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Existence of ‘Carbon Lock-in’ in construction sector: Stakeholder perceptions on barriers to green construction

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Abstract

The total emissions of the Indian economy in 2003-04 estimated at 1217 million tons (MT) of carbon dioxide, with construction sector occupying the top position with a 24% share of the total direct and indirect emissions. The Indian construction industry which is rapidly growing at a rate of growth of 10% compared to the world average of 5.2% could hold a huge potential in facilitating the shift to more energy efficient techniques.

The hierarchy and organisation in the construction industry causes inertia towards the shift to a lean construction regime which is supposedly greener. Even when the theory stresses on ‘win-win‘ scenario carbon efficient approaches like Integrated Design Approach (IDA) which promises energy savings and improved environmental performance faces barriers at various levels. The evolved structural factors, valuation and management methods which are promoting inefficiency and wastage in the building sector shows the existence of ‘carbon lock-in’ features in the economy. The minimisation of waste, optimal utilization of resources and importance of integrated design and importance of life cycle assessment tools makes it environmentally responsible construction. Lean construction can build low impact/high performance buildings and other infrastructure. The core thought behind lean construction philosophy is continuous improvement and thus it does not take the ‘status quo’ version that current system is working efficiently.

The barriers faced by the industry are multifaceted: the technology specific (micro), organisational (meso), external structures (like government, market), civil society (macro). The problems faced by different stakeholders in the construction sector, namely, the architects, engineers, builders, contractors and subcontractors, tenants, varies from the neglect of life cycle costs and long payback period to the lack of knowledge about green practices. The barriers to green construction are inherent in the basic organization of the industry and in the relationship between different actors. The barriers that appear of particular importance are imperfect information, agency problems, split incentives and bounded rationality.

The objective of this paper is to understand the institutional and organisational inertia of the stakeholders to take up lean construction regime which significantly reduces carbon emissions through an exploratory study. The interviews with the stakeholders were open ended and effort has been made to connect the theory with field realities. The main questions

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were related to the contractual relation between stakeholders, their position in the hierarchy, their power as one of the decision makers in the process, the internal customer relations etc.

Key words: Construction management, green construction, carbon lock-in, Integrated Design Approach, Lean Construction

1. Introduction

The world nations have committed to cut down carbon emissions thereby demanding a need for policies promoting dissemination of carbon saving technologies. The policies might include promotion of energy efficient, clean and renewable technologies as a way out for 'low cost emission reduction'. Despite the win-win scenarios attainted through this shift, diffusion rate of energy efficient technologies are slow due to the existence of carbon lock-in features that prevents the economies from realising the climate goals.

The total emissions of the Indian economy in 2003-04 estimated at 1217 million tons (MT) of carbon dioxide, with construction sector occupying the top position with a 24% share of the total direct and indirect emissions (Parikh and Panda 2009). Most of the commercial buildings in India have an Energy Performance Index (EPI)[3] of 200-400 kWh/m^2/year and the improved design[4] practices can reduce our EPI to 100- 150 kWh/m^2 /year (BEE 2007). It involves improving energy efficiency in building envelope, equipment and systems and lighting which give increased benefits to all stakeholders in the building process. The potential for energy savings is 40-50% in buildings, if energy efficiency measures are incorporated at the design stage through IDA or Integrated Design Approach (CII Report 2009).

Carbon efficient approaches like Integrated Design Approach (IDA) promises energy savings and improved environmental performance but face barriers at micro, meso and macro levels due to the existence of 'carbon lock-in'. This nurtures inefficiency in the building sector and prevents the adoption of green building practices.

The Intergovernmental Panel on Climate Change (IPCC, 2007) suggested a 50 – 85% reduction in the carbon emissions by the year 2050 to avoid the global temperature rise of 2.5° C. This involves transition to a low carbon economy thereby posing a threat to the current heavily carbon dependent global economic model. The Integrated Energy Policy of India (2006) and Ministry of Environment has specified some key provisions like promotion of energy efficiency, clean energy and renewable energy in all sectors. When less energy is used it reduces carbon emissions, enabling cost effective energy efficient investments as they can achieve environmental benefits at least cost thereby minimizing the economic costs of climate policies (Prindle 2009). There is a need for paradigm shift from 'energy enhanced progress' based on increasing energy intensity along with economic efficiency to be replaced with the energy efficiency motives by decreasing the energy intensity and increasing economic efficiency.

In this context the Indian construction industry which is rapidly growing at a rate of growth of 10% compared to the world average of 5.2% (CII Report 2009) could hold a huge potential in facilitating the shift. This is because energy consumption in buildings is about 30% and is

[3] EPI or Energy Performance Index indicates specific energy usage in a building. It is the ratio of total energy used by total built up area.
[4] Design is used to designate both design and engineering activities, not shaping space to aesthetic criteria.

expected to rise at 8% every year. In spite of the energy savings IDA promises in the building sector their market deployment poses a tough challenge.

The objective of this study is to deepen the understanding of hierarchy and decision making process through an institutional approach in construction sector. It tries to explain the construction as ‘one of a kind’ manufacturing. It analyses the new paradigm in the construction and its theoretical scope in ‘carbon lock-in’ literature. Apart from the theoretical understanding it includes the results of an exploratory to understand the practical picture in the sector. The exploratory study analyses the barriers and disincentives the stakeholders face when it comes for taking up decisions on green construction.

The institutional structure of building industry in India has certain features which challenges implementation of energy efficiency measures. This points to the issue of existence of inefficient ‘locked- in’ technologies and practices in construction sector which disrupts investment in carbon saving technologies. Despite the energy saving potential, low carbon emitting steps like IDA cannot find space in construction industry. One major concern is the hierarchy and organisation in the construction sector which shows the conflicting interests among coordinators and specialists. This creates inflexibilities and rigidities in the system and resists change. So several engineering practices, design techniques, management techniques which are supposed to be promote green construction faces barriers to adoption. So when theory stresses on win –win options, agents/stakeholders face disincentive in various forms. This points to the inertia of a carbon dependent system to shift towards non standardised technologies and to stick on to tested and tried solutions.

