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Strategic sustainable development in the UK construction industry, through the Framework of Strategic Sustainable Development, using Building Information Modelling

Abstract

The UK Government has set out ambitious plans for all new domestic and commercial buildings to be zero carbon rated by 2016 and 2020 respectively. These are some of the most progressive environmental targets for the built environment in the western world. There are also sustainability principles (SP) that need to be addressed by the UK construction industry, particularly negative impacts such as waste and pollution. Currently, 100 million tonnes of construction waste, including 13 million tonnes of unused materials, is generated each year, with only 20% currently capable of being recycled. The majority of this waste ends up in landfill, contributing to further pollution of the biosphere. The literature suggests that these negative impacts result from a variety of causes, including ineffective leadership, ingrained cultures, outdated technologies and poor logistics.

There are a number of innovative projects within the UK, particularly at a local level, that pose the question as to whether bottom up approaches may be more successful than top down policies, as set by national and local government. This paper presents a case study demonstrating the former approach within the construction industry. Research and consultancy has been undertaken collaboratively between industry, academia and professional practice in the production of 15 individually designed sustainable dwellings in the North East of England. This project has employed Building Information Modelling (BIM) as a new collaborative working platform, aligned to the Modern Method of Construction (MMC). By situating this inquiry within an authentic case study it has highlighted currently ineffective strategies, policies and leadership which have prevented full exploitation of the potential of BIM and MMC towards sustainable production. This inquiry supports the integration of the Framework of Sustainable Strategic Development (FSSD) into construction procurement, as a method for implementing bottom up leadership in a value driven project.

Keywords
Framework of sustainable strategic development
Sustainability principles
Modern methods of construction,
Building information modelling
Waste and energy reduction

1. Introduction

It is recognised that climate change is now a major problem facing human society (Huisingh, et al. 2015). Governments around the world have struggled to balance economic growth with its negative effects on the environment, in both the developed and developing world (Lewis & Conaty, 2012). Buildings, through their construction, operation and eventual demolition, account for 40% of the UK's total energy consumption and their associated carbon emissions (DECC, 2013). Around 380 million tonnes of materials and resources are consumed by the construction industry in the UK each year (BRE, 2012). The industry also generates over 100 million tonnes of waste per annum; this figure includes approximately 13 million tonnes of unused materials (Liu t al., 2011). This demonstrates neglect for much of the sustainability vision presented by the Brundtland Commission (Brundtland, 1987). In addition, Rockström et al. (2009) concluded that current human activities have transgressed many of the planetary boundaries (PBs). Construction has particular impacts through: carbon emissions; climate change; waste generation; change of land use; and loss of biodiversity. This poses a critical question as to what the limits are of the earth's biophysical systems, before our activities irreparably damage the biosphere.

A literature review was conducted of academic journals, industry publications and government reports, focusing on keywords which address the key research aims discussed in section 1.1. These include: leadership and sustainability; negative impacts of construction; environmental benchmarking tools; and Building Information Modelling. This process revealed a number of challenges faced by the construction sector, including:

a) Opportunities for improvement in strategic vision with regard to sustainability (from within the industry, local and national government).
b) Resistance to the implementation of new, more efficient technologies.
c) Inefficient logistics and communication methods inhibiting the adoption of new technologies to improve efficiencies.
d) That FSSD has been successful within other sectors towards zero carbon concepts and cleaner production.

1.1 Aim and research question

The aim of this research inquiry is to better understand how BIM can be used within the FSSD to facilitate *bottom up* strategies for cleaner production in the construction industry. Through the literature review, the Framework for Sustainable Strategic Development (FSSD) emerged as a robust, universal, principled definition of sustainability, which makes it possible for various actors to identify their respective challenges and solutions (Robèrt et al. 2002). This framework has been applied to assess the strengths and weaknesses of several sectors with respect to sustainability. It was employed to provide a systematic, effective and collaborative process for designing out negative impacts within construction. 'Bottom up' in this context is conceptualized as individuals, companies, and organisations taking ownership of their approach to sustainability and discovering opportunities for cooperation. This is facilitated through the use of the FSSD and BIM. In contrast, publicly and commercially procured construction projects generally do not employ sustainably focused step-wise methods in developing their business cases. Studies suggest that reductions in emissions generate positive impacts on companies and overall financial performance (Gallego-Alvarez et al. 2015). The FSSD has been adopted as a way of achieving a more strategic approach to the reduction of the negative environmental impacts of construction. The approach has been developed and tested by use of a case study methodology. Case studies in the past have demonstrated that costs and sustainability can be improved when environmental innovation is applied, transforming the traditional production system into a lean system (Aguado et al. 2013). The case study can provide useful multi-perspectival insights through an authentic, defined project that allows us to use bottom up strategies to deal with a complex, multi-faceted environmental problems (Yin, 2013).

1.2 Cultural challenges to sustainability within the construction industry

Current literature suggests that the sector generally views waste and carbon reduction as an additional and unnecessary expense (Osmani et al. 2008). The composition of the sector provides some context to this problem; despite its size and importance to the economy, the construction industry remains highly fragmented and eschews collaboration and strategic vision. Over 90% of the UK industry comprises small scale construction firms (ONS, 2008). Projects are generally run by small firms, employing between 1 and 59 employees; this profile mirrors the composition of the construction industry internationally. Thus, a substantial proportion of the responsibility for reducing the negative externalities of production rests with small scale companies. Due to the industry's composition, there is a low level of investment in training, education, innovation, and research. Saunders and Wynn

(2004) argue that a lack of systematic education and training has led to building personnel having only basic knowledge about the global consequences of construction waste, pollution and emissions.

