Transformative Products and Processes

A Building Manufacturing Value Chain Assessment Approach

A Sustainable Built Environment National Research Centre (SBEnrc)

Industry Report

Project 1.37

Sustainable Built Environment National Research Centre

SBEnrc Core Partners

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Preface

The Sustainable Built Environment National Research Centre (SBEnrc) and its predecessor, the Cooperative Research Centre (CRC) for Construction Innovation, is committed to making a strong contribution to innovation across the Australian built environment sector. We are dedicated to working collaboratively with industry and government to develop and disseminate practical research outcomes that improve industry practice and enhance our nation's competitiveness. We encourage you to draw on the results of this and our many other applied research projects to deliver tangible outcomes for your operations and look forward to opportunities to work together in the future.

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Synopsis

The need for innovation in the building sector in Australia is growing with fluctuating real-estate prices, increasing resource and utility costs, a shortage in affordable housing and the ongoing need to achieve greater productivity and increased job opportunities. This report presents findings of an industry led research project designed to assess opportunities to create greater value across the supply chain for building manufacturing. The project created a set of tools and models to identify the impact of changes to over 30 factors that affect the creation of value.

These findings provide a powerful tool to enhance value creation across the building manufacture supply chain. Specifically, the findings extend previous SBEnrc project findings by creating a digital model to investigate a range of causal relations and feedbacks between key factors that affect value creation. This model can be used to inform business development strategies by both highlighting the flow-on effects of a focus on particular factors and by comparing the influence on value creation of a range of different business development options.

Acknowledgments

This research has been developed with funding and support provided by Australia's Sustainable Built Environment National Research Centre (SBEnrc) and its partners.

Core Members of the SBEnrc include Aurecon, Curtin University, Government of Western Australia, Griffith University, New South Wales Roads and Maritime Services, Queensland Government and Swinburne University of Technology.

The Project Steering Group was chaired by John V McCarthy AO. The project was directly supported by SBEnrc Core Members, the Western Australian Department of Treasury thanks to Carolyn Marshall, Western Australian Building Commission thanks to Daniel Ellis-Jones, and NSW Facilities and Community Services thanks to Kathy Roil.

The research was advised by the WA Housing Authority thanks to Alix Rhodes, Monarch Building Systems thanks to Karl Schirmer, and AussiBuild thanks to Murray Spry. The research team is based at Griffith University and the Curtin University Sustainability Policy Institute.

A New Approach to Assessing the Value Chain for the Manufacture of Buildings in Australia

Introduction

According to previous research by the SBEnrc, '*The manufacture of buildings is defined as the manufacture of entire buildings, or components of buildings, in centralised facilities using repeatable processes based on traditional building techniques to achieve parallel construction outcomes, prior to transportation for erection on site*'.[1]

The benefits associated with manufacturing buildings are extensive as outlined in the industry report for SBEnrc Project 1.29,[1] with significant improvements now demonstrated across all three elements of sustainability, namely: Economic (reduced construction time, cost of finance, and materials use); Social (improved work place conditions and OH&S); and Environmental (waste reduction). All leading to a strong business case.

This project builds on previous SBEnrc research in this area and focuses on providing an approach to identify opportunities to increase the creation of value in the building manufacture supply chain.

Summary of Approach

The project was undertaken through the following steps as described in this report:

Step 1 – Select Stakeholders and Key Performance Criteria

It was assumed from the literature that the focus of supply chains is the creation of value for both customers (to ensure customer satisfaction) and supply chain members (in the form of increased profit). For the purpose of the study two categories were selected for investigation; 'Manufacturers' and 'Clients'. The initial research found that manufacturers were concerned mainly with creating process value, whereas clients were concerned mainly with product value.

Step 2 – Factors Affecting Value Creation

This process began with consideration of previous findings related to the strenghts, weaknesses, opportunities and threats.[1] This was then combined with research into the barriers and enablers associated with building manufacture,

An example of a high quality manufactured home from BGC

1. SBEnrc (2015) Investigating the Mainstreaming of Building Manufacture in Australia, Sustainable Built Environment National Research Centre in collaboration with the Cooperative Research Centre for Low Carbon Living, Curtin University, Australia.

and then compared to literature related to measuring the performance of supply chains.

The outcome was a list of 33 potential factors related to manufacturers that affect the creation of value, with a subset of 10 specifically related to clients.

Step 3 – Create a Base Causal Link Diagram

This process involved the development and review of a base causal loop diagram to represent the interaction of key factors that affect value creation. The diagram was created from the research findings and then tested through interviews with manufacturers and is shown in Figure 1.

Step 4 – Identify the Perceived Relationship between Factors

This process involved collecting data from both manufacturers and clients related to their perception of the level of influence each factor may or may not have on each of the other factors (with 0 suggesting no influence and hence no link, and 1,2,3 suggesting a link increasing from weak to strong influence as shown in Table 3). Not only did this provide the strength of the influence linkages between the various factors for the model development, it also informed consideration of the overall level of influence and dependence of each factor.

Step 5 – Create a Detailed Causal Link Diagram

In this step, the previous findings were brought together to create a powerful model of the causal links between factors that affect value creation in building manufacturing. A set of three causal link diagrams were created, each with a unique focus. The first focuses on 'Customer Satisfaction', the second on 'Profitability', and the third on the general dynamics of the supply chain. These diagrams were then combined to create a detailed causal link diagram of the dynamics of value creation in building manufacture, from the manufacturers' perspective, shown in Figure 5.

Step 6 – Undertake Sensitivity Analysis of Causal Link Diagram

Having created the detailed causal link diagram the next step was to use these findings to investigate potential scenarios. This was done by undertaking a sensitivity analysis of the contribution of 'Profitability' and 'Customer Satisfaction' to value creation using modelling software.

This stage used modelling software to investigate the impact on the key factors of 'Profitability' and 'Customer Satisfaction' of four scenarios, based on the sensitivity of customer satisfaction on demand.

Step 7 – Undertake Modelling of Scenarios

The findings of the scenario investigation were then interpreted to suggest:

- If the price is increased by a certain margin (assumed 10% for modelling purposes), it is likely that the customer satisfaction will reduce faster than the profitability. However, if the price is decreased by the same rate (i.e. 10%), the customer satisfaction will increase a small amount but the profit will be largely unaffected. Hence, there is little incentive to reduce the price; however, if the price is to be increased, the impact on customer satisfaction needs to be countered (through increasing quality or offering greater customisation).
- If the quality is gradually decreased this is likely to see an immediate reduction in customer satisfaction and an initial slight reduction of profitability that will continue to reduce over time. And vice versa, if the quality is gradually increased this is likely to see an immediate increase in customer satisfaction and an initial slight increase of profitability that will continue to increase over time. Furthermore, the findings suggest that a decrease in quality will lose customers faster than an increase in quality will gain customers.

