TOWARDS SUSTAINABLE BUSINESS IMPROVEMENT IN THE PRECAST CONCRETE FLOORING INDUSTRY

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Abstract

The manufacture of precast concrete flooring products is part of a £2bn precast concrete industry sector employing 22,000 people and accounting for nearly 28% of the total cement and concrete market in the UK. This sector has always been keen to improve its environmental performance and reduce the levels of its emissions, but this agenda has broadened in response to government and consumer demands and interest in sustainability principles. Of the triple bottom line components, environmental protection and business imperatives are closely linked within the precast manufacturing process, particularly with the sector being a core user of both primary energy and Portland cement. In this context, research is underway to identify the short and long-term environmental impacts of precast flooring products.

The BRE Life Cycle Assessment (LCA) methodology was used in five precast pre-stressed concrete flooring factories to identify the main environmental impacts directly or indirectly associated with production. The study explored 12 environmental impacts, including energy consumption and concrete waste generation. Energy use, cement consumption and waste emerged as key issues, these were found to be affected with specific production systems and techniques (such as accelerated curing, or bespoke product design) employed by manufacturers to maintain workability and increase profits. These have been explored subsequently through a series of focus groups. A range of research methods has been employed to further explore the outcomes of the LCA, with a view to mapping the operational decision making behind the data. This paper reports on all of these aspects and will be of interest to researchers, academics and industrialists.

Keywords

Precast concrete; Life cycle assessment; Business improvement; Environmental impact, decision making.

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Introduction

The concept of sustainable development addresses the need to include new dimensions to current production and business systems; other than economic criteria, environmental and social aspects require more consideration and attention. However, this can be a challenge to organisations across different businesses and industry sectors. Corporate management, as expressed by Smart (1992), recognises and responds naturally and efficiently to cost and price signals, selecting resources and converting them successfully into useful and profitable products. However, this perception of success has meant that many corporations have failed to adequately respond and adopt what they see as additional sustainability requirements (Dunphy *et al*, 2003).

Like other manufacturing sectors, precast concrete flooring manufacture is designed to produce high quality products with the shortest times and lowest overheads. Richardson (1991) stresses that capital cost, cost per unit of concrete cured and ease of application in the working environment and controllability must be the main criteria by which any precast production system is evaluated. However, the profit driven production system employed in the industry fails to recognise the environmental effects occurring during production. These include environmental impacts such as Carbon Dioxide (CO_2) emissions, energy consumed, industrial waste generated, etc. With the introduction of sustainability to the industry as a business and legislative driver, the precast concrete flooring sector is faced with the problem of adapting some long established working practices – but can such a change make good business sense?

Manufacturers recognise that profit is the bloodstream of any corporation and the means to its growth. However, the concept of sustainable development adds new dimensions to the precast manufacturing scenario as social progress and environmental protection become end goals in themselves. This may have a serious effect on precast organisations as the profit achieving production system employed in the industry fails to recognise several environmental impacts occurring during production (Elhag *et al*, 2005). This potential conflict of interest between environmental and economic aspects is one of the main challenges facing industries worldwide. In order to identify and address these issues, manufacturers need to understand clearly the relationships between economic objectives/ measures and environmental impacts.

This paper is part of a Precast Flooring Federation (PFF) sponsored research project being conducted in the UK. The aim of the study is to explore the link between environmental impacts and business imperatives and evaluate the possible impact of sustainable development and environmental protection measures on the business case of precast concrete flooring production systems. To do this, the following tasks are being carried out:

- Understand and evaluate the environmental impacts occurring during the production of precast flooring products using Life-Cycle Assessment (LCA).
- Determine how managerial, strategic, and technical solutions, measures and decisions affect environmental impacts by linking business imperatives and measures to LCA results.
- Understand the priorities of an organisation and how decisions can be reproduced to support sustainability. This objective is tackled through the use of focus groups and semi-structured interviews with industry participants.
- Identify the possibility of success and evaluate the most appropriate means of sustainable business improvements. This objective is tackled through the use of semi-structured interviews with a range of industry decision-makers.

In order to achieve the overall aim, the BRE[2] Life Cycle Assessment (LCA) methodology was used to identify the gate-to-gate (and some of the major cradle-to-gate) environmental impacts associated with precast flooring production. LCA is an decision support tool that explores and quantifies different environmental aspects from the widest possible perspective (Glavind *et al*, 2002). The major impacts can then be linked to specific production systems and techniques employed by manufacturers to increase quality and profits.

About precast concrete manufacture

To understand the business and production aspects in precast concrete flooring production, along with its possible environmental impacts, a short description of precast flooring production, business imperatives, and energy consumption levels in the industry is provided.