Construction companies currently carry the burden of environmental efficiency in the UK, but they are too far up the supply chain to effect real change. Landfill taxes, used as a way of reducing waste inefficiencies, do not have the desired effect, as the tax initially falls onto the contractor, who in turn passes the burden onto the client who is commissioning the building. This leads to more expensive buildings; however, the inefficiencies continue. The professional design team is missed out of the equation, even when it is intrinsically interested and motivated to act sustainably. BIM offers opportunities to use appropriate information technology strategies and a collaborative platform to facilitate the design team's involvement far sooner in the process, and with more impact.

Top down voluntary environmental benchmarking tools such as BREEAM, LEED and the Code for Sustainable Homes (CfSH) have been used around the world in public and private construction projects to effect change in terms of sustainability. They have also been used as a way of facilitating an environmental step-change using BIM (Alwan et al. 2015). A number of the conflicting pressures currently placed on the construction industry are outlined in a funnel diagram in figure 1. Over time the construction sector faces increasing social, economic and environmental pressures. Simultaneously there are dwindling resources that together result in pressure building up in the conceptual funnel, with severe consequences on the biosphere. Systematic use of BIM and the FSSD has the potential to alleviate the pressure.

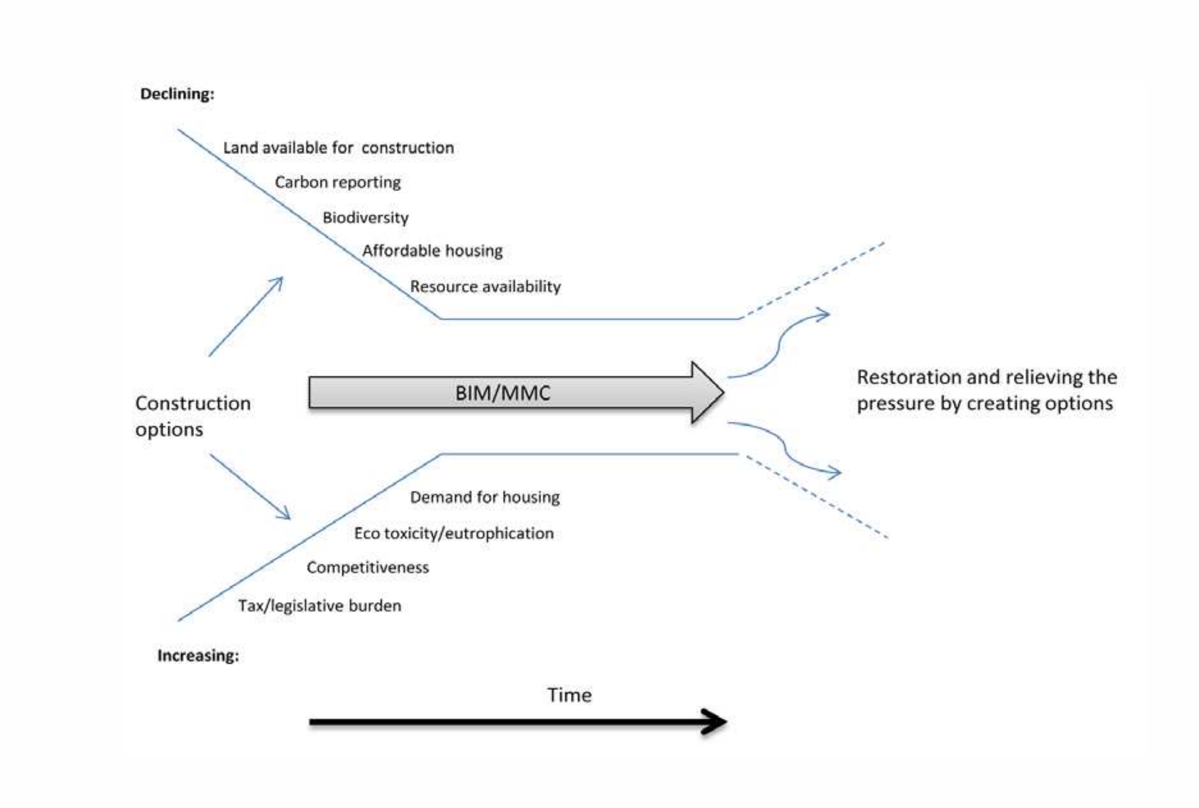


Figure 1: Proposals to alleviate pressures utilising FSSD within the construction industry that currently lead to excessive construction waste and inefficient practices

2.0 A need for change: Building Information Modelling

A unifying framework and technology would allow design data to be fed directly to manufacturers, establishing direct links between design, manufacture and supply, thereby seeking to eliminate errors and waste towards a goal of dematerialization (Robèrt et al. *2002)*. The construction of any building, even a small scale project, is a very complex process utilizing tens of thousands of components. In order to effect efficient construction assembly, a number of resource flows need to be aligned, including the workforce, building information, plant and equipment hire, as well as the procurement and delivery of materials and components. These logistics need to be systematically managed and controlled in order to deliver projects that are efficient in waste and resource management. It has been argued that there is currently no universal logistic framework - or supporting technology - that unifies construction procurement methods (Mossman, 2009; Love et al. 2011).