Step 1: Select Stakeholders and Key Performance Criteria

The research began with a desktop study that identified four key stakeholders associated with building manufacture, namely: manufacturers, contractors, developers/clients and end users. The research suggested that 'manufacturers and contractors' are most interested in profitability derived from process value (e.g. good cooperation, business relationships, information systems and, of course, their commercial benefit).

While the 'clients and end-users' who will ultimately sell, live and/or work in the constructed buildings are more interested in the final product value (e.g. quality, flexibility and economy), which affects 'Customer Satisfaction'. For the purpose of the study, two categories were selected for investigation, 'Manufacturers' represented by building manufacturing companies operating in Australia and 'Clients' represented by State Government agencies (SBEnrc Core Members).

It was assumed from the literature that the building manufacturing sector is focused on the creation of value for both customers, to ensure 'Customer Satisfaction', and for supply chain members in the form of increased 'Profitability'. As such, these two elements were assumed to have the most significant effect on value creation and were selected as the focus for the project.

Following investigations into what additional factors may affect the creation of value, the focus shifted to considering specific measurements to understand performance along the supply chain. This was undertaken by adopting two structures from the literature to create a scaffolding that considers four key variables (cost, time, quality and flexibility) across a five step supply chain process (plan, source, make, deliver and return or customer satisfaction), as detailed in Table 1.

Table 1: Supply chain processes and performance measurements

Stage[2]	Supply Chain Measurement[3] (Creating Relative Values)
Plan	• Cost: Total cost, sales, profit, ROI, IRR. • Time: Supply chain response and cycle, ordering, customer response, development, total cash flow. • Quality: Satisfaction with developer, fill rate, forecast accuracy, planning accuracy, order fulfilment. • Flexibility: Order flexibility, number of new products.
Source	• Cost: Wrong delivery percentage. • Time: Supplier lead time, purchase order cycle time. • Quality: Manufactured product quality, information accuracy, information availability. • Flexibility: Problem responsiveness.
Make	• Cost: Resources cost, inventory cost, inventory utilization, disposal cost, No. of items produced. • Time: Process cycle time, manufacturing lead time. • Quality: Built product quality, wrong products percentage inventory accuracy. • Flexibility: Inventory range, production flexibility, capacity flexibility.
Deliver	• Cost: Logistics cost, distribution cost. • Time: Delivery lead time, frequency of delivery, order lateness. • Quality: Delivery reliability, documentation quality. • Flexibility: Delivery flexibility, delivery responsiveness.
Return	• Cost: Warranty processing cost. • Time: Customer query time. • Quality: Final product quality, customer complaints. • Flexibility: Product customisation, service system flexibility.

2. Godet, M. (2006) Creating futures: scenario planning as a strategic management tool, 2nd ed. Economica, London, xiii, p. 349.
3. Sillanpaa, I. (2010) Supply chain performance measurement in the manufacturing industry, Industrial Engineering & Technology, University of Oulu, Finland.

Step 2: Identify Factors Affecting Value Creation

This process began with consideration of previous findings from an analysis of the strengths, weaknesses, opportunities and threats as part of SBEnrc Project 1.29, shown in Table 2. This was then combined with new research into the barriers and enablers associated with building manufacture, to then be compared to the literature related to measuring the performance of supply chains (as shown in Table 1). The outcome was a list of potential factors related to manufacturers that affect the creation of value, with a subset of 10 specifically related to clients (as shown in Table 3).

These findings where then compared to a number of barriers and enablers identified as part of the literature review for the new project as listed below:

Enablers

- Customer preferences
- Logistics and process
- Human skills
- Waste removal
- OS&H
- Final product cost
- Productivity
- Environmental performance
- Time
- Quality

Barriers

- Lack of leadership
- Logistics and site operations
- Existing processes
- Regulatory frameworks
- Industry market and culture
- Supply chain and procurement
- Initial costs
- Skills and knowledge shortage

Table 2: SWOT Analysis of Building Manufacture in Australia[1]

Strengths *What strengths can we build upon?*	**Weakness** *What weakness do we need to remove?*
• Cost reduction • Time • Productivity • Quality • Environmental performance (*Waste Reduction, Energy Efficiency, Land Use*) • Supply Chain Management • Safety	• Capacity building • Perceptions about Manufactured Building Systems • Process and People
Opportunities *What opportunities can we utilise?*	**Threats** *What threats do we need to be aware of?*
• Need for affordable housing • Job creation • International competitiveness • Contribution to sustainability • Capture first mover advantage • Financing • Increase in natural disasters • Growth in market for new building product	• Negative attitudes • Finance • Competition, market trends and geographical location • Reduced demand for traditional trades • Not getting stuck at the compliance/permit stage

Source: SBEnrc (2015) Investigating the Mainstreaming of Building Manufacture in Australia: A Sustainable Built Environment National Research Centre (SBEnrc) Industry Report, Curtin University, Perth, Griffith University.

Step 3: Create a Base Causal Link Diagram

This process involved the development and review of a generic causal link diagram, shown in Figure 1, to represent the interaction of key factors that affect value creation. This diagram was created from the research findings and then tested through interviews with manufacturers.

This was then used as the basic architecture for modelling focused on 'Customer Satisfaction' and 'Profitability' that included all 33 factors and the associated perceived influences between them.

In a causal link diagram the variables are linked together by arrows to indicate a causal relationship or a direct influence, such that:

- A causal link with a *positive effect* (denoted with a '+') suggests that the first element either adds to the second, or a change in the first will result in a change in the second in the same direction. For instance, a positive customer perception is assumed to lead to an increase in customer satisfaction, while a decrease in demand is assumed to lead to a decrease in profitability.
- A causal link with a *negative effect* (denoted with a '-') suggests that the first element either subtracts from the second, or a change in the first will result in a change in the second in the opposite direction. For instance, an increase in price may reduce the customer satisfaction level, while a decrease in supply is assumed to lead to an increase in price.