The barriers faced by the industry are: the technology specific (micro), organisational (meso), external structures (like government, market), civil society (macro). The problems faced by different stakeholders in the construction sector, namely, the builders, architects, engineers, contractors, sub-contractor, tenant, varies from the neglect of life cycle costs and long payback period to the lack of split incentives and lack of knowledge about green practices.

Assumptions made are:

a) There are non- economic factors like organisational and structural factors which influence the decision on investment in carbon saving technologies.

The institutional approach will help to understand the determining factors which influence the investment in environmental innovation. It can differ from one project to another in the case of construction as it is ‘one of its kind’.

b) Barrier perceptions of every stakeholder in the commercial building sector vary.

A barrier becomes a real barrier only when a stakeholder perceives so. Even when the theory stresses on ‘win-win’ scenario in energy efficiency investment, private investor faces barriers from many levels. This questions the reliability of the argument on huge potential savings by the adoption of such technologies.

2. Theorising Construction

Construction sector in most ways is a ‘comparison resistant’ sector as it is complex and dynamic. Each project is different and unique in its own way as each project is ‘one of its kind’ with each participant involved in this project being involved in other projects as well. As a result, construction process has to be understood differently from other sectors like manufacturing.

Koskela (2000) based on the readings of Shingo (1988) explains construction process from three perspectives say transformation (operations), flow (process) and value generation. According to them; Construction is a complex system with following elements in it:

- Autonomous agents with undefined values: It consists of independent or non-identical agents. All of them are equally valuable in the operation of the system where the individuality of each agent and his/her service matters and no executive node exists by design in the system. Therefore any control structure or leadership (representing power asymmetry) should emerge by self-organisation. The multiple agents follow their own local rules, laws, ‘rule of thumb’ and logic of practice because of their non-uniformity and self-organisation. It shows some chaotic sensitivity to initial conditions and external environment but at the same time this flexibility helps in the evolvement of learning procedure which leads to self-reproduction. Identical problems with similar constraints will have identical solutions in most of the projects. So along with contextual associations some standardisation would also emerge.
- Non-linear system: The process outcome is characterised by the whole being sum of the parts. But the result is not expressed in terms of arithmetic like outputs are proportional to the input. The usefulness of every step cannot be added. Even small differences between the stakeholders will results in different solutions. The specialised knowledge of stakeholders; their expertise is important but at the same time the coordination of all these knowledge and instructions given for every step are equally important.

Because of all these peculiarities the question is whether the conceptual revolution ‘lean thinking/lean production’ can find place in construction sector. The striking differences between the manufacturing sector and construction sector leaves space for doubt and suspicion.

The differentiating characteristics of construction from manufacturing are that they are ‘one-of-a-kind’ nature of projects, site production, and temporary multi organization. None of these are so peculiar to construction but what makes construction unique is the combination of all these characteristics. There is a general tendency to ‘projectize’ but the main properties which make it unique are that they belong to the category ‘fixed position manufacturing‘, and they are ‘rooted in place’. Since construction process make a ‘whole’ assembled from various parts some degree of site production is essential. Rootedness in one place brings uncertainty and differentiation. The differences in the physical surroundings like soil and seismic conditions, discrepancies in legal framework like codes and regulations brings uniqueness in one project. Construction at a site is a combination of fabrication and assembly whose success will depend upon effective planning and control mechanisms which will derive right directives for the processes. These directives will coordinate the flows and will condition the discrete work choices to make it close to optimal. The sequencing is very important in assembling which makes it a 'directive driven production'. (Ballard and Howell 1998)

All the peculiarities related to construction say its non-linearity, complexity, uncertainty etc are met in design, structuring and management respectively.

Koskela (2000) conceives three ways of design: as a process of converting inputs to outputs (conversion process), as a flow of information and materials (flow process), and as the generation of value for customers. To understand the three views please refer to the table 1.

Table 1: Conversion/Flow/Value Generation

	Conversion View	**Flow view**	**Value generation**
Nature of construction	A series of activities which convert inputs to outputs	The flow of information & resources, which release work; composed of conversion, inspection,moving & waiting	A value creating process which defines & meets customer requirements
Main Principles	Hierarchical decomposition of activities; control & optimisation by activity	Decomposition of joints. Elimination of waste (unneccessary activities), time reduction	Elimination of the value loss- the gap between achieved & possible value
Methods & Practices	Work breakdown structure, Crtical Path Method. Planning concerned with timing start and responsibility for activities through contracting or assigning	Team approach, rapid reduction of uncertainty, shielding, balancing, decoupling. Planning concerned with timing, quality and release of work	Development and testing of ends against means to determine requirements. Planning concerned with work structure, process

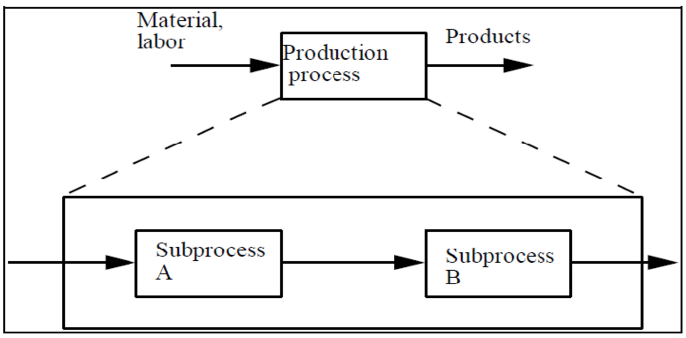
			and participation
Practical Contributions	Taking care to do necessary things based on Mass production system (Fordist system)	Taking care that the unnecessary is done as little as possible. Based on lean production (Toyota system)	Taking care that customer requirements are met in the best possible manner

Source: *Ballard (2000)*

The conversion model has been established by the end of 19th century when plants or companies were centered on one conversion process. Later the trend was to form hierarchically organised companies which handle many conversion processes. This was not problematic till the production processes were simpler, flows were shorter and organisations were smaller. The organisational lessons and accounting practices which were developed from this school of thought or production philosophy got locked into the institutional structure of the industry.