The manufacture of precast concrete flooring products is part of a £2bn precast concrete industry sector employing 22,000 people and accounting for nearly 28% of the total cement and concrete market in the UK. Precast and other off-site products have helped considerably in revolutionising the construction industry through the introduction of different mass production advantages: these include shorter construction periods, precision, standardisation, mechanisation, and economies of scale (Gibb, 1999).

The basic ingredients involved in precast flooring production are Portland cement, fine/coarse aggregates, water, reinforcing steel, and admixtures. Manufacturers consider a combination of technical, functionality and profitability factors in designing concrete mixes. The ingredients are batched in large mixers with a capacity of 2.5 – 3 m^3/batch; the concrete mix is then cast in 50 – 200 metres long production beds/moulds using slip-form, extrusion or wet casting techniques. The product is then cured; in order to meet time and delivery requirements, manufacturers use a range of accelerated curing techniques. Cured products are then sawed into the required shapes and transported, using fork-lift trucks or gantry systems, to stockyards and then by truck to construction sites.

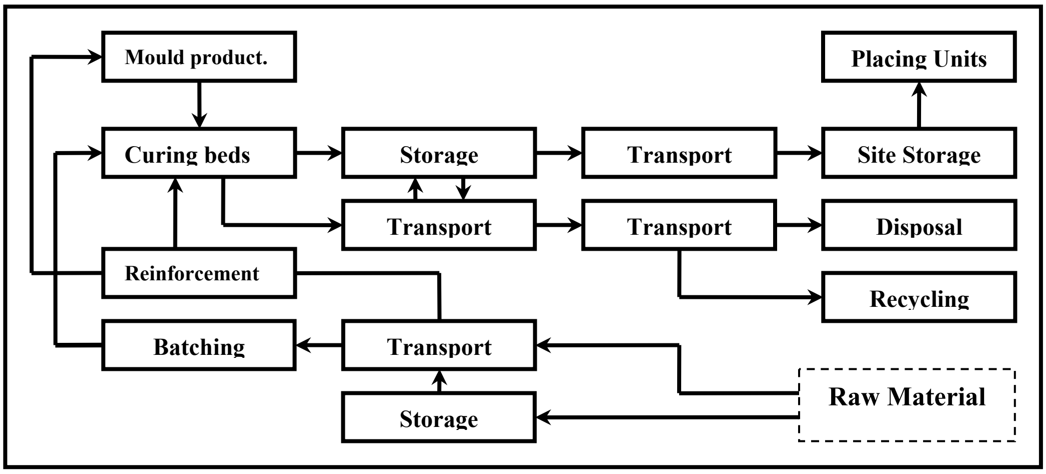

Figure 1. Simple flow chart showing the processes involved in precast flooring manufacture.

As many other industry sectors, precast flooring production systems are designed to produce high quality products within the shortest manufacturing times and least

[2] The Building Research Establishment (BRE) is a leading construction research organisation in the UK (see www.bre.co.uk for further information).

overheads possible. Virtually all the possible solutions, techniques and arrangements within a conventional precast concrete production facility are designed to add maximum value to the product. All procedures, measures and communication channels are built around the concept of maximum (short or long-term) profitability. Richardson (1991) for example clearly stressed that capital cost and cost per unit of concrete cured (in addition to ease of application in the working environment and controllability) must be the main criteria by which any precast production system is evaluated. In fact, there are many measures or solutions applied across different management and production levels in a precast organisation; these can be found in:

- Production systems used: decisions on these (i.e. machinery, type of casting, curing, or internal transport) are usually taken and approved considering several criteria including costs (both immediate and running), potential savings and profits, upgrading and manpower requirements, and quality of the products produced.
- Product ranges manufactured: following research and estimations on market demand volumes, opportunity costs, etc, manufacturers decide to invest in specific product ranges.
- Location of factories can be influenced by views from other specialised departments (such as marketing, or logistics). A decision on a factory location is a fundamental and strategic decision with a long-term effect that cannot easily be adjusted or reproduced.
- Concrete mixes employed: there are several solutions and techniques associated with the concrete mix to be used. Most of these solutions are influenced by economic factors, such as replacement of cement with industrial by-products (e.g. fly ash), use of fillers (such as limestone), admixtures, or recycled and secondary aggregates.
- Customisation is common in UK building projects. A study carried out in the 1990s for seven construction projects in Berkshire, UK revealed that 30% – 40% of the structural elements were of different types and the bespoke design level within cladding elements was even greater, ranging between 8% - 50% (Gray, 2001). In response, precast manufacturers employ customisation and bespoke techniques.
- Other time-saving solutions: these include the use of accelerated curing and hydration techniques, mass production techniques to reduce production times, accelerators, and increased cement content.

