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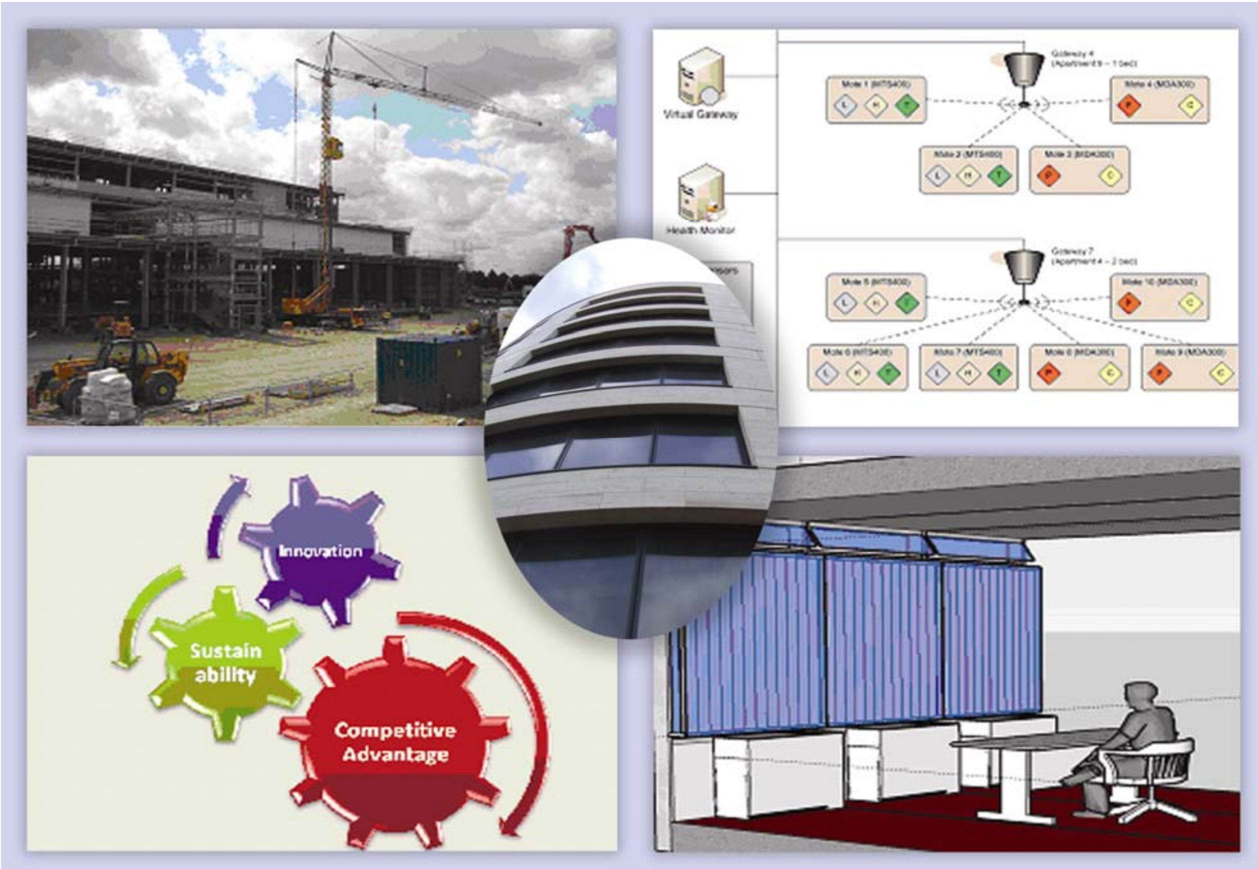