Conversion model allows for convenient measurements like productivity i.e., ratio of output to input at a specified time. Some of the underlying assumptions of this conventional production philosophy are: the conversion process can be divided into sub-processes, which also are conversion processes, the cost of the total process can be minimized by minimizing the cost of each sub-process and the value of the output of a process is associated with costs (or value) of inputs to that process. The conventional accounting theory which goes along with this assumes that total cost of the production process is equal to the cost of each operation in the process of construction and therefore total cost of each operation is proportional to direct labour involved for that operation.

Figure 1: Production as conversion

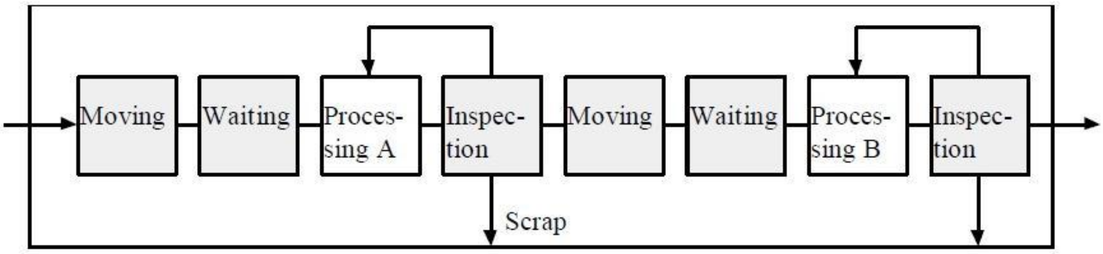


The conventional view of a production process as a conversion process that can be divided hierarchically into subprocesses.

Source: *Koskela (1992)*

The conversion model of production which was popular in the construction industry is contested as it could not explain the increasing space of non- value adding activities. Value of the output emphasises on using better quality of materials which questions the cost minimisation by using design-bid-build strategy in the conversion view.

Figure 2: **Non-Value Adding (NVA) Activities**



Source: *Ballard (2000)*

The main reasons for the cause of non- value adding activities are: design, ignorance and inherent nature of production (Koskela 1992). NVA[5] activities exist by design in hierarchical organizations. Conventional view believes in compartmentalisation of work into tasks and subtasks which increases the NVA activities like inspection, moving, waiting etc. which increases the cost and duration of the project. The design-bid-build shows conventional constructions wasteful sequential method which results in sub optimal solutions.

Ignorance is another source of NVA activities. Especially in the administrative sphere of production, many processes have not been designed in crew-centric fashion, but instead just evolved from the chaos to take their present form. The immeasurability related to the resource and time consumption of NVA activities prevents stakeholders from taking any step from curbing them. Some of the NVA activities are essential for some stakeholders but may not be the client. The inspection for example ensures safety and error correction. Thus it becomes a necessary non value adding activity.

The quality critique of conversion view questions its assumptions on cost minimisation through buying raw materials and services of lowest price. This compromises value maximisation. However time is considered as money. In BAU scenario, with conventional production/construction philosophy wastage happens. The ‘workers waiting for work’ and ‘work waiting for workers’ are common phenomenon in construction sector. There are wastages in the form of increasing project cost, increasing project duration and underutilization in the form of compromised quality.

The project management tool which is used commonly in construction is CPM [6](Critical Path Method) does not model non value adding activities like moving, waiting and storing

[5] NVA or Non Value Adding Activity is one that takes time, resources or space but does not add value to the end user.

[6] CPM or Critical Path Method is an algorithm for scheduling a set of project activities and an important tool for project management which is activity oriented.

inventory etc. It follows the deterministic approach which can be used in repetitive types of projects. Since it is an activity oriented network, it understands construction as a set of activities which logically flows as per the network. CPM assumes that enough information is available and hence one time estimate is sufficient. Uncertainty is not modelled in CPM as activity duration is considered as a deterministic factor to them (Seetharaman 2003).

Conventional accounting considers the price differential between two products or processes and emphasises on reducing the cost but taking the lowest bid but does not stress on the cost by increasing number of steps. The number of steps whether necessary or not involves costs. If the process is complex, that also increases the cost. Reducing the number of components or number of steps can simplify the process and bring down the costs.

The division of labour in the construction sector increases the share of NVA activities in terms of monitoring, communication, planning etc. Development of autonomous teams with multi skills and constant communication with them can eliminate a lot of resource wastage without compromising on quality.

The lean revolution is essentially a conceptual revolution, at the heart of which are the flow and value models. The flow model facilitates waste reduction. The value model facilitates value maximization. To date, most lean thinking in construction has concerned waste reduction.

Flow processes can be characterized by time, cost and value. Value refers to the fulfilment of customer requirements. In most cases, only processing activities are value-adding activities. For material flows, processing activities are alterations of shape or substance, assembly and disassembly. Flow view treats construction industry as one with both conversion and non-conversion activities, with associated values and wastes.

Ballard (2000) shows that most acute flow problems of construction are caused either by traditional design, production and organization concepts, or the peculiarities of construction. There are two main processes in a construction project: Design process and construction process.

Design process is a stage wise refinement of specification, transformation of needs and wishes into requirements, then via a varying number of steps, to detailed designs. This is a process of problem detection and solving, which can be further divided into individual sub processes and supporting processes.

Construction process is composed of two different types of flows. The material process consisting of the flows of material and their assemblage and secondly the work flow of the construction teams on the site.

Other processes are Project management process by the owner, Design management process by the engineering or design project manager and Construction management process where the detailed design is transformed into a construction/fabrication plan and into day-to-day coordination and control of processes on site or in a factory. Every process incurs a cost, takes time and may or may not have a value for the customer.

Cost and duration also depends upon the value adding[7] and non-value adding activities of final customer. In this view there is a clear distinction between value adding activities and non- value adding activities. Some activities are important for the internal customers. Inventory storage, inspections are important for the 'next customer' than the final customer. So what is valuable for the next customer may not be valuable for the end user of the product.

The effort to reduce waste and to increase value is an internal, incremental, and iterative activity that can and must be carried out continuously (Koskela 2000). There are several necessary methods for institutionalizing continuous improvement like measuring and monitoring improvement, setting stretch targets (e.g. for inventory elimination or lead time reduction), giving responsibility for improvement to all employees; rewarding steady improvement from every organizational unit, using standard procedures as hypotheses of best practice, to be constantly challenged by better ways, linking improvement to control etc.