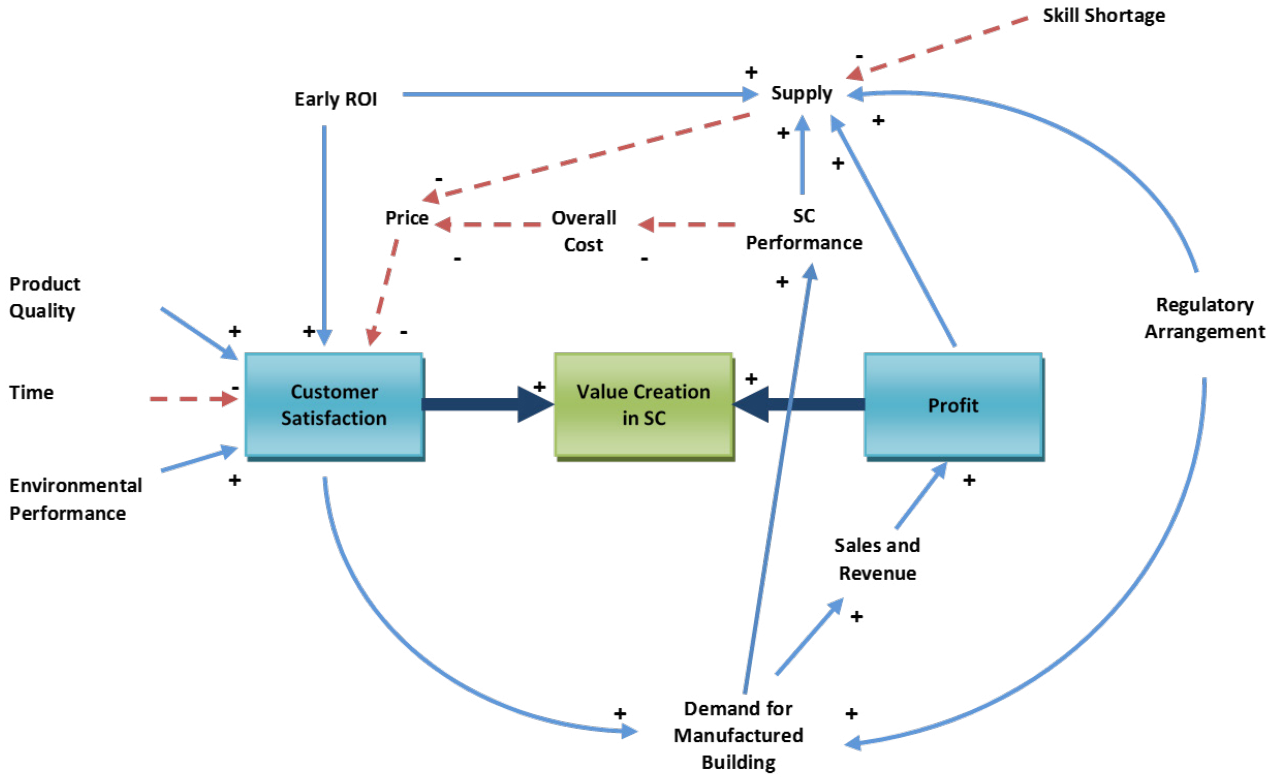

Figure 1: Causal Link Diagram representing the inter-relations between key factors affecting value creation in building manufacturing (from the manufacturers' perspective)

SC = Supply Chain

Step 4: Identify the Perceived Relationship between Factors

This process involved collecting data from manufacturers related to their perception of the level of influence that each factor may or may not have on each of the other factors (with 0 suggesting no influence and hence no link and 1,2,3 suggesting a link increasing from weak to strong influence).

In order to quantify the causal relationships between the factors, data was collected in the form of a structural analysis matrix, as shown in Table 3. The purpose of the matrix was to gather the perceived strength of the relationships between the factors by having respondents compare each factor to each other factor. This data provided three main findings:

1. The identification of factors that were likely to have a greater influence on value creation.

2. The identification of the perceived level of influence each factor had on each other factor.

3. The identification of the perceived level of dependence between each factor.

A sample of a structural analysis matrix is provided in Table 3 with respondents asked to provide a rank from 0-3 when comparing each factor with each other factor.

The findings suggest that there is general agreement on the level of influence and dependence across the variables. However, some show a differing view, such as the influence of price, product quality and final product cost, and the dependence of customer perceptions and product quality. Such variance in perceptions will not only help to inform the design of the detailed causal link diagram but also provides an interesting area for further investigation.

Table 3: Example of a structural analysis matrix of factors affecting value creation

	Product Quality	Product Customisation	Customer Satisfaction	Customer Perception	Production Flexibility	Supply Demand Gap	Customer Preferences	Price	Delivery Speed	Final Product Cost
Product Quality	0	0	3	2	0	0	2	3	2	3
Product Customisation	0	0	3	2	1	1	2	3	3	3
Customer Satisfaction	2	1	0	3	0	0	1	2	2	2
Customer Perception	1	0	3	0	0	1	2	1	1	1
Production Flexibility	1	3	3	3	0	2	2	2	2	2
Supply Demand Gap	1	2	1	3	1	0	2	3	2	2
Customer Preferences	1	3	3	3	1	1	0	2	1	3
Price	3	2	2	2	2	1	2	0	2	3
Delivery Speed	2	1	2	2	1	1	2	2	0	2
Final Product Cost	2	2	3	2	1	1	2	3	2	0

Step 5: Create Detailed Causal Link Diagram

In this step, the previous findings were brought together to create a powerful model of the causal links between factors that affect value creation in building manufacturing. A set of three causal link diagrams were created, each with a unique focus. The first focuses on 'Customer Satisfaction' (Figure 2), the second on 'Profitability', (Figure 3), and the third on the general dynamics of the supply chain (Figure 4).

This was done in each case by starting with the base causal link diagram (presented in Figure 1), and adding nodes and linkages to each of the three diagrams based on the findings of the influence/dependence investigation outlined in Step 4. In this process, 17 of the 33 factors that were perceived to have a strong influence and high level of dependency were used as key parameters in the scenario modelling.

Then each of the links between the nodes were identified as having a (+) or (-) effect on the other node, and assigned a value between 0 and 3 to indicate how influential the manufacturers perceived the link to be.