Ian Wallis, Lesya Bilan
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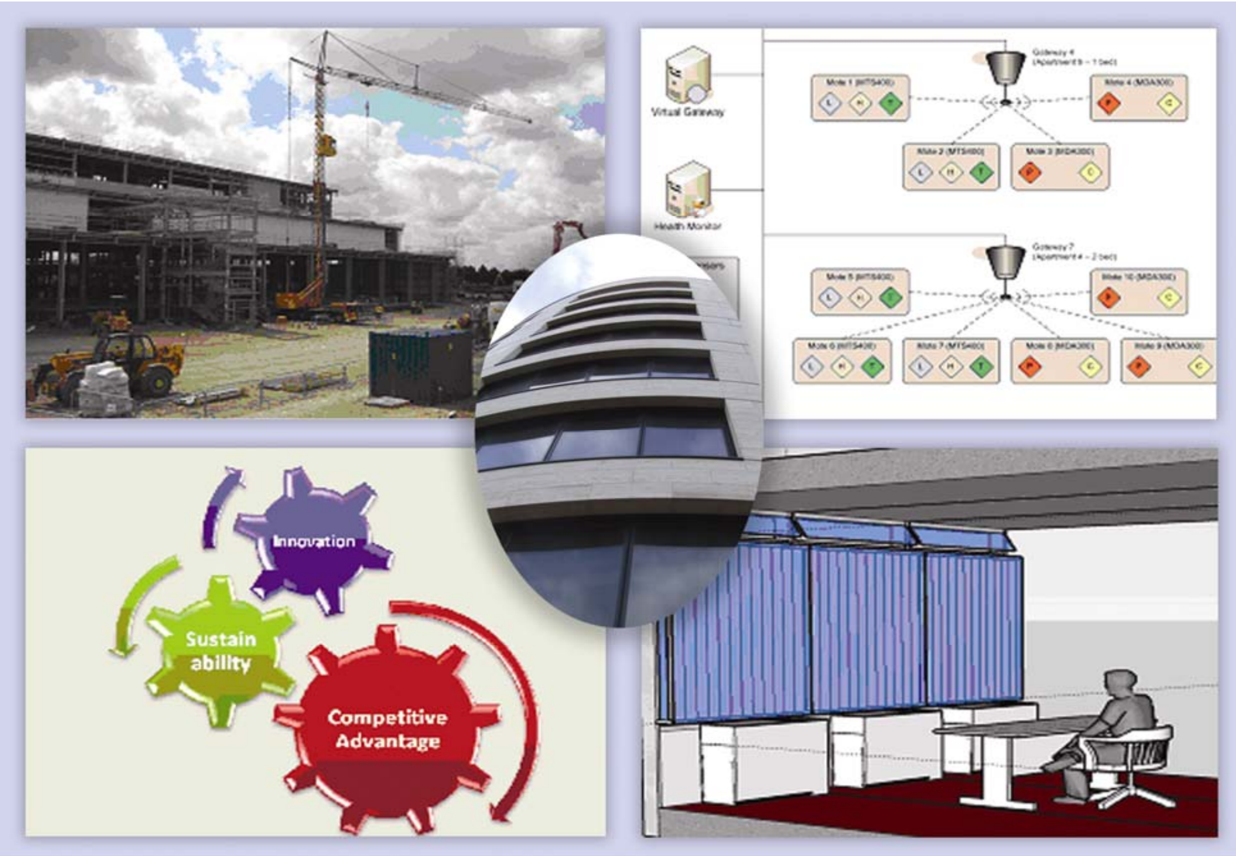

Industrialised, Integrated, Intelligent sustainable Construction

I3CON HANDBOOK 2

Edited by:

Ian Wallis, Lesya Bilan
Mike Smith & Abdul Samad Kazi

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PREFACE

Foreword

The European construction industry is highly diverse with the supply side comprising anything from relatively few huge multinational organisations employing many 10,000s of personnel to several millions of SMEs and sole traders. It is inherently fragmented with a wide range of professionals, trades and materials suppliers utilised to create a building. This fragmentation is intrinsically inefficient.

The I3CON research project aims to enable the transformation towards the European Construction industry delivering ***I**ndustrially produced, **I**ntegrated processes and **I**ntelligent building systems* that will deliver ultra high performance buildings.

Achievements and outcomes from the project will be marked by construction times being cut by 50% and construction costs reduced by 25%. It is not just about construction companies being more productive and profitable; the intention is to create improved life cycle value for the end users where life cycle costs will be reduced by up to 40% with improved flexibility, reduced energy consumption and improved comfort and security.