In contrast to the design-bid-build process in the conventional system, in the integrated design process constructors join the team at or very soon after the start, they develop understanding the client needs and ways to satisfy them with the designers and can come out with cost effective production process alongside the design.

However the buzzword in a fragmented construction sector is 'incentive based integration' where stakeholders work together to eliminate wastage and reduce non value adding activities. Lean project delivery builds cooperation in the context of a single integrated team involving the owner, architect, constructor and other critical players all as equals in the pursuit of a shared goal[8]. It shows the linearity and iterative nature of the design process and stresses on the fact that certain aspects in construction process happens in a parallel way in contrast to the sequential processes.

The project management tool widely used is the last planner[9] system which is proved to increase the reliability of planning and improve workflow in design and construction operations[10]. Interestingly the lean construction also faces hurdles in implementation during the transition phase. From the smallest job to the toughest one, every task requires a lot of planning and control in construction industry in the existing hierarchical structure at different stages of project and at different levels of work. The planners at the top of the hierarchy might take up global objectives and optimisation targets which are for the entire project. The next level planners will specify means to achieve the end. But the planners at the end of the hierarchy whose target is to meet next day's work, giving directions for the direct work either physical or managerial or supervisory has to frame assignments. These assignments will be based on the experience of the last planners from their previous projects, 'rules of thumb' and logic of practice. The practicability of the design features becomes more important than the aesthetics and noble aims of design. That is how a lot of alterations happen in the design in

[7] Activity that converts material and/or information towards that which is required by the customer
[8] Mossman (2010)
[9]Last Planner system (LPS) is a project management tool which helps to increase the reliability of planning and improve workflow in design and construction operations. Last Planner refers to the coordinating specialists in the business of construction.
[10] Ballard

the construction phase. These coordination specialists who are involved in project are known as ‘last planners’.

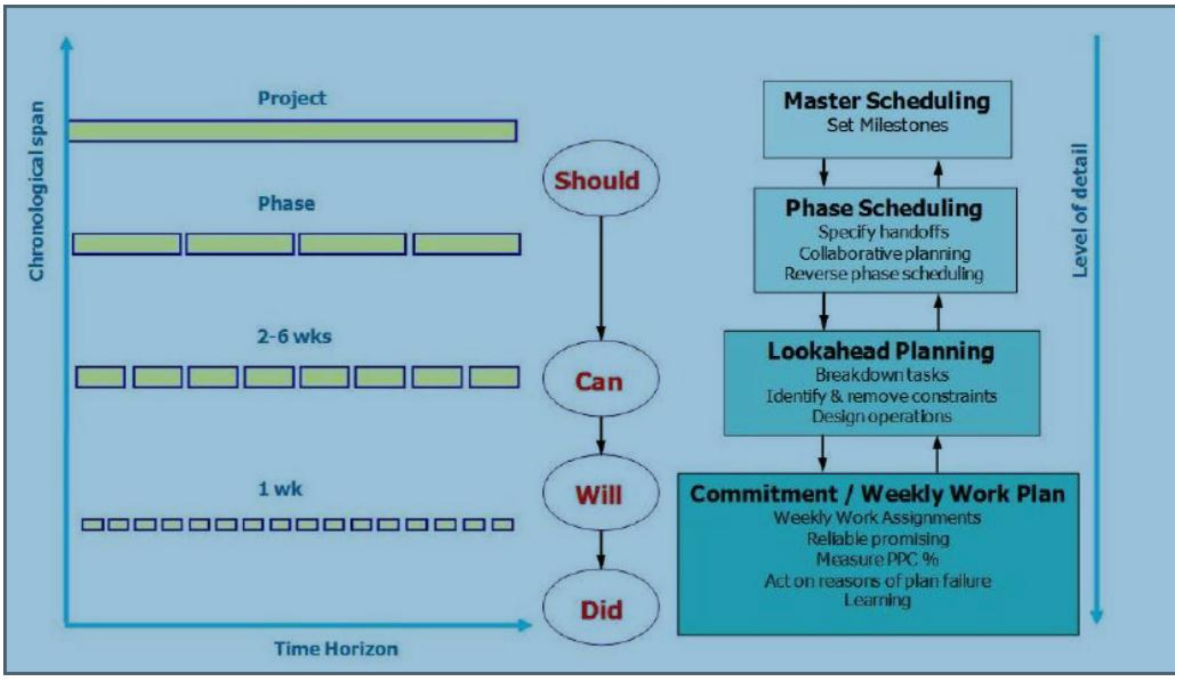
The assignments should be sound regarding the prerequisites of the work. It should be ensured that work should not be started until all the items required for the work are available.

The measurement and monitoring of the assignments are equally important and this is done through PPC (Percent of Plan Complete) scheme. It is the number of planned activities completed, divided by the total number of planned activities and expressed as a percentage.

PPC has to become a standard in extremely complex set of procedures at the production unit level like project schedule, project execution strategies etc. It should ensure that by right prioritisation and sequencing, higher productivity and progress is achieved. Thus last planner system becomes construction crew oriented also at the same time keeps a check on value maximisation by carefully checking the number of steps, its need, execution failures and reasons for that.

Assignments stresses on the coordination and communication needs between the specialists in the design and construction crew. Planning stresses on what WILL be done and execution stresses on what SHOULD be done within the constraints of CAN.

Figure 4: Planning stages/levels in the Last Planner system



Source: *Hamzeh (2010)*

It is more about scheduling, planning, identifying and removing constraints. It gives weightage to the immediate work which is to be done hereafter through PPC system and thus becomes more realistic by simplifying the construction management to every day‘s work.

The core thought behind lean construction philosophy is continuous improvement and thus it does not take the 'status quo' version that current system is working efficiently.

3. Lean construction and green buildings

The minimisation of waste, optimal utilization of resources and importance of integrated design and importance of life cycle assessment tools etc makes it beneficial in terms of environmentally responsible construction. Lean construction can build low impact/high performance buildings and other infrastructure.