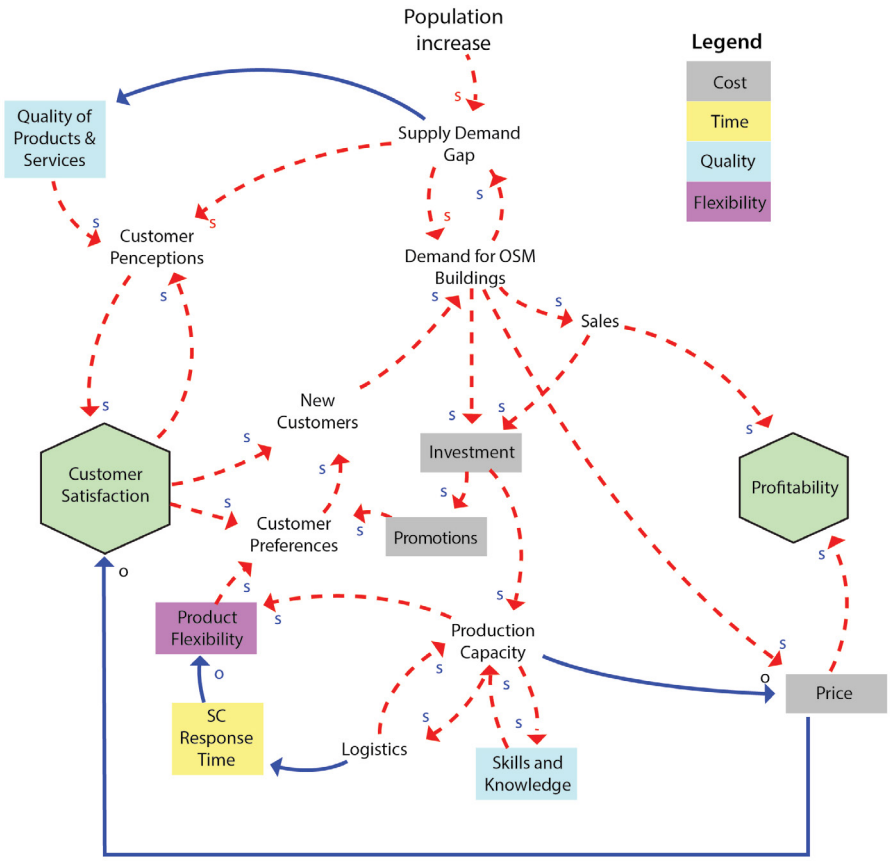

Figure 2: A causal link diagram representing the dynamics of 'Customer Satisfaction' associated with building manufacture (from a manufacturers' perspective)

OSM = Off Site Manufacture

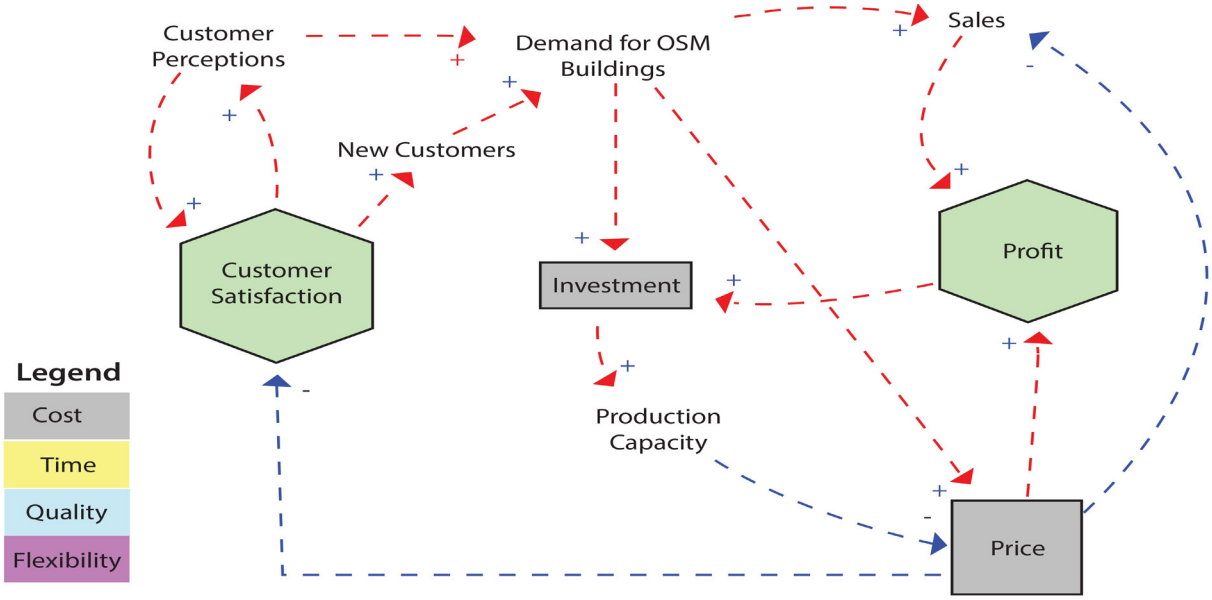

Figure 3: A causal link diagram representing the dynamics of 'Profitability' associated with building manufacture (from a manufacturers' perspective)

