature search and the stakeholders involved at each identified stage of the model designated as Hubs of Activity are articulated through a series of brainstorming workshops. For each Hub, techniques such as mind-maps and spider-diagrams are applied to further elaborate on linkages between the primary actors involved and secondary stakeholders present. Furthermore, techniques such as the International Finance Corporation’s ‘impact zoning’ approach are employed, whereby through the process of mapping the sphere of influence of different types of environmental and social impacts of a given project, it is possible to identify distinct groups of stakeholders by impact area [42]. Finally, stakeholders for each stage are summarised and consolidated, and outputs are extrapolated to develop a draft model of the EER market place. A generic list of stakeholders associated with each Hub of Activity of a typical EER project is shown in Table 2.

<table>
<thead>
<tr>
<th>Hub of Activity</th>
<th>Key Stakeholders</th>
<th>Other Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1: Upstream activities</td>
<td>Manufacturers; Policy Makers; Legislators; Statutory Regulators; Investors</td>
<td>Primary Producers; Material Processors; Financiers; Standard Bodies; R&amp;D Institutions; Retailers and Distributors; Logistics; End-users.</td>
</tr>
<tr>
<td>Stage 2: Initiation &amp; viability check</td>
<td>Owners; Investors; Solution Providers; Designers</td>
<td>Occupants / Tenants; End Users; NGOs; Neighbours; Municipalities; Insurance Companies; Utility Companies; Financiers; Policy Makers; Legislators; Public</td>
</tr>
<tr>
<td>Stage 3: Design &amp; planning</td>
<td>Designers; Owners; Project Managers; Investors; Solution Providers; Planning Authorities; Building control</td>
<td>Occupants; Public; NGOs; Neighbours; Financiers; Third Party Product Certification; Infrastructure providers / Utility companies</td>
</tr>
<tr>
<td>Stage 4: Construction and/or installation</td>
<td>Designers; Owners; Project Managers; Neighbours; Solution Providers</td>
<td>Occupants; Public; NGOs; Investors; Infrastructure providers; utility companies; Policy Makers; Legislators; Financiers</td>
</tr>
<tr>
<td>Stage 5: Operation and maintenance</td>
<td>Owners; Project Managers; Neighbours; Occupants</td>
<td>Designers; Investors; Solution Providers; R&amp;D Institutions; Public; NGOs; Infrastructure providers; Utility companies; Financiers; Retailers and Distributors; Logistics</td>
</tr>
<tr>
<td>Stage 6: End of life and downstream activities</td>
<td>Owner; Planning Authorities; Waste Authorities; Local Government</td>
<td>Environmental Protection Agencies; Service Providers; Contractors; Public; Retailers and Distributors; NGOs; Infrastructure providers; Utility companies</td>
</tr>
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</table>

3.4 Mapping Activities & Relationships

The Hubs of Activity framework provides an understanding of the marketplace that allows for analysis of stakeholder relationships, power flows, drivers, conflicts, and potential synergies. The interaction between the stakeholders outlined in Table 2 at the different Hubs of Activity may be assessed in terms of different flows including: energy and material flows; financial flows; and other value transactions. To achieve this, value mapping is conducted through the six Hub of Activity stages. Figure 1 illustrates some of the activities that take place in each of the six stages for a typical residential domestic retrofit project.
Figure 2 connects Table 2 and Fig. 1 by, showing an example value flow map for the fourth Hub of Activity (Construction / Installation), illustrating the interactions among the stakeholders. For illustrative purposes a simplified hypothetical scenario involving the retrofitting of glazing, lighting and insulation in a house is presented. For this particular example only the most directly involved stakeholders are included, with more indirect stakeholders such as society at large, and the environment omitted. From the scenario shown, several activities and relationships can be identified; the purchase of goods and services by the building owner from the designer and contractors, and interactions between the main contractor and the sub-contractors or suppliers of the individual glazing, lighting and insulation products for example.

Definitions of project requirements and project success may vary significantly between the stakeholders depicted, depending on their individual concept of value. The insulation sub-contractor may be working on a loss-leader business model, trying to get a foothold in the market, while the main contractor may be more profit-driven, and the home-owner may consider value to be quality of workmanship and enhanced quality of life through improved thermal comfort and better air quality. Such conceptualisations of value are likely to be very different for other retrofit project types. For example, for a school project requiring a comparable retrofit solution of glazing, lighting and insulation, school board perceptions on the effect of building thermal efficiency on the performance of students or education authority requirements may directly inform desired project outcomes resulting in a different value proposal from respective stakeholder perspectives. Differing requirements and perceptions at the project level therefore give added significance to the stakeholder interactions taking place, and dictate the need for an analysis based on various conceptualisations of value across the whole lifecycle.