The possibilities in lean construction system show that there are non-technical options available too for the low carbon buildings and that lies in the construction management. Lean enables more to be achieved with the same. Less carbon is used for increased output. Carbon use is lowered through reduced transport on site, reduced resources used to address faults due to increased quality performance, improved productivity and control of resources and reduction of waste and production losses.

The construction industry is constantly being challenged to reduce its large amount of energy consumption, raw material, and water usage. Buildings consume 36% of the total energy used, 30% of the raw materials used and 12% of potable water consumed in the USA. American Institute of Architects (2007) estimated that nearly 50% of all the GHG emissions are generated by buildings and their construction in terms of the energy used in the production of materials, transportation of materials from production factories to construction sites, as well as energy consumed in the operational stage. However, there is considerable potential to control and reduce carbon emissions in the construction industry with appropriate management. By applying the lean concept to a production line, 6.5 to 9 people (labour waste), 12% space (equipment waste) and 10% wallboard (material waste) could be reduced (Peng, 2011).

Lean construction as a concept goes hand in hand with sustainability goals of Reduce, Reuse, Recycle and Regulate. It focuses on minimising the waste in terms of money, resources, maximising productivity, continuous improvement. Since it aims at sustainable practices to meet environmental goals, lean methods are green. It minimises the wastage of resources, improves energy efficiency, adopt design and construction practices which reduce carbon emissions in a productive way. Minimal building impact, maximum building system efficiency, energy efficiency, waste reduction, and a healthy, productive environment for occupants are the key features of the lean and green construction.[11]

Lean Design Models promotes IDA[12] (Integrated Design Approach), Design for Maintainability (DFM) and 3D Modelling. IDA reduces duplication of work, improves communication, increases accountability and brings down the percentage of errors which

[11] Ahuja R (2012)

[12] IDA means Integration of various green materials and construction technologies by encouraging stakeholders in the design phase for maximizing the sustainability of a facility while reducing the need for energy, equipment, or resources. It is also known as Whole Building Design.

reduces rework and re-designing. It also reduces the lead time[13] and avoids frequent inspections. DFM increases reliability of a building by reducing its O & M (Operation and Maintenance) costs. These methods promote application of technology; simulation models etc. which help the designers to do energy need and load calculations on ex ante basis. Also this will help in the right sizing of mechanical and HVAC (Heating Ventilation & Air Conditioning) systems in a building.

Lean Supply models suggest Just in Time (JIT) delivery which reduces over storage of inventory, reduce damage and materials. However there are doubts about the greenness of JIT as it increases emissions through transport.

Lean Assembly Models recommends for use of pre- fabricated materials for construction. It reduces environmental damage by cutting down processes like transferring workers, machines, staked materials, temporary structures and onsite activities to a prefabrication plant. It will reduce a lot of NVAs like moving and waiting for articles (work equipment and materials) and workers and also it reduces indirect emissions through lessening transport.

The potential challenges attributed to project circumstances and the team includes fairly new experience in lean methods, traditional project management methods, lack of experience with Last Planning System, fragmented leadership, and team chemistry. General factors impacting the implementation of a new process include: human capital, organizational inertia, resistance to change, technological barriers, and climate. Human capital is associated with human skills and experience required in construction process: Specialisation and coordination. It addresses the need to continuously develop new skills as new technologies, processes, and policies are implemented. Barriers are due to internal structural arrangement (meso) and external environment (macro). Internal factors include: (1) investments that are sunk in plant, equipment, specialist and coordinators (2) incomplete information reaching decision makers, (3) internal political constraints such as fear that change may disrupt internal political equilibrium, and (4) constraints generated by an organization‘s history such as standard procedures and normative agreements. External factors are equally significant and include: (1) barriers to entry and exit from markets, (2) incomplete information about external environment, (3) legitimacy constraints arising when a new norm challenges the established norms, and (4) collective rationality problems. (Hamzeh, 2010)

The above listed account of barriers shows that there is a systemic inertia in the industry towards change. Inertia increases the resistance to change in organizations. The barriers to implementation of lean construction show that construction industry is locked up into a carbon emitting system. It actually shows the existence of ‘carbon lock-in’ phenomenon in the construction sector.

Gregory Unruh theorised carbon lock-in the condition in which technological advancements, due to scale and learning economies, and institutional forces—including social, firm, and public institution responses—become co-evolutionary and interdependent. The highly

[13]Lead time is the time between initiation and completion of a project. Lead time clock starts when the request is made and ends at delivery.

evolved Techno Institutional Complexes (TIC) in developed (industrialized) economies prevents them from switching to environmentally feasible and economically efficient technologies. The relative stability of the standardized technological system is due to the irreversibility of the investments made by several generations in the infrastructure.

Establishment of dominant design will lead to a shift occurring from product (Schumpeterian innovation) to process (Usherian) innovation. Incremental improvements in design, market driven R & D, specialization and development of core competency of the firm, management and organizational practices which nurture it everything will lead to standardization of the technology. Also the capital investments go to the area where production costs and uncertainty are low and risk-averse lending practices will fund the standardized technologies. The professions, discipline etc based on this technological system preserves the technology along with unions and industry organizations which have the same interests of the oligopolistic firms. The state and its policies ascertain the existence of such system which ultimately leads to the standardization of the system. Because of the inflexibilities new innovators in clean technology area is facing excess inertia since they have to compete with the standardized models. This results in the persistence of multifaceted barriers in this field. The lean construction system which is relatively a low carbon path in construction industry faces the historical condition of carbon lock-in.

4. Barriers to adoption of green technologies

Some of the selected literature on barriers to energy efficiency and environment superior technologies categorise them into different categories. Some of them are given below.

Brown (2007) classified barriers to development and deployment of environment superior technologies as cost effectiveness barriers, fiscal barriers, regulatory and statutory barriers, intellectual property barriers and information barriers, which are explained below.

Cost effectiveness barrier includes the competition of GHG reducing technologies with the price of fossil fuel based energy sources. With the risk of an unproven technology, high capital costs and technical uncertainty, a huge market risk is created for the initial start-up. Inadequate knowledge and lack of specialization creates a knowledge lag which prevents from the adoption of these technologies.