The production of ever more comprehensive and accurate models has facilitated significant potential for cleaner production processes (NBS, 2013; WRAP, 2012). In an effort to counter the static culture within the construction industry, the UK Government mandated that from April 2016, all centrally funded public sector work will be procured using BIM technologies, to help facilitate the step-wise transition of the construction industry towards greater efficiencies (Barlish & Sullivan, 2012), through improvements in cost, time, value and environmental performance. The UK has quickly become a global leader in the employment of BIM in the construction industry. The Government has identified levels of expertise within the sector in terms of a maturity index supported by professional bodies (Brew & Underwood, 2009; Bew, 2013; BSRIA, 2012). The four levels of gradual steps are described below:

- Level 0: uses paper-based traditional methods and two-dimensional Computer Aided Design (CAD) in terms of the transferability of construction and design information.
- Level 1: employs 3D formal modelling, in addition to the 2D CAD data to British Standard BS1192:2007, *'Collaborative production of architectural, engineering'*.
- Level 2: introduces BIM models for each discipline in the construction team. Comprising interoperability and intelligent data, whereby properties of costs, quantities, thermal performance etc. are embedded in the model, capable of being shared between all parties.
- Level 3: is the highest level of the index employing of a fully integrated BIM process, where data is shared and open during the overall building life cycle, including Facilities Management.

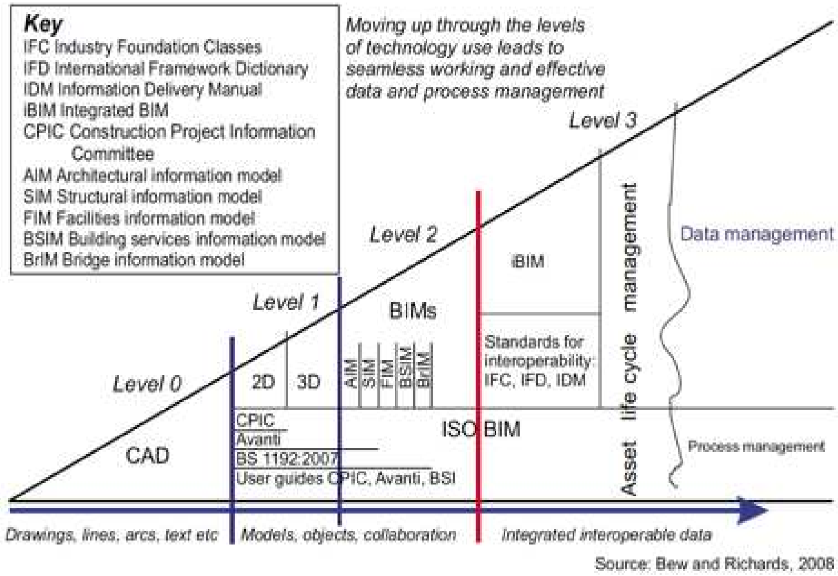


Figure 2: Diagram showing BIM maturity

As it stands, the majority of the supply chain currently resides at Levels 0 and 1, and BIM is largely under-utilised in terms of realization of sustainability principles (SPs). As part of the Government's mandate, it requires practices to achieve Level 2 maturity in order to tender for public sector contracts. The production of ever more comprehensive and accurate models could facilitate significant potential for cleaner production processes (NBS, 2013; WRAP, 2012). BIM enables the industry to comprehensively evaluate a construction project in terms of quantities, performance and coordination, thus potentially avoiding negative environmental impacts. The coordination of dimensions in an intelligent model could also be utilised to standardize component and sheet modularisation, thereby reducing waste generated through material and onsite operations. Identified components could also be re-used or recycled. However, BIM is only a tool, albeit a powerful one; to fulfill its potential in terms of environmental efficiency it needs to be used within a robust sustainable framework that considers wider planetary boundaries and systems.

3.0 The case study and evaluation

A recent development has provided an opportune case study to evaluate the potential of BIM technologies utilizing FSSD in the house building sector. This approach could be used to gain insights into the problems within the industry in order to develop strategies that may be transferable to similar projects worldwide. The developer initiating the project is committed to environmental design, and has proposed the construction of 15 individually designed sustainable dwellings in the North East of England. This development was seen as an opportunity to challenge some of the cultural, technological, and collaborative shortcomings of the UK construction industry, as well as to provide a rich primary data source for comparison with similar developments. A research project was initiated to run concurrently with this development, in order to capitalise on emergent knowledge and skills. The perceived limitations of this small scale local project, in terms of relevance to the industry, are countered by the authenticity of the brief. Such domestic projects reside in a major sector of the construction industry, which has yet to engage with new strategies and technologies. Additionally, the social sustainability dimension needs wider consideration, particularly in the UK. For small and medium-sized consultancies, the likelihood of influencing national policies with respect to environmental efficiencies is negligible. However, the validity of bottom up approaches is increasingly accepted as a means of countering shortcomings in top down policies that often fail to engage with issues on a local, social and micro level (Crescenzi & Rodríguez-Pose, 2011; Youngs, 2003). This project advocates bottom up leadership by championing multi-stakeholder collaboration. Yin (2013) suggests that case study methodologies, while challenging, can help find solutions to contextual problems, especially in the construction industry, because they encompass and capture multiple perspectives. The construction industry pragmatically addresses research complexity through the evaluation of built projects set within authentic contexts. The validity of case study inquiry is accepted by the academic community, as a way of advancing and disseminating knowledge, particularly within professional and practical disciplines (Francis, 2001; Yin, 2013). The global construction industry would benefit from a wider range of relevant case study projects that address the practical reduction of waste and negative impacts.