Environmental impacts in precast concrete production

In precast production a number of specific environmental concerns typically emerge. Bijen (2002) stresses that the main environmental burdens in precast manufacturing are associated with cement content and transportation. Cement manufacture accounts for nearly 65% of CO_2 emissions and 46% of the embodied energy for precast hollow-core manufacture (Addtek, 2000). Transportation impacts for precast products can be significant due to the weight and size of units transported, and the sourcing distances for raw material and finished products. In addition, considering the economic aspects of production, two more environmental impacts need to be considered. These are energy consumption and raw material use/ waste generation levels, these are mainly associated with the economic penalties set by government (e.g. The Climate Change Levy and the Aggregates Tax).

Results from previous research studies in the UK and elsewhere offer consistent and substantive information on these environmental impacts.

- Cement content: the average amount of CO_2 emissions associated with the production of one tonne of cement in the UK is around 880 Kg (Gilbert, 2005). Although the amount of cement present in concrete may be less than 15-20% of the mix (in mass), a cement increase or reduction of just 1% can affect the cradle-to-site impacts by nearly 9 kg of CO_2 emissions per tonne of precast product. Considering that one tonne of hollowcore can cause cradle-to-site CO_2 emissions of around 218.6 kg of CO_2 eq. (Addtek, 2000), cement is obviously a major aspect.
- Transportation impacts in precast elements: Alexander *et al* (2003) argue that the repetitive routes and standardised operations for precast products and raw material transportation are simple to tackle and improve. However, considering the concentration of quarry and cement production activities in specific regions in the UK, factories located in areas far from the East Midlands or South West might face difficulties in achieving such savings (National Statistics, 2003).
- Energy consumption in precast plants: Asumnaa (1999) estimates the range of energy consumption in precast factories to be around 350 – 790 MJ/m^3. However, other studies estimate this figure to be much higher ranging between 851 MJ/m^3 (Alexander *et al*, 2003) to 1113.2 MJ/m^3 (Punkki, 2001). These figures are lower than energy consumption averages for manufacture of other construction products such as timber, which is >1200 MJ/m^3 (Buchanan and Honey, 1994).
- Raw materials use: every year, more than 214 million tonnes of virgin aggregate (QPA, 2003) and 125 million tonnes of cement, concrete, plaster and other cementitious materials – including 8.7 million tonnes of precast concrete – (Smith *et al*, 2002) are consumed in the UK. With increased economic growth, these amounts will increase significantly which the UK may not be able to sustain. Therefore, the level of mineral extraction is a major environmental indicator that needs consideration by precast manufacturers.
- Concrete waste generation in precast manufacture: this is a priority issue for all construction sectors. The UK construction industry produces vast quantities of waste. In 1999 and 2000, it was estimated that 72.5 million tonnes of construction and demolition waste, including clay and subsoil, were produced annually (Symonds Group, 2001). This represents some 17.5% of the total waste produced in the country. Improving concrete waste generation in precast factories can contribute significantly to reducing their environmental impacts.

Use of the Life Cycle Assessment (LCA) methodology

A range of data collection tools and data analysis techniques were selected as part of the life-cycle assessment methodology. This section explains how the BRE Environmental Profiling methodology was used to calculate and classify the key environmental impacts in precast flooring production. This is based on Life-Cycle Assessment (LCA) technique, which is a decision-support tool used to environmentally map manufacturing processes and assess the environmental performance and potential environmental value of products throughout their life-cycle.

The BRE Environmental Profile methodology accounts for a collection of environmental burdens and impacts classified in 13 main environmental impact categories – these are detailed below. For the purposes of this study, the methodology was used only to assess life-cycle environmental impacts directly associated with precast manufacturers' responsibilities – these are therefore mostly gate-to-gate.

Guinée *et al* (2002) consider goal and scope definition to be a crucial step in LCA which can be conducted for commercial, technical or operational purposes. In this study, the PFF members (target audience) wanted to explore the different environmental impacts associated with precast flooring production (i.e. hollowcore and pre-stressed beams).

With reference to ISO 14040 (1997), clause 5.1.2 (and referred to in ISO 14041, clause 5.3.1), the scope of the PFF research is described below.