Fiscal barriers include the perverse subsidies and unfavourable taxes and tariffs on several GHG mitigating technologies. The tension about the uncertain future tax policy on new technologies can also act as a barrier.

Regulatory barriers are the regulatory barriers that promote the conventional energy sources directly or indirectly disrupts the diffusion of renewable energy technologies like poor land use planning, favouring a particular construction design, rules that bans using techniques like combined heat and power. There is an uncertainty about the future regulations on GHG reducing technologies and there is a disparity between international laws and national laws regarding this.

Statutory barriers are the legal constraints that prevent energy efficient innovations and lack of updation of legal system with technological advancement become part of statutory barriers. The renewable and energy efficiency portfolio standards are to be made clear to promote private investment in this. This will also help to remove the uncertainty in these areas.

Intellectual property barriers are the high transaction costs on patent filing, unclear laws on patents, and conflicting views on the value of patents can be misleading for further investment in technology and sometimes may be harmful to R&D process. Weak international patent protection will create disincentives for the promotion of technology transfer. Anti-competitive patents and conflicting goals in academic research and commercial research create challenge in IPR issue.

Information barriers consist of misinformation and information asymmetry can create market for lemons. It prevails in the case of energy efficiency and renewable options. The problems of bounded rationality and misleading information cause serious problems in the diffusion of a certain technology.

Reddy, Asenza, Hasselman & Gaudenz (2009) categorized barriers in turn have been classified into Micro barriers, Meso barriers and Macro barriers.

Micro barriers are technology specific barriers, which create obstacles that are unique to a particular project. The micro barriers can specifically be in terms of project design, which affects the feasibility of the project. By changing the features of the project, modifying design, improving energy saving features, giving confidence through proper consultation etc such barriers can be reduced or removed. Meso barriers are related to the organization or firm level barriers such as lack of incentive for energy policy, absence of environmental policy etc. These can be tackled by split incentives, re training of energy department staff etc. Macro barriers can be the barriers that exist due to the state policies; market related and can be even civil society related. For project designs and organization, they are external barriers and firms cannot influence them unless they have the power to influence politics, market or culture. Barriers related to state are visible in government policies, laws, ministry declaration, subsidy allocation etc while market related barriers include reluctance of private banks to finance new technology, hidden information etc. Barriers relating to civil society include the behaviour and attitude of NGOs, academic institutions etc.

Neiji & Mundara (2009) makes it clear that key determinants of technology choice are capital and operating costs and immediate cost is considered more important than long term savings. The relevance of operating costs is often measured as low in studies of determinants of choice for the adoption of energy efficient technologies. When it is coming to individual appliances they tell that design, style and aesthetics matters. Like high initial cost, design style, aesthetics, unavailability, lack of awareness, incompatibility, performance problems, compatibility dissatisfaction, product size, discontinuous features etc were the main barriers of CFL lighting. In the case of refrigerators price, technical efficiency, price brand etc matters and with washing machines and dryers operating costs has weak effect and initial costs are a major determinant. This study shows that information dissemination through energy labelling has a positive effect on the diffusion of the technology.

Gillingham, Newell & Palmer (2009) listed energy market failures (environmental externalities, average cost electricity pricing, and energy security), capital market failures (liquidity constraints), innovation market failures (Research and Development spill overs, learning by doing spill overs), information problems (lack of information, principal agent problems, learning by using) under the category of potential market failures and prospect theory , bounded rationality and heuristic decision making under potential behavioural failures.

Shu & Bazerman (2010) points to the high discounting practices in organizations due to capital constraints emphasizing the minimization of current costs over the long term costs of running the building. That is people tend to focus on or they overweight short term considerations. This study also points to findings like losses loom larger than the gains.

5. Exploratory study

The objective of the study is to deepen the understanding of hierarchy and decision making process in the construction sector. Different stake holders in construction sector are subjected to an unstructured interview to understand the hierarchy and decision making process in the sector. This tries to check the institutional and organisational inertia in the industry when it comes to take a call on green investment. The study was to connect the stakeholder view to the findings in the literature review.

The interviews were open ended and effort has been made to connect the theory with field realities. The main questions were related to the contractual relation between stakeholders, their position in the hierarchy, their power as one of the decision makers in the process, the 'internal customer' relations etc. Their perception about value adding activity and non-value adding activity was also subjected to analysis. Some of the questions were on the awareness on energy efficient and green techniques.

Architects are the first category to get involved in the design process. They are in direct touch with clients requirements on the design and are responsible for visual and aesthetic appearance of a building. Their 'one to one' connection with the builder/developer shows that the 'greenness' of the design will a lot get affected by client awareness and client demand. The civil engineers are mainly not in direct touch with client.

Front facade of the building, location etc actually adds to the face value of the property so visual appearance matters a lot. Aesthetical value is one of the determining factors of the land property. In a tropical country like ours orientation of a building should be east or west to get maximum light and it is advised not to put glass facing west and south as it traps more heat but visual appearance sometimes makes clients to pressurise architects to resort to such designs which is not wise as per the ecology of the area.

New building construction is one end-use market that has been identified as having significant potential for 'green' improvements. When the construction is for developer‘s own use, in which case the developer is responsible for future energy costs or when building owners have well-articulated energy management practices, there is chance for energy efficiency investment as they will be concerned about the operating costs. But if it is rented out or sold to tenants then developers will only try to minimize their initial costs. So there is a strong incentive to minimize the upfront costs and limited or zero incentive to minimize lifetime costs. The poor energy performance of building services equipment is difficult to monitor and this results in a moral hazard problem where actions of one party to a contract are unobservable to the other.

When it comes to taking energy efficient steps split incentive problem will come into picture. If the client occupies and bears the future operating costs of the building then there is an incentive to invest on energy efficient technologies whereas if it rented out for offices and other purposes reducing capital costs is the most important thing. High payback period often prevents investors from investing on renewable and energy efficient technologies. Even a two year payback period for solar panels is a long period in the eyes of client. There is a scepticism associated with ‘green’ technologies whether the maintenance costs are large. Easiness of using, aesthetic value, availability etc excludes some of the greener and cheaper products from competing in the market for example ceramic tiles. This shows that some of the products have some ‘gold plating features’ which prevents them from adoption.