3.1 Aims and objectives of the development

The aim of the inquiry was to establish how to achieve collaborative working methods, effective management of the supply-chain, and employment of modern methods of construction (MMC) through BIM supported by the FSSD. The objectives were as follows:

- To use a case study methodology to test the use of BIM/MMC in relation the Framework of Strategic Sustainable Development (FSSD).
- To evaluate the business case for addressing sustainability principles using the FSSD and BIM.
- To address the pressures identified in figure 1 through creative use of the FSSD and BIM.
- To develop a bottom up leadership model, based on participatory methods and cooperation in the reduction of negative impacts (waste and energy reduction), within the construction sector.
- To inquire whether sustainable life cycle management, material substitution and dematerialisation can act as leadership drivers for change.
- To design for the entire life cycle of the project, considering whole life running costs.

3.2 FSSD in association with BIM/MMC

The theoretical basis of the case study is the adoption of the Framework of Strategic Sustainable Development (FSSD) constructed by Robèrt et al. (2013), used in association with BIM and MMC to reduce the negative impacts of construction development. This framework is conceptualized to aid strategic planning and effective action in relation to sustainability principles. It sets out five distinct, but interrelated, levels of engagement within a systematic process. These range from societal and macro conditions, through to thematically specific micro issues. The *systems* level is the context to the problem, comprising societal issues, stakeholders, policies and laws, and their impact on the biosphere. The *success* level relates to the goal and how effective the project will be in its realisation. The *strategy* level is the method or plan devised to attain the objectives. The *action* level is the application of the strategy, in effect putting the process to work. Finally, the *tool* level comprises the methods and devices used to apply the strategy.

The success level is the piece of the sustainability jigsaw most commonly missing. This level should inform the other levels and serve as a *nexus* between the systems level (in this case, unsustainable construction practices that impact the biosphere) and the strategic level (step-wise approaches for the construction sector to develop sustainable practices). Current strategies employed in the industry tend to move directly from identified problems at the systems level; however, they fail to consider the other levels of the FSSD, consequently solving one problem by simply inventing another. Thus, the success level helps identify the principal challenges at the initial 'systems level', understanding and managing the problem of system boundaries. A vision of environmental stewardship helps to identify step-wise approaches to achieve the aims of the third FSSD level (strategy level).

The FSSD has been shown to be a driver for companies to reduce their planetary impact. The authors argue that BIM maps almost seamlessly onto the FSSD, as fundamentally it too is a framework. However, unlike the FSSD, for BIM to realize its potential as a tool for sustainable design, it requires societal and sector buy-in; this is a key component of the systems level. Existing cultures and policies within the industry that comprise the systems level obstruct BIM's potential in terms of strategic planning. The table shown in figure 3 illustrates a unification of FSSD and BIM with the systematic intentions of cleaner construction production. Each of these levels can be focused on specific sustainability issues, in order to encourage strong leadership and collaboration cultures.