- Temporal and geographical coverage: the study covered the period between 1st January and 31st December 2002. The study was UK based, however, some of the suppliers are based in Spain or Italy: this influences raw material transport impacts.
- System Boundaries:, this study is limited to the factory *gate-to-gate* phase of the product's life. This should not violate the principles of LCA as this gate-to-gate analysis will be added later to other life-cycle impacts in the BRE database to form a complete LCA (González *et al*, 2000). It should be noted that the BRE methodology does not include impacts associated with manufacturing, maintenance and decommissioning of capital equipment. Moreover, the methodology allows for omission of any inputs/outputs with marginal impact on the environmental profile.
- Functional Unit: among the different functions achieved by precast flooring elements (including structural, fire resisting, thermal and sound insulation functions), only the basic (provision of flooring) function is used. The functional unit is one tonne of precast concrete used for Hollowcore/ Pre-stressed beams flooring with a thermal resistance of 1.43 m^2 K/W and a 60 year service life.
- Included data categories: the study accounted for 12 categories – the Ozone Depletion category was excluded due to lack of significant impacts – these are Climate Change impact (measured in Kg of CO_2 equivalent), Acid Deposition (Kg of SO_2 eq), Ozone Depletion (Kg of CFC_{11} eq), Fossil Fuel Depletion (TOE), Human Air, Human Water, and Eco-Toxicity (Kg and M^3 of TOX), Photochemical Ozone Creation Potential (Kg of CH_4), Eutrophication (Kg of PO_4), Mineral Extraction and waste disposal (tonnes of mass), water extraction (litres of water), and transport pollution and congestion (tonnes.Km and Eco-points).
- Data Quality and reliability: The BRE methodology applies a recognised simplification system developed by SETAC[3] (Christiansen, 1997): Precise company recorded data are preferred, if not found company standardised estimations or information from other periods or similar factories are used. Cut-off and eliminations to some elements were also carried out in accordance with the BRE methodology.

The population, i.e. PFF members, producing hollowcore, pre-stressed beams, or both in Britain was 13 - 15 factories (some factories were closed later in the study). It was decided that each member company should nominate a single factory site for the study. With just one PFF member declining to participate, it was decided to carry out the study for hollowcore/ pre-stressed beams product systems in five precast flooring factories belonging to five different members of the PFF.

Due to lack of sub-metering and reliable information in some of the manufacturers' records, it was decided to reinforce the results of environmental profile data with two in-depth surveys conducted on energy consumption and concrete waste generation – these are discussed later.

[3] The Society of Environmental Toxicology and Chemistry (SETAC) is a non-profit, worldwide professional society comprised of individuals and institutions engaged in research, management, and regulation of different environmental aspects (see www.setac.org for further information).

Table 1. Precast Flooring Federation (PFF) factories involved in the research (in alphabetical order).

Company	Site	Products manufactured
Carter Concrete Ltd.	Beeston Regis and Cramer, Sheringham	Pre-stressed beams Hollowcore
Hanson Building Products Ltd.	Hoveringham, Nottinghamshire	Pre-stressed beams Hollowcore
Milbank Floors Ltd.	Colchester, Essex	Pre-stressed beams Hollowcore
Cemex UK materials (previously RMC Concrete Floors)	Wick, Bristol	Pre-stressed beams
Tarmac Topfloor Ltd.	Ashbourne, Derbyshire	Pre-stressed beams Hollowcore

Compiling the Life Cycle Inventory (LCI)

To build a sufficient environmental profile, a Life-Cycle Inventory (LCI) was developed. LCI is the core component of any LCA, according to the definition of LCA in ISO 14041, which defines it as: "Compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life-cycle" (BSI, 1998), so the LCA is dependent on the content of a Life Cycle Inventory. An extensive survey of manufacturers' records was carried out to collect the necessary information; Table 2 lists the main data elements collected to complete the inventory.

Table 2. Inventory data handling checklist (modified from Howard *et al*, 1999).

Input	unit	***Output***	unit
Sourced cement	Tonnes	Net production	Tonnes
Sourced aggregates	Tonnes	By products (A)	Tonnes
Sourced reinforcement	Tonnes	By products (B)	Tonnes
Sourced admixture	Tonnes	Products A/B to recycling	Tonnes
Sourced replacement materials (PFA, etc.)	Tonnes	Profits from by-products A/ B sold.	GB Pounds
Production: fuel oil used	Litres	Profits from net production	GB Pounds
Production: electricity used	KWh	Water discharged	Litres
Water used	Litres	Emissions to water: silver, zinc, nitrate, nitrite, nickel, etc.	Mg/ Litre
Sanding paper, timber and other consumables	Tonnes	Waste oils disposed	Litres
Lubricating and release oil used	Litres	Concrete waste	Tonnes
Transport: Truck sizes for each raw material	Tonnes	Concrete waste to recycling	Tonnes
Transport distance for each raw material	Km	Other non-hazardous waste	Tonnes
Ship/ train travel info.	Km	Other hazardous waste	Tonnes

However, as the study handles two different precast products, the LCI information was broken down and allocated into two separate inventories each for hollowcore and pre-stressed beams. Due to the lack of sufficient and very detailed information instances, several BRE certified methods of allocation were employed, these were used for the following inputs/ outputs:

- Allocation for raw materials: the allocation was mainly based on specific information on the required period's number of batches/ casts and the tonnage/ waste per casting for each flooring type. However, due to lack of information from some manufacturers, the most appropriate means of allocation was to use the quantities and proportions of gross production for the two products to break down ingredients (allocation via mass).
- Ancillary and processing materials: these were broken down and allocated using gross production mass information.
- Energy use: a separate energy breakdown survey was carried out to breakdown and allocate factory energy consumption. However, energy for specific production activities was allocated between the two products using gross production – mass information.