This handbook, "Sustainable Construction: Industrialised, Integrated and Intelligent" is created to showcase some of the recent developments in the area of industrialised, integrated and intelligent sustainable construction. The portfolio of chapters in this book presents ways that industrialised, integrated and intelligent methods and techniques can be used to help the construction industry become more sustainable.

This is the second handbook of I3CON and is aimed at helping stakeholders to understand and motivate others into thinking along the I3CON principles. It has been formulated at the outset of the project; a subsequent volume will provide more information at the outturn of the work.

The I3CON Project

I3CON is an industry-led collaborative research project, part-funded by the EU under Framework 6. Commencing in October 2006, it is a four year project involving 26 partners from 14 countries across Europe.

I3CON Handbook 2

The I3CON project consortium launched this book "Sustainable Construction: Industrialised, Integrated and Intelligent - I3CON Handbook 2" to disseminate work carried out within the area of sustainable construction to a wider audience.

PORTFOLIO OF BOOK CHAPTERS

Under What Conditions are "Industrialization" and "Integration" Useful Concepts in the Building Sector?

Stephen H Kendall

This chapter examines the meaning of "industrialization" and "integration" as they apply in the construction industry. Argues that some of the principles of open building theory have relevance to these words. Concludes with examples where their use describes what happens during the design, construction and adaptation of buildings.

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Integrating Affordable Housing and Sustainable Housing: Bridging Two Merit Goods in Australia

George Zillante, Stephen Pullen, Lou Wilson, Kathryn Davidson, Nicholas Chileshe, Jian Zuo, Michael Arman.

This chapter considers the issues surrounding the debate about affordable and sustainable housing in Australia. Discusses work on an embryonic model that might offer conceptual and practical direction for the construction of affordable and sustainable housing.

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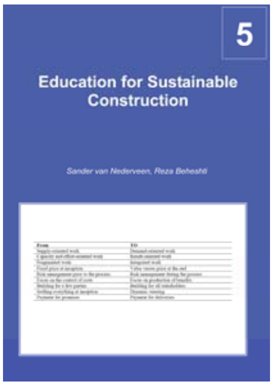

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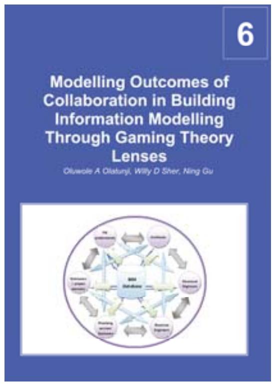

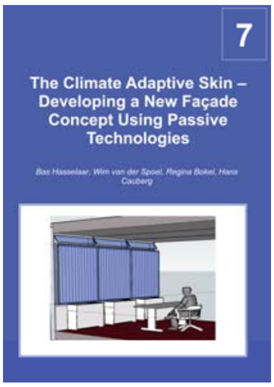

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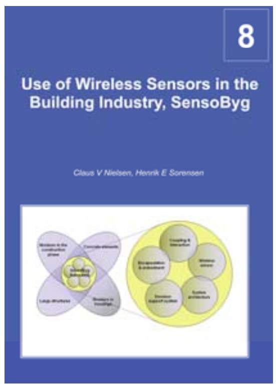

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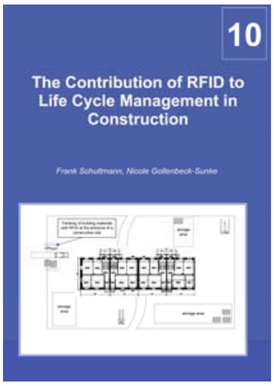

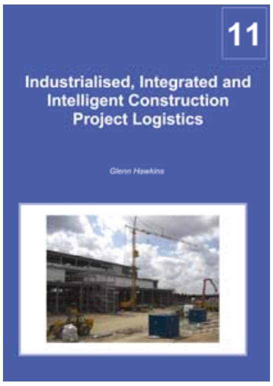

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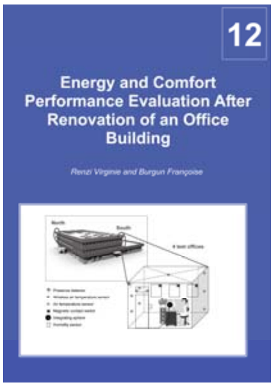