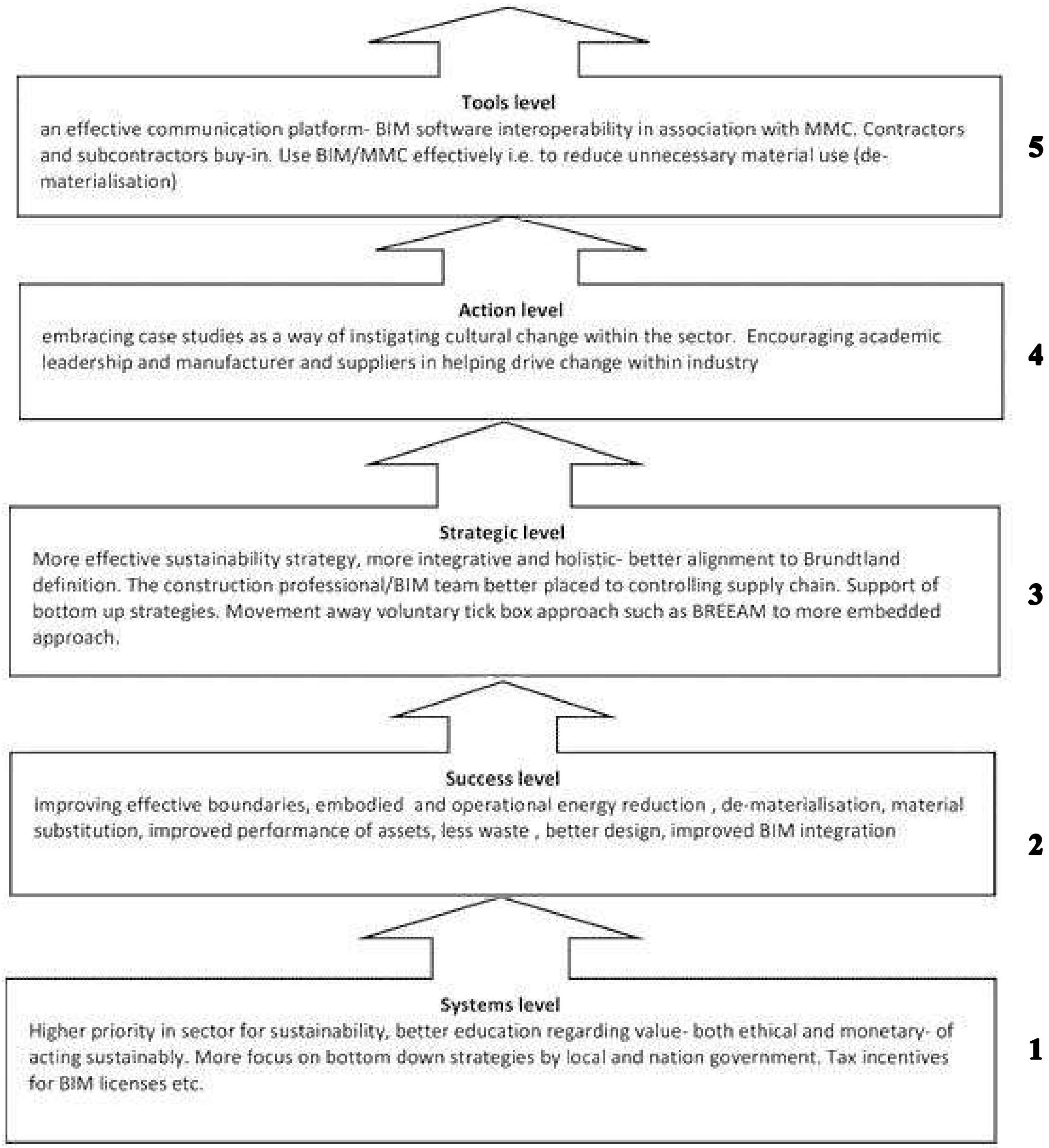


Figure 3: FSSD/BIM alignment leading to better leadership in the promotion of sustainability

3.3 Blurring system boundaries

The case study has revealed that cleaner production is not limited to the period of construction and site operations, but extends throughout the life cycle of the development, from design inception to demolition. Bratt et al. (2011) assert that lack of structure and cohesiveness hamper the effectiveness of (construction) programmes to drive change towards a more sustainable position. Negative issues such as waste and pollution are often dealt with in isolation; there is rarely any consideration of overlap of the system boundaries. It is in these interstitial territories, where discrete processes overlap and interact, that strategic leadership is required, supported by policies that devolve more environmental responsibility and ownership to local stakeholders.

3.4 Collaboration and communication: towards a commonality of purpose

The developer was keen to collaborate with Northumbria University in order to consider alternative approaches to cleaner construction processes, and to intelligently incorporate environmental design principles. As well as being committed to sustainable design, the developer recognized that there were considerable monetary savings to be made in terms of dematerialization, for instance in reducing the burden of landfill taxes. From the inception of the project, it was decided that BIM would be the unifying technology between the collaborators; this provided robust and unified strategies for the *tool* and *action* levels of the FSSD. This arguably placed the construction project within Level 3 of the BIM maturity index. All members of the core team are BIM enabled, not only in terms of technological competence, but also in understanding its use in terms of management and strategy. Importantly, these skills and attributes also extended to the developer/contractor. Central to BIM's conceptualisation and approach is collaborative working (Lockley, 2014); the researchers performed multiple, embedded roles within the project, bringing value through their professional expertise, knowledge and experience, and observing whether the assertions set out in section 1 of the paper were reflected in a real life context.

Many construction projects suffer from not assigning enough time to the *strategy* level as set out in the FSSD. To clarify, this framework promotes a step-wise approach, where each investment towards adherence to a robust definition of sustainability should provide a platform for further initiatives and opportunities, towards a successful outcome. There is also the potential to generate cost savings in order to incentivize an ongoing stepwise approach. As with any industry, preparation is key. Within the case study, planning and strategy was considered paramount. The project team included the developer/contractor, the design team (architects, engineers, architecture students, BIM specialists, and a BREEAM assessor, drawn from practice and academia), as well as key suppliers, manufacturers and fabricators. BIM and the FSSD were central to drawing together this expertise: the management and strategic aspects of the framework meant that it could also be employed to facilitate holistic collaborative working. The shared model enabled continuous communication, fundamental to a successful *strategic* level.