Further data on energy use and concrete waste

Due to the lack of sufficient information in some categories, the LCA was reinforced with two surveys on energy and waste generation. These were extremely useful in the analysis and recognition of the major environmental impacts associated with different business imperatives. A concrete waste survey was developed to quantify the amounts of concrete waste generated weekly during the production of hollowcore and pre-stressed beams. This was carried out for eight weeks in the first half of 2004. The survey identified four main concrete waste streams:

- remaining concrete waste and slurry at hoppers/ extruders (S1);
- discarded cast concrete portions (S2);
- units scrapped at the stockyard (S3); and,
- site rejects (S4).

The survey was designed to enable the estimation of concrete waste via three different routes: using gross/ net production information, using estimates based on concrete waste transport information, and through quantifying each concrete waste stream separately based on operational managers' own estimations per cast. The waste survey was successfully completed by three manufacturers. Incomplete replies by manufacturers from the other two factories were used to correct defective figures received earlier from the LCI survey.

In order to eliminate activities not directly associated with energy consumption at factories, and in order to gain more insight into the specific measures and aspects affecting energy consumption at precast factories, it was decided to carry out a breakdown of energy consumption at three of the larger PFF production facilities. Primary and secondary information on building energy consumption standards were used to estimate energy consumption for different office use, general lighting and canteen activities. It was possible to identify some of the manufacturing activities (such as accelerated curing, sawing, and crane movements) from the overall energy consumption at some sites. The breakdown helped to establish findings linking environmental impacts to different technical, commercial, and operational solutions.

Conducting the impact assessment

Using standardised conversion tables, the LCI information collected was used to calculate and estimate a range of emissions to air, water, and land. These were then characterised into impact categories and correlated to the appropriate functional unit:

- Transportation impact: these were calculated using the modified BRE methodology (Anderson and Edwards, 2000), in which the impacts are automatically characterised into six main environmental impact categories: Climate Change, Acid Deposition, Human Air and Water Toxicity, Eutrophication, and Fossil Fuel Depletion. An additional transportation impact category was also considered.
- Energy consumption: UK average levels of fuels' calorific values were used to estimate amounts of energy consumed by factories. These were considered in the Fossil Fuel Depletion category.
- Emissions to air (using conversion factors): due to lack of emission detection in the factories studied, conversion tables provided by BRE and gas emissions manuals (DETR, 2001) were used to calculate gas emissions. Different emission impacts include CO_2, CH_4, N_2O, NO_x, CO, NMVOC, and SO_2. These were characterised using the CML Heijungs' methodology (also used by BRE) into the six environmental impact categories mentioned above.
- Water use: Levels of water use were simply correlated to the functional unit used.
- Emissions to water: No information was available on water discharged from most factories. Therefore, secondary information was used from the only factory with sufficient water emission information. Information on emission to water was then correlated to amount of water discharged per one functional unit.

The impact assessment, characterisation, and normalisation processes were completed with presentation of 11 complete environmental profiles for hollowcore and pre-stressed beams gate-to-gate production systems. The process also included the use of the BRE Eco-point score system, this is a single unit measurement of the total environmental impact of a particular product/ process expressed in units known as Eco-points (Dickie and Howard, 2000). Using this measure, it was possible to identify the major environmental impacts associated with the manufacture of precast products, these being raw materials use (including cement), Climate Change (mostly from energy consumption), concrete waste, and a range of transportation impacts.

Analysis and discussion

The results of the LCA study covered many aspects including the major environmental impacts (mentioned above) and information associated with the major factors and elements affecting the level of these impacts. The results showed variations in impacts between different factories' environmental profiles. Figure 2 shows a proportional energy breakdown for hollowcore production at factories included in the study to demonstrate the variations shown in the results.