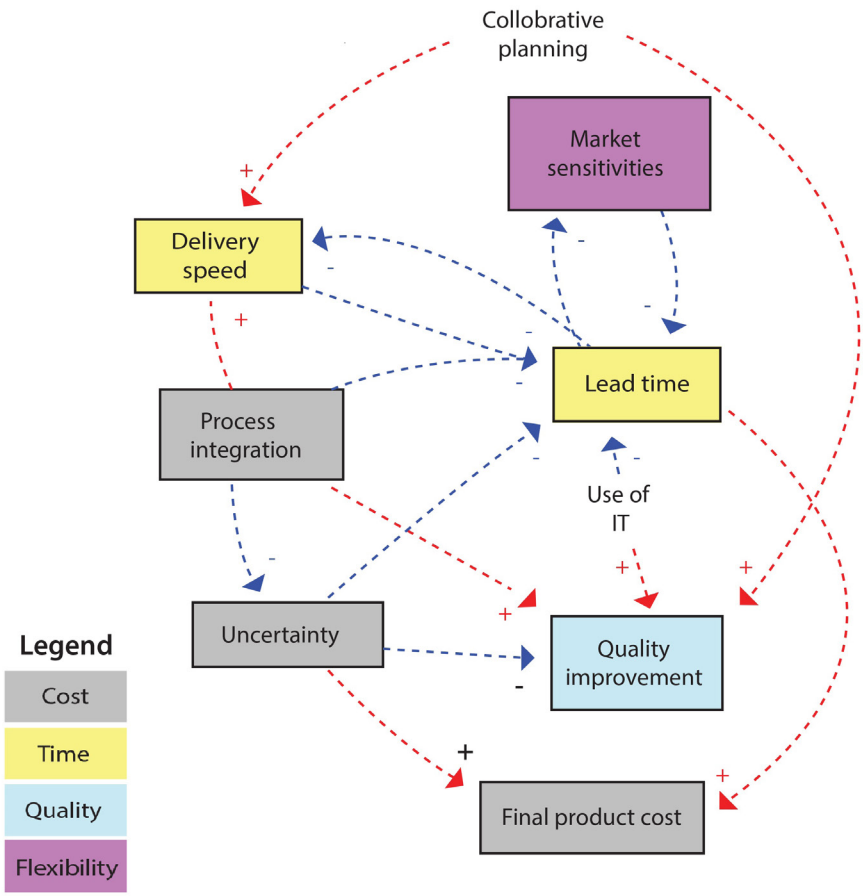

Figure 4: A causal link diagram representing the dynamics of supply chain management associated with building manufacture (from a manufacturers' perspective)

Based on the causal relationships in Figure 5, in a scenario where the manufacturer focuses solely on improving 'Quality' this would lead to a series of influences that if not foreseen could lead to reduced value creation. For example:

1) Increasing 'Quality' leads to,

2) Increasing 'Customer Satisfaction', that then

3) Attracts more 'New Customers', that then

4) Leads to an increase in 'Demand', that then

5) Increases the 'Supply Gap', and ends up

6) Decreasing the 'Quality'.

So, assuming the manufacturer only focuses on increasing quality they run the risk of creating a flow on effect that could end up decreasing quality overall as they attempt to satisfy the increased demand by stretching their production capacity. Should this happen, then a secondary causal loop is activated where;

1) Decreasing 'Quality', leads to

2) Decreasing 'Customer Satisfaction', that then leads to

3) Declining 'New Customers' (or return customers), that then

4) Reduces 'Demand', that then reduces 'Sales,' that then reduces 'Profit'.

According to the causal link diagram, in order to avoid this outcome manufacturers could take action to improve the quality of products and services, such as simplifying the construction process, increasing investment, or improving process integration. These actions could be complimented by marketing campaigns, seeking additional market segments, or amalgamation with other manufacturers.

The causal links diagram in Figure 5 also suggests that should the manufacturer decide to increase the price of the product, there would be a lag time before this affects sales, as the first impact would be a reduction in 'Customer Satisfaction', leading to a reduction in 'New Customers', leading to a reduction in 'Demand', leading to a reduction in 'Sales'. However, an increase in price would have an immediate effect on profitability, shown by the causal link directly between 'Price' and 'Profitability'.

Hence the causal link diagram and associated modelling software can be used to identify strategies for manufacturers to increase value. This is done by not only highlighting the causal relationships like the examples above, but also by using the perceptions of the stakeholders to quantify the impacts of changes to any of the nodes, as outlined in the next section. Therefore, rather than limiting the users to a set of predefined scenarios, this approach allows the selection of key variables to simulate changes and explore the resulting impacts across the supply chain based on various assumptions about the strength of connections between nodes.


Manufactured homes from BGC

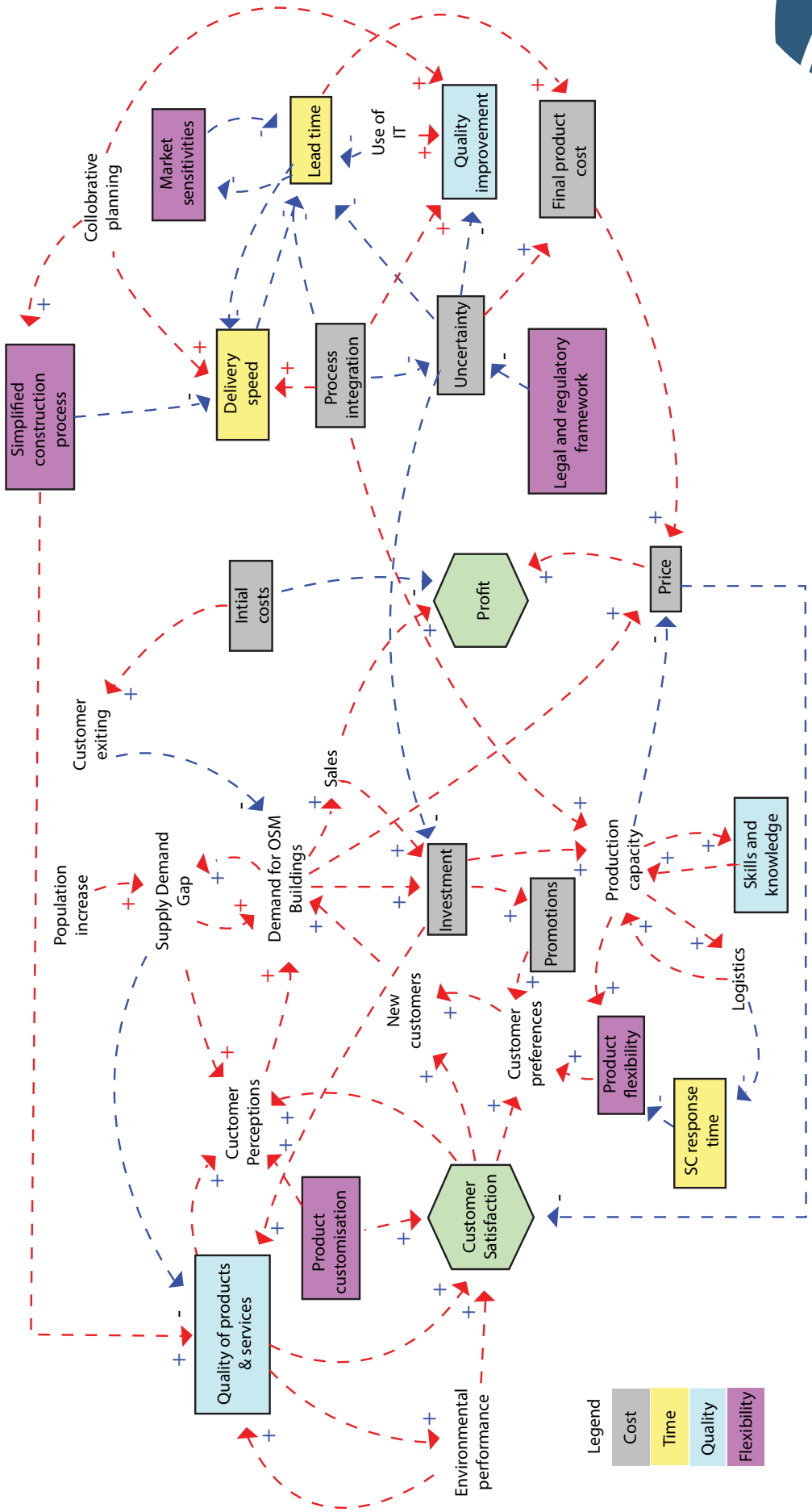

Figure 5: Detailed Causal Link Diagram of the dynamics of value creation in building manufacture (from a manufacturers' perspective)