4.0 The use of material substitution and demateralisation

Any approach taken within the construction sector has to be simple, robust and accessible to appeal to an industry adopting a step-wise methodology towards adopting the robust sustainability principles of the FSSD. Two broad strategic guidelines were adopted in the case study, in the forms of dematerialisation and material substitutions. Both could be feasibly applied through the use of BIM/MMC. These two guidelines have been successfully utilized across different industries; dematerialization saves resources and money. Material substitutions, in consideration of whole life performance and cost, may prove to be the more sustainable option when considered through the FSSD framework (Robèrt 2002; Lindahl et al. 2014). Ny et al. (2006) point out that both dematerialisation and material substitutions can be applied to significantly reduce waste production over time, in order to achieve globally sustainable outcomes. In addition, global sustainability boundaries (Robèrt et al. 2013) are not widely considered in the current construction sector. The proposed case study alerts the industry to the wider impact to the biosphere arising from ineffective system boundaries. The design team recognises the vital role that manufacturers and suppliers have within the case study project, in terms of effecting a paradigm shift within the industry.

4.1 Using BIM/MMC to reduce construction dematerialisation

Current practice relies on paper based communication methods (schedules, programmes, quantities etc) between the design team and the construction team, with respect to material use in the supply and manufacture of building products for construction projects. These established methods are inflexible and inefficient, as they have no effective system boundaries in comparison to the FSSD. This is a result of ingrained practice within traditional construction processes, where sustainability and cost benefits could be realised if BIM and MMC were used in combination with the FSSD at the *strategy* and *action* levels. In the case study, it is proposed to employ BIM and MMC to effect dematerialisation, as defined by Robèrt et al. (2002). BIM provides a live and active interface, where design iterations can be made right up to the construction phase. This ensures that only the correct materials and accurate components are produced, utilising MMC through offsite fabrication methods, thereby minimizing waste generation. It can be argued that this approach clearly addresses system boundaries by eliminating excessive material waste. This also reduces energy combustion, transport emissions and resource depletion in accordance with the success level of the FSSD. Once such benefits are realised in this *system level*, this should lead to an improved understanding of how BIM and MMC, in association with FSSD, can be optimised towards cleaner production.

In the case study, the prefabricated wall panel suppliers stressed the need for their input at an early stage of the design process (i.e. at a *strategic* level of the FSSD). Needless waste inevitably results from not exploiting manufacturers' expertise at the formative design phase. Similarly, early supplier involvement has the potential to reduce negative impacts of production, such as packaging and transport, which violate the principled definition of the *success* level (Robèrt et al. 2002). Judicious and systematic planning in the *tool* level of the FSSD can promote the re-use of protective packaging, thus saving the supplier and contractor money, as well as reducing onsite waste that ends up in landfill. The authors assert that suppliers could (and should) become significant change agents in the industry in terms of waste and resource management, but to do this their expertise needs to be incorporated from the start of the project at a *systems* and *strategic* level of the FSSD. By utilising a step-wise approach in specifying standards and principles above those that are required for current building codes and regulations, this methodology can holistically acknowledge planetary boundaries as set out in the robust definition of sustainability.

4.2 Materials substitution and specification

Substitutions can be readily made from an informed position, if a material is found to be potentially violating the sustainability principles of the FSSD. The design team was committed to the use of inert materials for the construction of the project. This was considered doubly important in terms of reducing pollution, not only in the manufacture of the construction materials, but also with respect to their capacity to degrade, should such materials ultimately end up in landfill. This is an area that is often neglected in the UK, especially with normative practices that continue to use materials such as PVC without regard for pollution over the life cycle of the material; this is a violation of the second level of the FSSD. An approach where BIM and MMC drive the process within construction provides the design and construction team with a very accurate model to evaluate chosen materials from the point of view of performance, toxicity and energy efficiency. Material specification can be derived from a manufacturer in advance, and integrated into the BIM model (see figure 4). Quantities can be accurately estimated from the model, showing how much of a particular material exists in the building.

Options for material specifications can also be inputted into the BIM model derived from reputable environmental databases. A strategic decision was taken to rationalise the design by using as few materials as possible. This enabled closer control of the specification, a reduction in component numbers and sources, production efficiencies, cost savings and a greater sense of material uniformity among the individual houses in the development. Here, BIM effectively supports and facilitates several levels of the FSSD, particularly: *strategic, action* and *tools*.

The utilization of environmental benchmarking tools, such as LEED and BREEAM, to improve environmental practices in the construction industry generally occurs via credit-based systems which result in an overall score. However, such quantitative methods do not give credit for wider practices dealing with climate change, and do not adequately acknowledge major step change or paradigm-shifting advances (Zimmerman, 2007). For example, the energy requirement criteria of these tools reward the use of renewable technologies to reduce operational carbon demands; however, there are no recognized system boundaries to consider end-of-life issues, as well as ecosphere contamination caused by the technologies employed (as exemplified by the use and manufacture of photovoltaic panels). By the same token, these environmental benchmarking tools reward small incremental improvements, applied in a one-size-fits-all approach. This constraint precludes true innovation in tackling environmental issues in wider society. The case study sought a far more holistic and integrated approach, utilising FSSD to achieve system conditions for ecological sustainability (Robert et al. 2002).