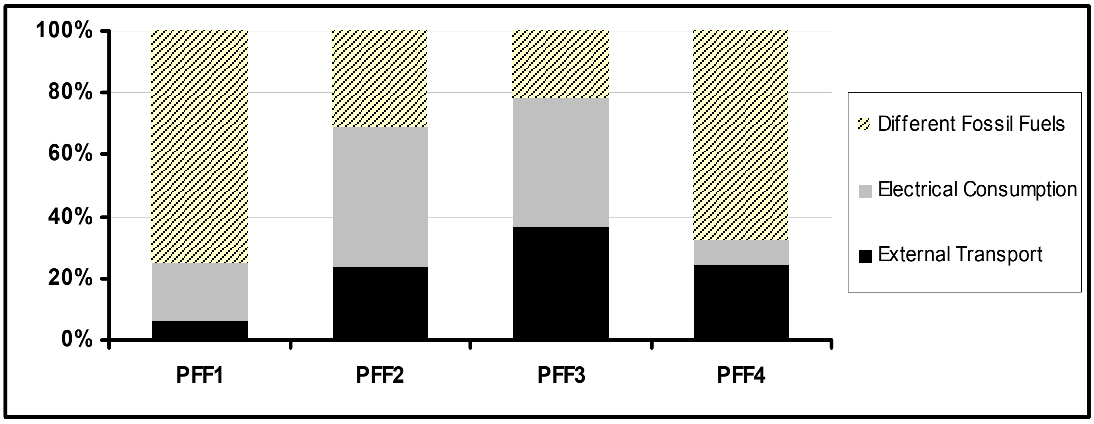

Figure 2. Breakdown of energy directly associated with the production of hollowcore in PFF factories.

To identify the reasons and factors behind these variations, the data was divided in two large groups, dependent and independent variables information and then interrogated further. Links were then made between two sets of information from each group, including links such as:

- Production scale as independent variable, energy consumption as dependent variable.
- Cement content as independent variable, curing energy consumption as dependent variable.
- Production systems as independent variable, energy consumption as dependent variable.
- Curing systems as independent variable, energy consumption as dependent variable.
- Levels of production system employability (set of variables) as independent variables, curing and casting energy consumption as dependent variable.
- Rate of customisation as independent variable, concrete waste as dependent variable.
- Casting bed/ mould length as independent variable, concrete waste as dependent variable.
- Products' depth as independent variable, transportation energy consumption as dependent variable.

Tracking these differences helped considerably in establishing findings and links between environmental impacts and a group of factors and solutions associated with production. These were also linked to specific decisions undertaken in different levels of management within a precast organisation.

Results from the LCA and the two surveys were used to construct several scenarios identifying how the use of combinations of specific solutions can substantially affect the environmental performance of different production systems. The scenarios were constructed from a chain of events, these events being triggered by decisions undertaken at different stages starting from the very early decision to actually build a precast flooring factory through to mix design and casting decisions. Figure 3 explains the methodology for identifying possible scenarios; where diamonds represent decision areas and arrows are decision routes (or options).

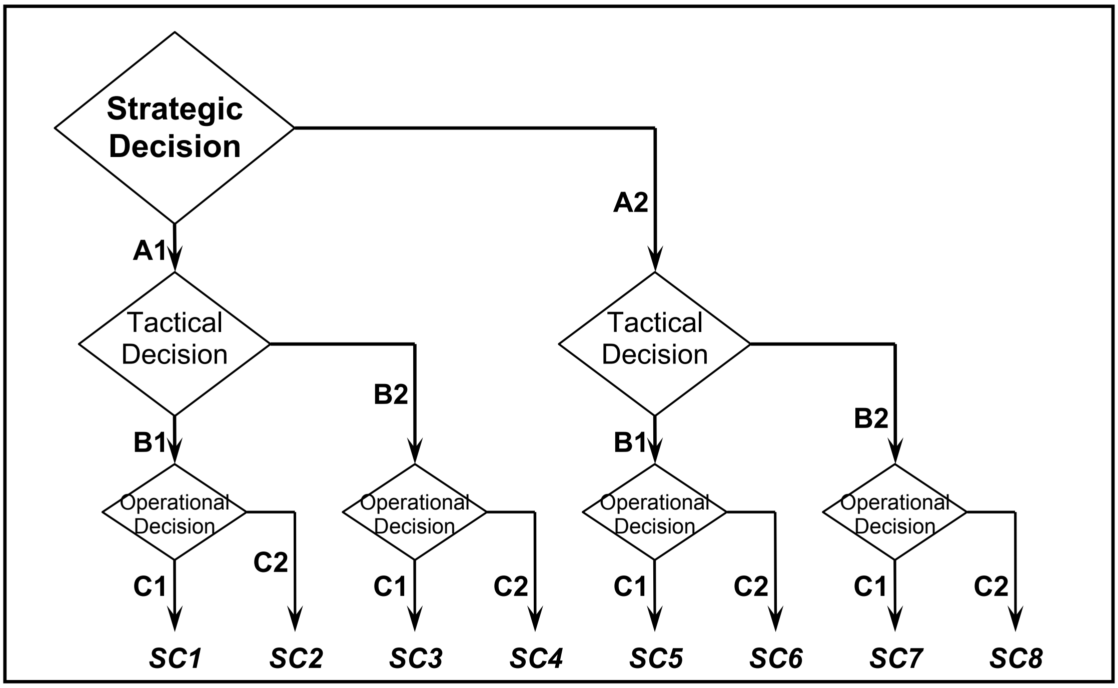

Figure 3. The suggested methodology for generation of options and construction of scenarios

Around 214 scenarios were constructed, these scenarios are all directly associated with the major environmental impacts identified through the use of the Eco-point score. With these scenarios available to the researcher, it was possible to determine the precise decision areas where environmental and business imperatives can clash. This was a key step towards meeting the overall aims of the research project. To identify and understand these decision areas properly, there was a need to use additional research methods capable of tackling the softer, qualitative issues associated with managers and their decision-making practices within different levels in a precast concrete manufacturing organisation. These are described below.