Step 6: Undertake Sensitivity Analysis of Causal Link Diagram

This stage used modelling software to investigate the impact on the key factors of 'Profitability' and 'Customer Satisfaction' of four scenarios, based on the sensitivity of customer satisfaction on demand. The scenarios are shown in Table 4 and were created by systematically replacing the link strength with the data in the table (for the nodes listed and others deemed closely linked) and running the simulation (with 1 = Low, 2 = Medium and 3 = High). The data for the first three were assigned by the research team, while the data for the last simulation was drawn from the data for the structural analysis that represents the perception of the manufactures as to the influence of each of the four variables.

Table 4: Key variable parameters for simulation scenarios

Scenarios	Sensitivity of demand on Customer Satisfaction 0-100%	Flexibility level	Quality level	Price level
Best	40%	3	3	3
Average	60%	2	2	2
Worst	100%	1	1	1
Manufacturers	100%	2	3	3

The results in Figure 6 show how the manufacturers' perception of the causal links would affect the contribution to each value creation factor over time, shown as a thick red line, compared to the 'Best Case' scenario, shown as the top of shaded area, the 'Worst Case' scenario shown as the bottom of the area, with the 'Average' case shown by the thin black line through the middle.

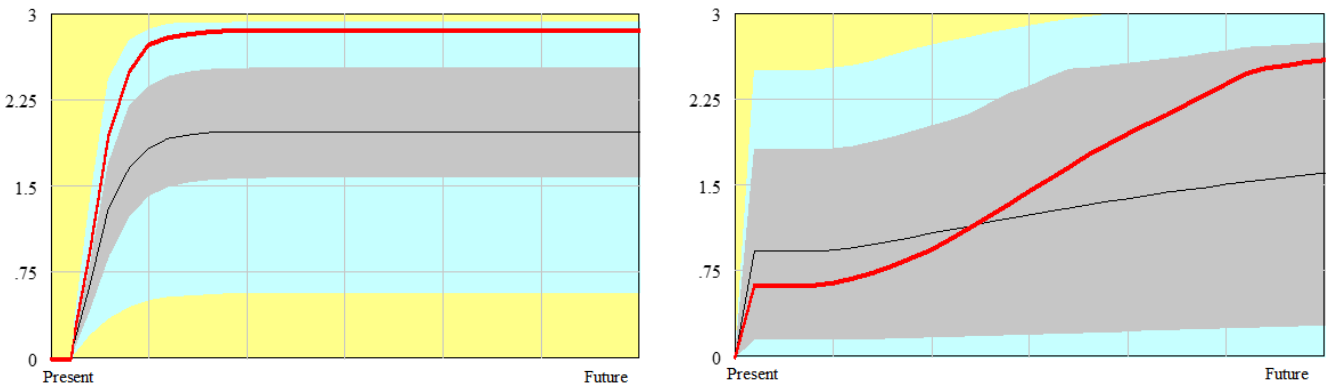

Figure 6: Sensitivity analysis of the contribution of (a) Customer Satisfaction and (b) Profitability to value creation for a set of 4 defined scenarios

As can be seen from Figure 6(a) the manufacturer's perception of the contribution of 'Customer Satisfaction' (otherwise referred to as 'Product Value') to value creation aligns closely with the simulated best case scenario and hence is not considered a key perception requiring further analysis. However, Figure 6(b) suggests that the manufacturer's perception of the contribution of 'Profitability' (otherwise referred to as 'Process Value') does not align with the best case scenario. Although the manufacturers' perception generates a result better than the average (black line), it doesn't provide the 'best' outcomes (top of shaded area), and suggests that changes could be made to better harness the potential of process value creation leading to greater profitability.

Step 7: Undertake Modelling of Scenarios

This step involved the selection of the next most influential factors, after those examined in Step 6, to systematically adjust them using modelling software to see how the overall system responded and, in turn, how the overall value creation was likely to be affected.

The model shown in the Causal Link Diagram (Figure 5) provides the potential to vary the factors to investigate the impact on value created through both 'Customer Satisfaction' and 'Profitability', taking into account the perceptions of the manufacturers.

As such, this provides a powerful tool to identify leverage points for investment. For the purpose of demonstration, a comparison between the perceptions of the two stakeholders ('Manufacturers' and 'Clients') related to the relative influence of each factor was used to select two factors to be the focus of the scenario simulations.

As can be seen in Figure 7, the factors that were perceived to be the next most influential were 'Price' (by clients) and 'Product Quality' (by manufacturers).