4.3 Design for life cycle and running costs

The design of the residential development incorporated consideration of disassembly, supporting material re-use and waste minimisation, energy consumption, and emissions. BIM was employed together with early input from fabricators to achieve these aims. Figure 5 displays one of the houses proposed for this development, showing the type of data that can be extracted from the BIM model, such as material quantities, qualities and weights, as well as communicating the modular assembly process. Data regarding environmental specifications, clash detection, heat loss and condensation calculations can also be derived from this model. Figure 5 illustrates that the use of BIM and MMC towards cleaner production has reduced waste and associated global impacts. The use of modular construction, with dimensional coordination for the primary floor, wall (internal and external) and roof units, seeks to reduce waste in the houses to less than 3% of overall material use. The compares favourably to standard UK house construction, where up to 30% of the material use goes to waste (BRE, 2012). The houses have been designed to utilise whole sheet sizes, or modular components thereof. This avoids the violation of the FSSD in terms of degradation and deforestation, through minimising waste generation. There is inevitably some minor wastage through site processes, for example having to chamfer wall panels to connect to the roof; this waste, however, can be recycled in the factory. This is an example of dematerialization in its application in the construction industry and this exercise has been repeated with other components, such as the glazing and the flooring units.

Figure 4: Computer Generated Image showing a house designed in the case study

2700X800 SIP PANEL	full	106
	3/4	28
	1/2	8
	1/4	28
2400X800 SIP PANEL	full	72
	3/4	22
	1/2	0
	1/4	22

sips panels set out to modular coordination ensuring zero waste

<Floor Material Takeoff>

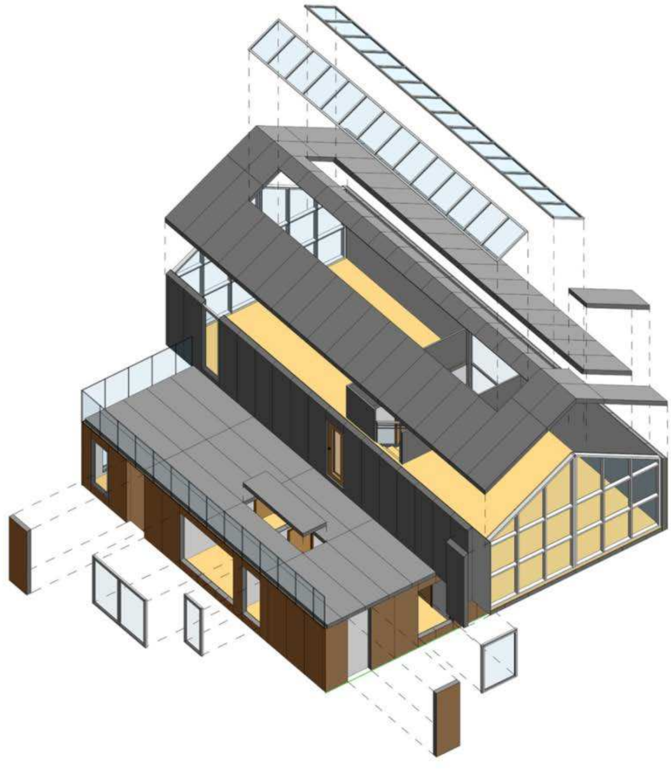
A	B
Material: Area	Material: Name
74 m²	Vapor Retarder
74 m²	Oak Flooring
74 m²	nbl_StructurallyInsulatedPanels
102 m²	Vapor Retarder
102 m²	Oak Flooring
102 m²	nbl_StructurallyInsulatedPanels
40 m²	Vapor Retarder
40 m²	Oak Flooring
40 m²	nbl_StructurallyInsulatedPanels

example of building component where BIM calculates areas

Global Warming Potential	Less than 5
Green Guide Rating	A or A+ (depending on full wall construction
Mass Density	33 kg/M3 insulation
Ozone Depletion Porential	zero
Standard length	7500 maximum
Standard thickness	200mm
Standard width	800mm
Thermal resistance	5.100 m2K/W
Water Vapour Transmission	33.6 MNs/g insulation 7.5 MNs/g OSB/3 facing
Thermal Conductivity	00.23 W/mK insulation, 0.13 W/mk OSB/3 facing

example of environmental data from BIM- shown here is the data for prefabricated wall units

Example of one of the house showing construction through modular coordination



House area is calculated at 196m2
Total weight using BIM calculated at 13.4 tonnes

Figure 5: Performance data derived from the BIM model

5.0 Discussion

This paper presents a case study housing development with an aspiration for zero waste and zero carbon in its construction. It is hoped this this project could potentially act as a catalyst to influence policy, and industrial and academic practice. Situating this inquiry within an authentic case study has highlighted complexities and contingencies which, to date, have prevented the exploitation of the full potential of the FSSD and BIM, particularly regarding negative environmental impacts within the construction industry. The project attempts to offer an alternative paradigm in implementing a bottom up, value-driven approach. In conjunction with the technologies of BIM and MMC, the FSSD is implemented to drive change within the construction industry in the recognition of sustainability principles (SPs). The supplier/fabricators' engagement with the sustainability philosophy and the use of the FSSD has also been instrumental in the ambition to create holistic solutions to current issues within industries. This project exemplified cross-disciplinary collaboration, innovation and leadership, demonstrated through commitment and creativity in overcoming technical and societal issues. In principle, the project's aims and objectives appear to be achievable; all the houses have been designed to significantly reduce waste and associated pollution. The current contingencies of component fabrication and site assembly processes have been limited using the FSSD to coordinate the various phases, processes and actors.