Using focus groups to interrogate the results

Following the findings from the LCA study, it was necessary to establish a proper grasp on business case objectives within different departments in a precast flooring organisation and how objectives are translated into tangible solutions and techniques. It was also necessary to understand the priorities of these departments and assess the boundaries between business needs (and objectives) and environmental needs. Furthermore, there was a need to explore whether their decisions/ solutions can be reshaped or reproduced to support sustainable development and improvement in environmental performance. Focus groups, to be followed by semi-structured interviews to identify the most appropriate means of sustainable business improvements, were selected as proper data collection tools for this purpose.

The focus group methodology was chosen to understand qualitative decision-making aspects behind environmental impacts, justifications were also required from manufacturers on their perceptions on the proposed boundaries between environmental and economic needs. Focus groups are described as being an effective tool that can offer clear explanations, depth, and sufficient interpretation through group interaction (Barobour & Kitzenger, 1999).

The population of decision makers within precast flooring organisations was broken down to three major groups, these are: strategic/ operational managers, technical/ operational managers, and financial/ commercial managers. It was decided to select the professional committees within the PFF: PFF Council (a committee for strategic level managers), PFF Technical committee, and PFF Marketing committee. One committee (the PFF Health and Safety committee) was excluded from the study. The membership of each committee was around 10 – 12 members, which is the sample size suggested by Krueger (1994) for successful focus group sessions.

The aim of the focus groups was to address the following issues, to:

- explore how manufacturers perceive sustainability;
- explore the relationship between business needs and sustainability needs; and,
- identify major restrictions to implementation of sustainability (moral, technical, etc.).

Roome (1998) notes that sustainable development criteria may be developed and put forward under extraordinary conditions; businesses nowadays are being urged to rethink their product/ service systems and take extreme measures contributing to environmental improvement and sustainable development. Manufacturers identified several pull/ push factors when considering sustainability, including: governmental measures (taxes, levies, etc.), possible profits, marketing and corporate image, potential competitive advantages, customer focus and service, social responsibility, and the urge to do the right thing.

In the focus group, respondents discussed and debated extensively the issues and expressed their views using a range of question/response methods. Using Soft Systems principles (after Checkland and Scholes, 1990), the results were then used to construct rich pictures enabling the elaboration and understanding of many of the real-world hidden problems (or potential difficulties) within the management, procurement, or production systems for precast manufacturers. The focus groups offered a wealth of information into how different professional groups and departments think and operate within a precast organisation, plus information on how sustainability can be implemented. A series of semi-structured interviews identifying manufacturers' views on solutions for identified conflicts between environmental needs and business imperatives is now planned. The interview format will include:

- the nature of the decision-making process;
- managers' priorities in production;
- managers' levels of awareness;
- how decisions can be implemented and replicated over time; and,
- managers' preferences for certain solutions.

The interviews should offer valuable information on the actual chances manufacturers stand to improve their sustainable performance (notably environmental performance) without compromising their business case.