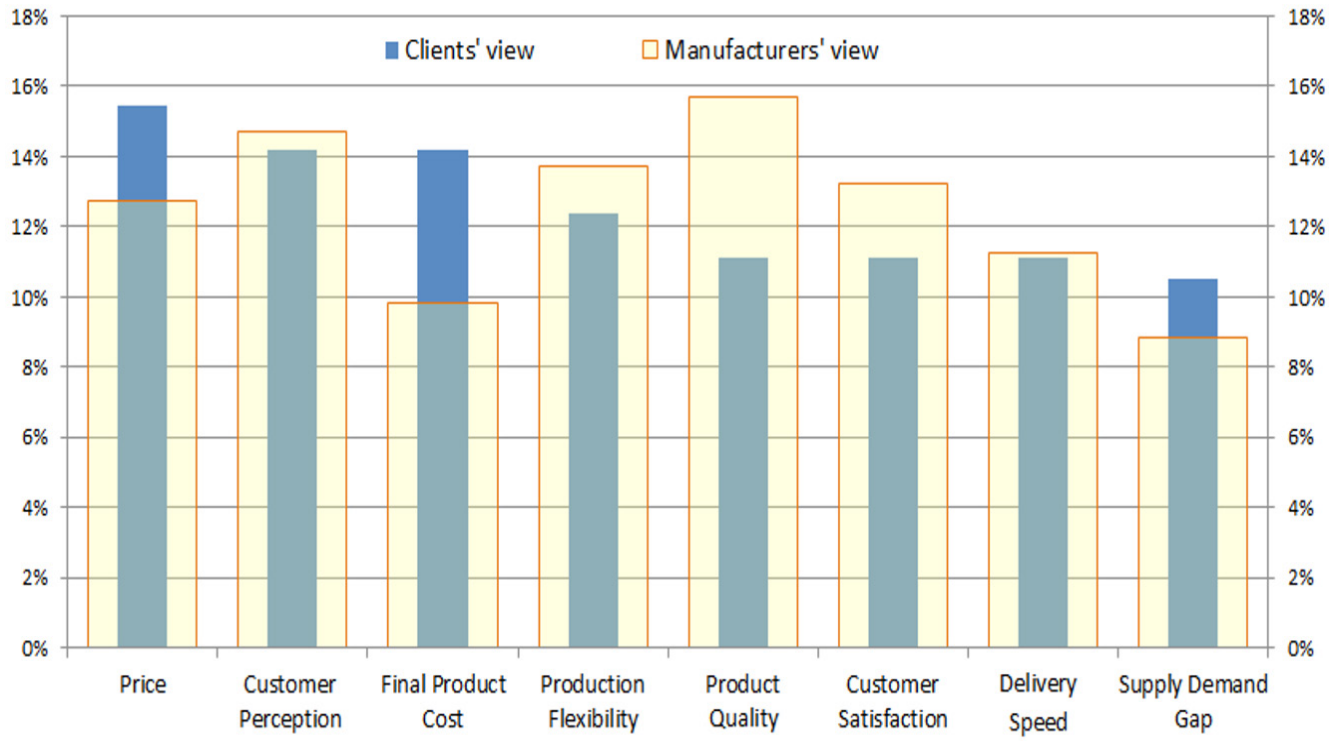

Figure 7: Level of influence of key factors across the building manufacturing supply chain from different stakeholder perspectives

The Effects of Increasing and Decreasing the 'Price'

Considering a change in 'Price', the scenario simulations shown in Figure 8 suggest that if the price is increased by 10% it is likely that the customer satisfaction will also reduce, however if the price is decreased by 10% the customer satisfaction will increase a small amount compared to the manufacturer's baseline in Figure 6.

However, Figure 9 suggests that the profit will be largely unaffected by either of the changes. Hence there is little incentive to reduce the price, although if the price is to be increased, the impact on customer satisfaction needs to be countered (such as through increasing quality, or offering greater customisation).

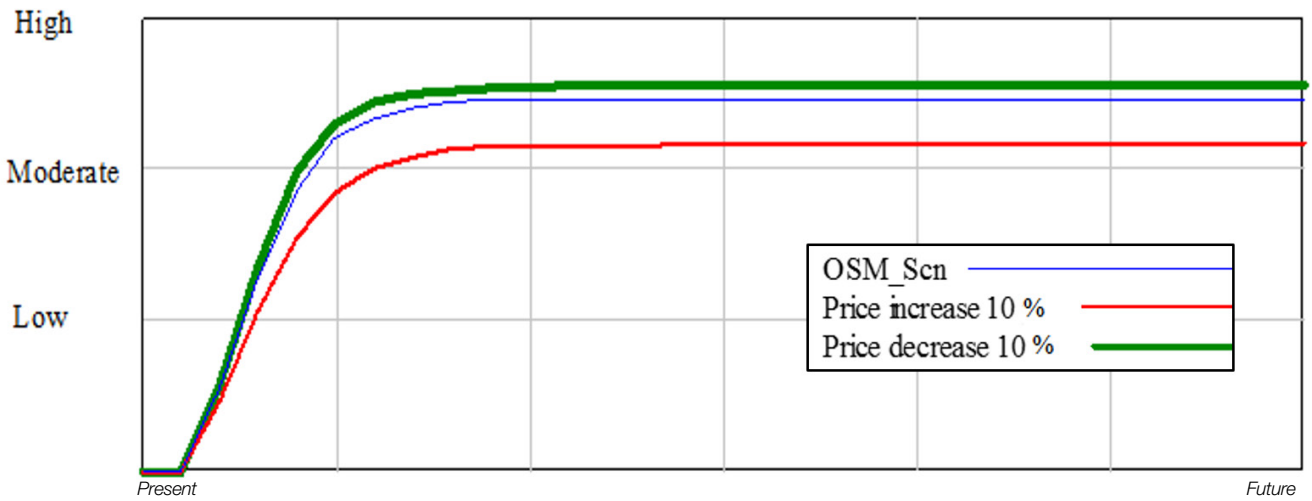

Figure 8: Predicted impact on 'Customer Satisfaction' from altering the 'Price'

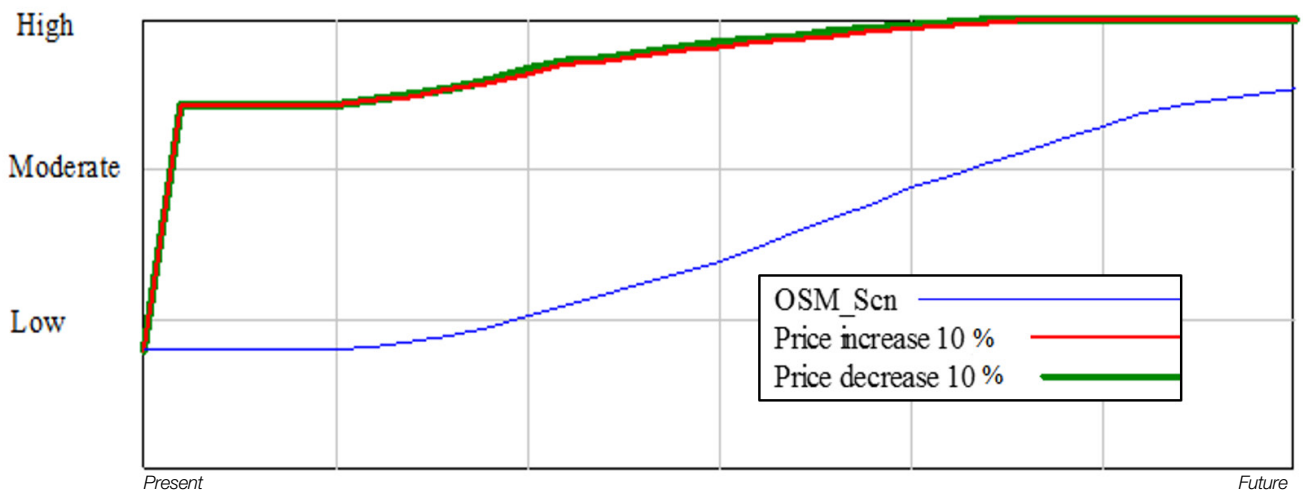

Figure 9: Predicted impact on 'Profitability' from altering the 'Price'

The Effects of Increasing and Decreasing the 'Quality'

Considering a change in 'Quality', the scenario simulations shown in Figure 10 suggest that If the quality is gradually decreased this is likely to see an immediate reduction in customer satisfaction, with Figure 11 suggesting an initial slight reduction of profitability that will continue to reduce over time.