A separate and key aspect that has emerged in the research is the role of education in the project; particularly the involvement of the researchers, who have helped to deliver the project from inception to the fabrication phase. Strategic education can be used to drive change by reframing a holistic understanding of sustainability (Hay et al. 2014). Academia, in this case, has potentially filled a gap in the industry that currently exists with projects procured through bottom up leadership towards sustainability; the academy provided research and design expertise, as well as technical innovation and skills training. However, it is the authors' assertion that this already exists in the sector, but it is informal and uncoordinated. The authors believe that this type of case study can be replicated within the industry, towards sustainable outcomes from small scale to global level.

In recent years the BIM framework has been continuously amended and improved by researchers and practitioners; perhaps a new line of inquiry may be how BIM could be formally subsumed into an FSSD to provide synergy and effective outcomes. The design team can potentially control the *strategy* and *action* level. Behind every good project is an educated client, who can be a major component of the *system* level. The design team needs to help in the education of the client, emphasizing the importance of and providing information about sustainability principles, particularly within the *success* level. The business case for sustainability is often a good place to start with clients; by relieving the pressure over time this can lead to economic as well as societal and ecology benefits. Figure 6 reflects the importance of the *strategy* and *action* phase with the use of BIM, emphasising the training and education of design professionals in this regard. The diagram also acknowledges blurred and permeable boundaries and envisages the process moving up and down the chain. The dashed red line indicates potential for improved system and success level, but as yet these aspects of the FSSD in relation to construction are comparatively weak.

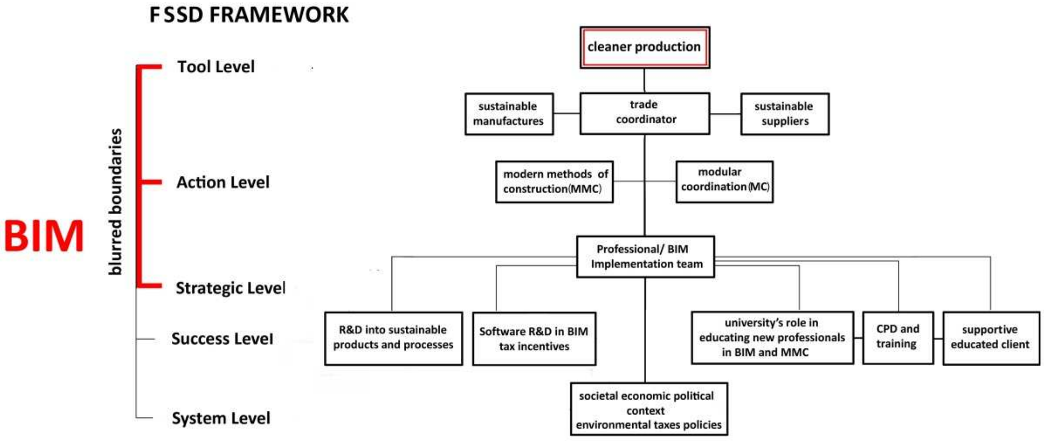


Figure 6: FSSD and BIM integration towards cleaner production

The authors assert that a framework that elevates the importance of new technologies, such as BIM and MMC are essential, focusing on:

- The development of new courses, both CPD and university programmes that focus on sustainable frameworks, such as the FSSD and collaborative working incorporating broader aspects of BIM, such as governance and leadership, life cycle assessment, towards zero waste projects.
- Sustainable practices in association with BIM, including: modular coordination, dematerialisation, material substitution, and reduced demolition.
- Better dissemination of the benefits of this new approach, with particular emphasis on the business case for sustainability.
- The development of a prototype model, where an interactive sustainable interface (or dashboard) can be used by the industry to better assess environmental impacts of construction.

6.0 Conclusion

A well-structured, unified framework for sustainability has been missing in the construction industry. There is need for a framework that supports and enriches sustainable development. To instigate a change in leadership practice in the construction sector, this paper argues that the FSSD can be effectively and systematically applied to this industry. This is a scientifically verified method, and has been proven to work at a variety of scales of environmental and industrial problems. However, the *system* and *success* levels are not effectively embedded within the construction industry at present. BIM is a game changer with potentially powerful impacts in terms of the *strategic*, *action* and *tool* levels of the FSSD. However, if there is an unsupportive *system* level, then this potential will remain unfulfilled in achieving the desired *success* level. This is where there needs to be a culture shift. The industry comprises many small scale enterprises, which are in effect, too remote from the policies and initiatives that national governments instigate. If the FSSD was adopted by construction sectors around the world then cultures and belief systems that contribute to the system level could change over time as a consequence of it becoming accepted practice. The case study presents a bottom up strategy as a way of coordinating the majority of the stakeholders within the industry. In the illustrated case study, there was a very strong *systems* level, because the collaborators agreed upon a shared purpose and ethic. The challenge is scaling this up to the wider construction industry. Otherwise, at a localized level, similar case studies to the one described have to be disseminated to act as catalysts, precedents and data sources for other bottom-up projects. Guido et al. (2012) recognize that bottom up strategies can be particularly successful in conjunction with the FSSD, as they tend to operate on their own terms: there is often powerful, intrinsic motivation, concerning small-scale stakeholders, whether they be public, private or local communities, that can act as change agents for other similar developments. They can build momentum and a robust *systems* level that can over time result in changes in culture and accepted practice.

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