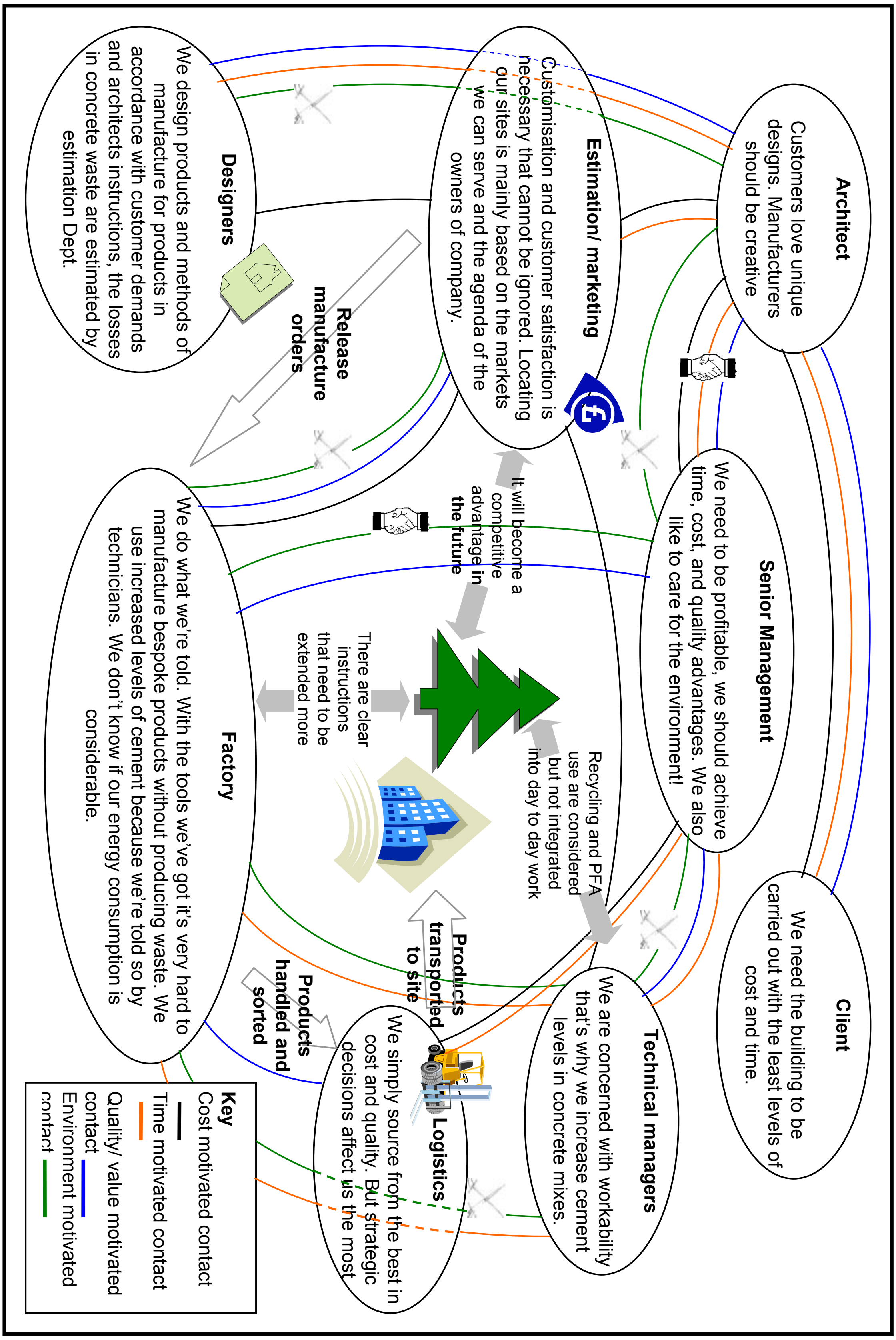

Figure 4. Rich Picture for the problematic situation in precast flooring organisations – based on findings from the first and second focus group sessions.

Conclusions

The results and findings established in this study will have a significant effect on manufacturers' efforts to embrace the triple bottom line components of sustainable development. A potential conflict between economic, social, and environmental interests has been referred to in numerous studies (Nixon *et al*, 2005). Manufacturers will always have to compromise. However, the mode of compromise has always been left widely open to interpretation and personal judgement, leading manufacturers to discard sustainability objectives for the benefit of economic objectives.

To date, no manufacturer has tried to take the debate one stage further by understanding and quantifying the link between environmental impacts, physical shop-floor solutions causing these impacts, and business objectives triggering the implementation of these solutions. This study takes a straightforward, structured approach to tackle the potentially conflicting principles of business and environmental performance. Analysis of the information and available literature show that there are several clashes between business imperatives and potential environmental impacts, which pose a substantial threat to the conventional precast concrete business model.

The LCA has identified cement content, waste production, emissions and transport impacts to be the most significant environmental impacts in precast flooring production, but to fully explore the scope for improvement the business case must be examined. To that end, this study recognises the quantitative and qualitative complexity of the problem. While LCA, additional surveys, and Eco-points were used to identify specific environmental impacts and link these to specific activities and production measures, qualitative tools are being used to identify other social, intangible factors associated with the implementation of sustainability within a conventional production system. The use of focus groups and soft systems techniques have helped considerably in identifying important factors that will play a major role in any future solution used to convert traditional production systems into sustainable/ environmentally efficient ones.

This study provides a significant step forward in helping manufacturers to understand where the potential conflicts lie and is working towards identifying a range of effective solutions. Manufacturers can also take the results, findings, and suggested problem solving mechanisms identified in the study to develop their own solutions. Each manufacturers' location, mode of operation and product range as well as their understanding of sustainable development and environmental improvement (as a competitive advantage, customer responsiveness issue, cost burden, etc.) will play a major role in deciding on the most appropriate type of solutions required.

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