The construction process provides numerous examples of split incentive problems as designers, consultants and sub-contractors have no long term interest in a building since they are not liable for running costs and have an overwhelming incentive to keep within time and budget. They have strong incentive to cut the corners to energy efficiency in order to maximize the profit margins within a highly competitive market. They have direct incentives to oversize equipment and another disincentive to energy efficiency as this means more work for less money.

Bounded rationality may therefore create an additional barrier to energy efficiency, as well as reinforcing the operation of other barriers. The bias is in favour of trusted and tested solutions and ‘rules of thumb’.

The stakeholders admit that construction industry can become chaotic so proper management is required to reduce wastage. Wastage can be in terms of time, money and materials. However stakeholder perception of wastage was proved to be different from that in literature especially on their ideas on inventory management and inspection. They value safety of the structure more than other parameters so inspection is considered as an essential thing and a necessary non value activity. The inventory management teams some times over purchase materials due to the anticipation of rise in prices of materials and energy. However moving and waiting is considered as a wastage and non- value adding activity. In construction sector there are many instances where ‘work is waiting for workers’ and ‘workers are waiting for work’. Having a project management team is always good to reduce wastage but this increases the initial cost. Here the problem is that whether wastage reduction occurs through the project management team or not is kind of unobservable for the client. Though non value adding activity has no value addition for the client, it is difficult to calculate the loss due to it. Only thing for which he has information on will be the cost/price of the management team and information about possible reduction of wastage has to be estimated. If the primary motive is to cut down the cost, then client backs out from paying a manager or a team.

Lump sum contracts and competitive tendering is still the popular option among the clients. One reason for this is that qualities of services/products are unobservable as there is an information asymmetry. Sellers value their goods/services more than a buyer who does not have enough information on it and thereby they go for signals like low price, competitive tendering etc and end up compromising on quality. This is one of the examples of problem of 'Adverse selection' from construction sector.

The green rating systems like LEED ((Leadership in Energy and Environmental Design), GRIHA (Green Rating for Integrated Habitat Assessment) etc. are popular among big clients/builders only. Green buildings with ratings are seen as an elite concept in India. The smaller firms have not even heard about this rating system. They admitted that they have not worked with IDA teams ever but admitted that coordination and communication can be improved by integration. The usage of software in designing, estimation of costs, future expenses etc actually widen the scope of integration. Whole life costing calculation and accounting of Operation & Maintenance Costs is easy with such techniques.

The stakeholders admit that there are reasons for over specification/over engineering /over designing. If data shortage is there, then it prevents designers from being accurate. Lack of information flow brings inaccuracy and increases uncertainty. Such cases over engineering will happen. If the data fails to give measurement of a pipe alignment, it will lead to over specification. Also if there is a scope for expansion then also it leads to over engineering so that it gives enough space to carry out future activities. Over engineering also is connected with structure stability which ensures safety. Usually maintenance clause in the building contracts gives scope for expansion so there is a direct incentive for overdesigning. There are cases where designers over specify in the plan thinking that contractor will redesign and underspecify it.

Fierce competition and low margins create an incentive for the winning contractors to cut costs. Due to fear of liability with bad design choices, over specified equipment are preferred. Capital constraints are commonly seen as the reason for missed energy efficiency opportunities. Most of the building goes over the budget and most of the times environmental features are dropped. Most of the new initiatives are avoided as they drain time.

Subcontracting is very common to reduce the risk of employing staff directly. The resulting contracts are detailed and complex, and low trust, adversarial relationships between the actors. This shows the fragmented structure of the industry and it sustains a contractual and confrontational culture.

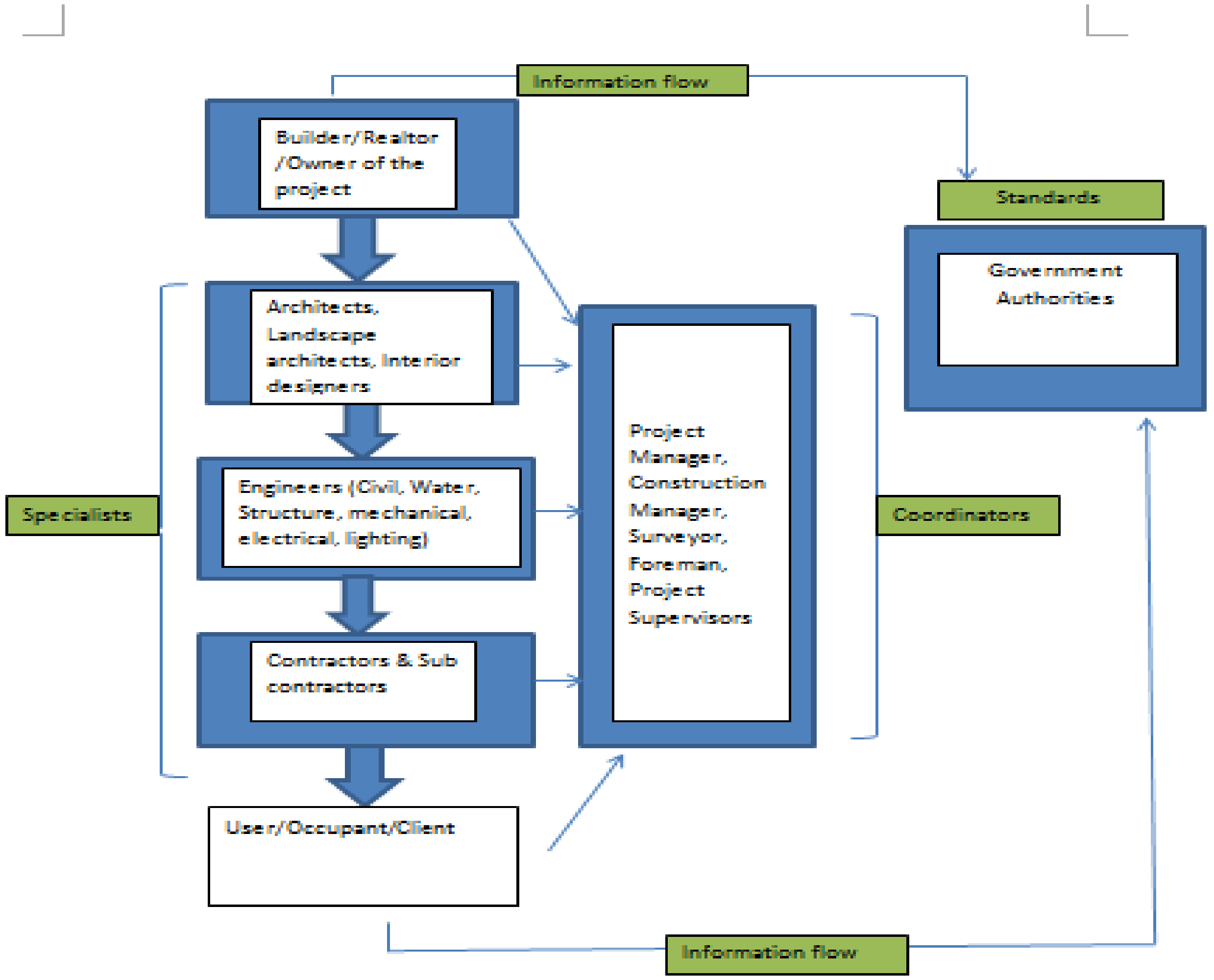
The low cost tendering actually leads to compromise of quality in building works. This makes contractor to cut down the cost further to increase their margins. The primary incentives on contractors are to deliver to time and budget. They do not have incentives to optimize the performance of the building in use and their fees do not cover the cost of post occupancy evaluations of building performance. They only have a short term relationship with the client/ builder and a lacks the spirit of partnering. Partnering greatly reduces transaction costs and opportunism aligns the incentives of different groups and encourages information transfer. It facilitates integrated, cross disciplinary design processes, it should reduce the incentives to cut down on several green measures. When the client has an incentive to minimize whole life costs, the contractors and consultants do not as they have no long term interest in the building and are not accountable for performance in use. The project manager's main objective is to build to the budget. Cost/m^2 is the most important capital cost guidelines for different types of building.