3.5 Value mapping at the project level

The generic value mapping process described in Sections 3.1-3.4 can then be used as a guiding framework through which to develop a specific, tailored and individually responsive value map for the temporary multi-firm network associated with any given retrofit project. To achieve this, key stakeholders in the retrofit project need to be identified and engaged through a process of substantive stakeholder engagement. Within this framework, stakeholder engagement occurs across three phases: (1) addressing technical aspects; (2) addressing qualitative aspects of the value network and its stakeholders; and (3) addressing issues at the macro level, including the policy landscape, and power relations across the full scope of the value network. The phases are not chronologically dependent, and there is capacity for cyclical feedback and reflexive iteration between each phase of analysis. Figure 3 provides an overview of how the framework works in practice, describing a value identification process for individual retrofit projects.
The first phase of stakeholder engagement involves the collation of information on the building, including details on the building size and floor area, pre-retrofit energy use and performance specifications and the business model(s) associated with the operation of the building. In addition, the technical details of the proposed retrofit is ascertained, including the materials and design alterations planned and the consequential modelled impact on the energy performance of the building and on the performance of the building’s business model. Phase 2 of stakeholder engagement explores the perceptions and views of the fullest range of stakeholders possible on their own role in the value network, their perception of value, the roles of peer and competing stakeholders and on the general characterisation of key stakeholders who are associated with the Hubs of Activity. This data gathering stage serves to form a unique characterisation of the stakeholder landscape of the retrofit value network, highlighting those aspects, which differ from generic project characterisations, and those stakeholder roles, which are particular or unique to the retrofit project in question. When all key stakeholder roles have been identified, the locations of value-add activities across the value network supply chain need to be established. To achieve this, indicators of value and indicators of network functioning are developed in respect of the differing stakeholders’ concepts of value. Indicator development enables an analysis of value creating configurations across a number of domains, including monetary, energy and environmental value flows. Such indicators can be presented in a number of ways, including: integrated (including weightings if required) to shows total value flows through the lifecycle; as individual values flows on a normalised basis at different stages of the lifecycle; disaggregated to illustrate relative value flows to/from each stakeholder. In this way, analysis provides the basis for changes to the value network to enhance capacity for value creation for each stakeholder as deemed appropriate [9]. Phase 3 of stakeholder engagement seeks to prompt stakeholders to articulate their views on the political, policy and regulatory landscape within which the retrofit value network operates. Data collection at this phase seeks to identify the distribution of added value gains across the value network, the distribution of value creation capacity and the distribution of risk incurred in value creation activities. In addition, stakeholders’ views of the political and institutional influence on their activities are important to evaluate real and perceived constraints on, and enablers of, value creation activities across the value network.

Using this procedure for value mapping of the temporary multi-firm networks associated with individual projects serves a number of functions. Mapping of value creation across value configurations as a whole, including identification of those points of critical importance to the creation of value, can enable a broader and more comprehensive view of stakeholder activities and their role as part of the wider impact of a project [9]. As construction projects generally possess a wide range of constituent stakeholders, priorities and definitions of value are likely to change between different actors [43]. Value mapping can provide clarification on these stakeholder motivations and priorities, and specifically provide an explicit acknowledgement of alternative conceptualisations of value, including non-monetary conceptualisations. This value mapping approach can foster cross-boundary, whole-of-life thinking, highlighting links between activities across the entire value configuration and determining individual stakeholder value propositions and business models [9]. The identification of such linkages is critical to recognising environmental externalities and systemic risk, as well as future capacity and opportunity for energy savings. However, resources in terms of time and funding available are likely to vary between different project actors [43], influencing where and how interventions across the value network can be feasibly applied, and where these interventions can effectively exert greatest impact. A mapping of these intervention points can therefore significantly aid in the planning and management of projects, but
also in the design and implantation of policy instruments aimed at increasing market capacity and thereby uptake of EER solutions.

4. Mapped Value Flow and Business Models

The literature shows that VCA is increasingly interpreted in a broader and more flexible manner in practice, than envisaged by the original concept. Understandings of value have changed over time with different ‘value configurations’ evolving to meet newer understandings. While, conventional VCA has a focus on value as profit, this is of limited applicability in tracing value creation in the energy efficiency and retrofit marketplace. Overemphasis on (short-term) profit by some stakeholders will impair the value proposition of other stakeholders and the overall value proposition of the EER project including weakening other non-monetary values (quality, sustainability, durability etc.). This short-term profit emphasis has an adverse effect on the construction industry as a whole when such practices contribute directly to cyclical boom-bust cycles. More specifically within EER projects, such focus on the profitability of one stakeholder or group of stakeholders acts to dis-incentivise the involvement of other stakeholders in such projects, reducing EER capacity and consequentially having a detrimental impact on the uptake of energy efficiency solutions in the marketplace. There is therefore a need to holistically address the types of complexities, intangibles, and variations in the value analysis of a retrofit project with numerous, often very loosely connected, and even opposing stakeholders.

The value mapping approach forwarded in this chapter is inherently flexible, and can be applied across domains (monetary, energy, emissions, capacity) and for a range of value propositions. This is useful for individual stakeholders evaluating their role in the value network, but also for consortiums of stakeholders involved in retrofit projects. As the construction industry is characterised by its product uniqueness and ad-hoc organisation of the project team [44], value proposals are likely to be significantly different between different projects. For any given retrofit project, success may not be defined by any one criterion, but by the degree to which multiple criteria can be balanced, or competing criteria can be traded-off against one another [9]. The criteria selection and weighting factor assignments, essential in the formulation of the optimisation problem for building retrofits [45], therefore represent a unique value proposal for each retrofit project. The value mapping approach provides a means of identifying the unique value proposal of individual retrofit projects, on a project-by-project basis.

Understanding value creation in retrofit processes and thereby developing business models suitably attractive to all stakeholders is crucial to successfully harnessing the available energy savings potential from the existing built environment. The definition of value therefore, like the definition of success of a project, varies according to the criteria, viewpoint and requirements of the stakeholders involved. Value for some may be lower utility and running costs, increased property value, and return on investment. For others the definition of value may include thermal comfort, architectural aesthetics or quality of life. Ensuring the various stakeholders’, especially those identified as occupying key roles within the Hubs of Activity, extract sufficient ‘value’ (however they would measure it) from their involvement in the EER project is crucial to maintaining and increasing capacity and therefore increasing uptake in the marketplace. A value analysis approach is important in this context, as it can account for the subjective perceptions of various stakeholders, and is flexible enough to cover multi-criteria priorities and outcomes. Value approaches can facilitate the accommodation of optimal solutions (from multi-dimensional performance perspectives) with the interests and priorities of stakeholders.

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