And vice versa, if the quality is gradually increased this is likely to see an immediate increase in customer satisfaction and an initial slight increase of profitability that will continue to increase over time. Furthermore, the findings suggest that a decrease in quality will lose customers faster than an increase in quality will gain customers.

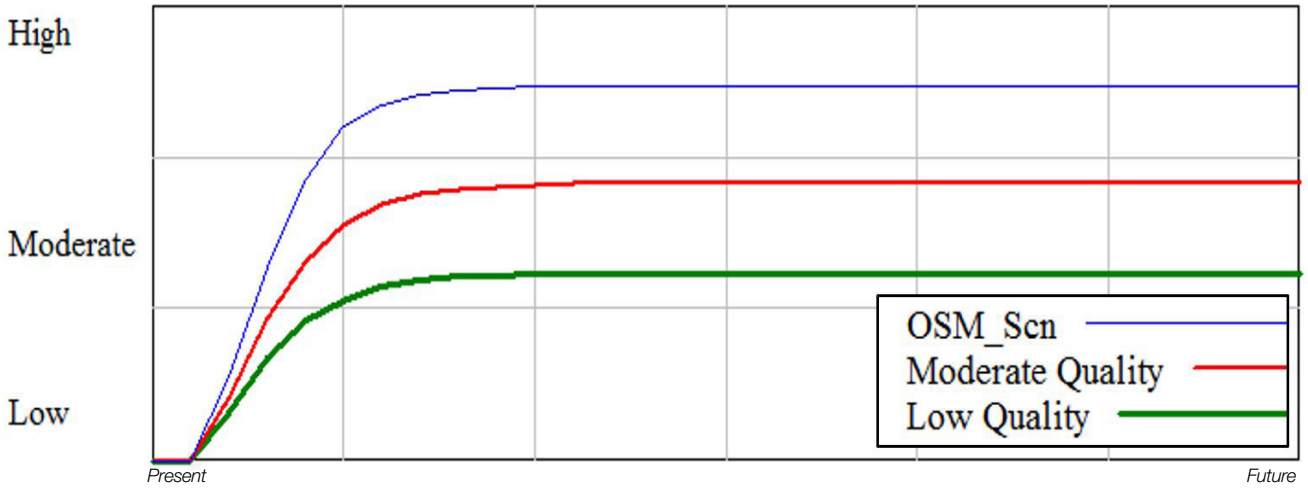

Figure 10: Predicted impact on 'Customer Satisfaction' from altering the 'Quality'

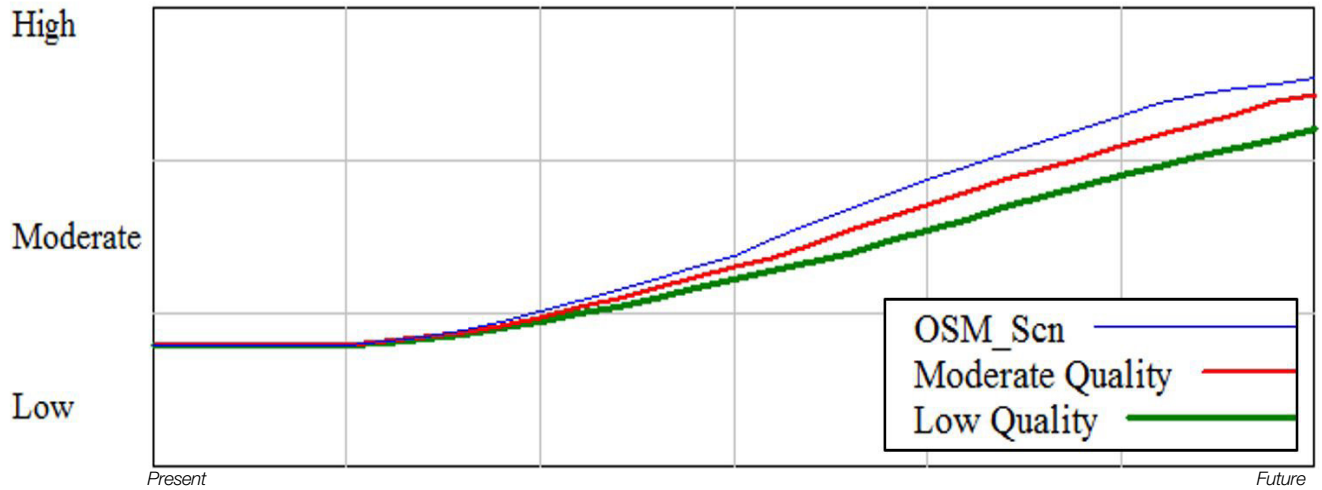

Figure 11: Predicted impact on 'Profitability' from altering the 'Quality'

Sustainable Built Environment National Research Centre

SBEnrc Overview

The Sustainable Built Environment National Research Centre (SBEnrc) is the successor to Australia's CRC for Construction Innovation. Established on 1 January 2010, the SBEnrc is a key research broker between industry, government and research organisations for the built environment industry.

The SBEnrc is continuing to build an enduring value-adding national research and development centre in sustainable infrastructure and building with significant support from public and private partners around Australia and internationally.

Benefits from SBEnrc activities are realised through national, industry and firm-level competitive advantages; market premiums through engagement in the collaborative research and development process; and early adoption of Centre outputs. The Centre integrates research across the environmental, social and economic sustainability areas in programs respectively titled Greening the Built Environment; People, Processes and Procurement; and Productivity through Innovation.

Among the SBEnrc's objectives is to collaborate across organisational, state and national boundaries to develop a strong and enduring network of built environment research stakeholders and to build value-adding collaborative industry research teams.

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