Table 2: **Stakeholders in construction sector**

Stakeholders	**Performance Measures/Objectives**	**Challenges stakeholders face in business**	**Barriers faced for promotion of green building**
Developers, Investors & Builders	Rupees per square foot, Resale value, Rent	High Initial cost, Energy costs is just one of the costs, Absence of Life Cycle Accounting	Increased cost of building does not fetch high resale value or higher rents.
Occupants	Increased employ satisfaction & productivity, Long term comfort, low O & M costs	Lack of knowledge about new innovations & technology	No indicator for a high performance or green building, Invisibility of green elements, No post occupancy evaluation.
Architects, Landscape architects, Interior designers	Aesthetics, Visual & space planning	Safety motives, data shortage discourages optimal sizing. Design is changed as per convenience	Lack of innovation in design, concerns about potential liability is met by oversizing at the expense of clients. Fees does not reward optimal sizing.
Engineers (Civil, Water, Structure, mechanical, electrical)	Watt/sq m, Kw/ton	Joins at a later stage and not part of conceptualisation, working on multiple projects at a time, lack of interaction between different departments	Engineering fees have been customarily based on a percentage of the capital cost of the project, subcontract or equipment installed (rewards oversizing)
Contractors & Sub contractors	Budget & schedule, profit margin	No long term contract on efficient functioning, liability is there for under sizing, familiarity and punctuality of suppliers is important	Absence of relational contracting, short term partnering Low cost tendering: Problem of Adverse selection.
Project Managers	Critical path & drawing adherence	Between owner & designer. Time, price & familiarity works.	More work in limited time, more coordination required. Always there is a tendency to follow 'rules of thumb'

		Not responsible for operating budgets. Needs to change design as per convenience and availability of materials, green rating mechanism incurs more work.	

Figure 5: Hierarchy in Construction sector: Coordinators & Specialists



Discussion and Conclusions

The study throws light into the organisation and hierarchy in construction sector with multiple stakeholders with conflicting interests. The objectives in lean construction like 'value management' which meets client's needs in effective way will be compromised in such a scenario with serious principal-agent problems.

The activities and services that are value adding or useful to the end customer are costly to other agents because of disincentive structure in the industry and what the agent does are costly for the final customer to observe. Sometimes the lack of information, high discounting rates, rules of thumb etc can tamper the efficiency motives. Moral hazard and conflict of interest may arise. Indeed, this will rule out the market for green or energy efficiency options in construction sector and brings the whole industry to sub optimal outcomes.

Decision making in a multiple stakeholder set up is complex when information is incomplete, incentive structure is skewed and most of the relationships between stakeholders are short term and based on 'low trust'. The issues between coordinators and specialists has to be addressed as conventional building set up shows disintegration among them which results in low quality buildings.

The problems faced by different stakeholder in construction sector varies from neglect of life cycle costs and long payback period to lack of split incentives and lack of knowledge about the green practices. 'Incentive based integration' may address concerns of every stakeholder in the sector.

Proper labelling and endorsements by authorities can promote energy efficient technologies. The proper dissemination of information on energy efficient products should be there. Proper arrangements should be there to solve the problems of information asymmetry at the producer level and consumer level. The policy level approach to spread awareness about energy efficient technology is very important as it reduces the transactions costs in the economy. Partnering and long term contracting reduces risk and opportunism and instils confidence among people to pursue for integrated technologies. International standards and best practices has to adopted and proper updation must be there regarding energy saving and low carbon emitting technologies elsewhere in the world.

The transition management should have the strategic and long term vision of the development of a technology from 'niche to landscape'. For that there should be an interaction between stakeholders. Government, market and society have to be partners in the process of setting policy proposals, creating opportunities and undertaking transition experiments. When it comes to business, stake holder should need clarity from government on future policy, long term agenda on environment, technology, technological development and transfer of technology.

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has to adopted and proper updation must be there regarding energy saving and low carbon emitting technologies elsewhere in the world.

Sector wise policies have to be developed which are attentive towards the climate and energy goals of the nation.

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