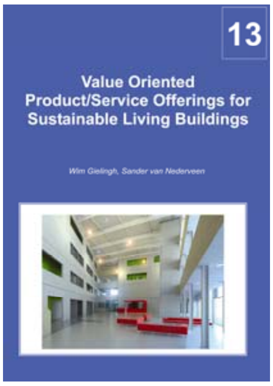

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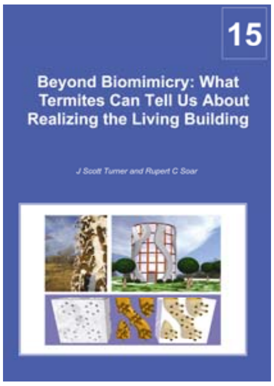

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J Scott Turner and Rupert C Soar

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ACKNOWLEDGEMENTS

We would like to acknowledge and appreciate the enthusiasm and contributions from the numerous authors who have shared their experience and lessons learnt in this book. This book would not have been possible had it not been for them.

We would also like to acknowledge the support of the European Commission and in particular its NMP programme for partly funding the I3CON project.

We would like to thank you, the reader, for taking the initiative and time to explore and learn from sustainable construction using of industrialised, integrated and intelligent methods and techniques presented in this book.

Ian Wallis – BSRIA, UK
Lesya Bilan – University of Stuttgart, Germany
Mike Smith – BSRIA, UK
Abdul Samad Kazi – VTT, Technical Research Centre of Finland

I3CON, March 2010

1

Under What Conditions are "Industrialization" and "Integration" Useful Concepts in the Building Sector?

Stephen H Kendall

Concurrent engineering	Optimizing	Collaborative participation	Multidisciplinary teams	Inclusion	Sharing of knowledge and learning	Interoperability
Introducing knowledge early	Thinking in levels of abstraction	Sharing of visions	Lean construction	Group processes	Supply chain integration	Value engineering

Under what conditions are “Industrialization” and “Integration” useful concepts in the building sector?

Stephen H. Kendall, PhD – Professor of Architecture, Ball State University, Muncie, Indiana, 47306, USA
(skendall@bsu.edu)

Abstract

When are “Industrialization” and “Integration” operative concepts in the building sector? This paper examines this question. It discusses the multiple – and confusing - ways these terms have been used in the building industry literature. The paper proposes that reliance on confusing definitions of these terms has for too long obscured careful observation of how the building sector actually works and has thus made innovation and advancement of the sector more difficult. The paper points out that the principles of Open Building and its related literature have clarified these issues and thus serve as a useful diagnosis and innovation platform.

Keywords: industrialization, integration, open building, levels of intervention and control, design distribution

"We teach students to integrate design and technology" (from a design course syllabus)

“A great epoch has begun. There exists a new spirit. Industry, overwhelming us like a flood which rolls on towards its destined end, has furnished us with new tools adapted to this new epoch, animated by a new spirit. Industry on the grand scale must occupy itself with building and establish the elements of the house on a mass-production basis. We must create the mass-production spirit. The spirit of constructing mass-production houses; the spirit of living in mass-production houses; the spirit of conceiving mass-production houses.” [1]

Introduction

Words have their pleasant ambiguity, making them useful in everyday conversation because they convey shades and nuances of meaning that, in the context of gestures, tone of voice and social context, make communication possible. But when we need more formal descriptions, these nuances and gestures are not helpful. It is then that we must be more precise and unambiguous, and are faced with the choice of coining new words - always difficult - or narrowing the meaning of already known words, a task no less fraught with problems [2].

This paper examines two important and well-known words found in the building industry literature – “industrialization” and “integration”. It points out some of their associations, meanings and their capacity to obfuscate.

The ambiguity of these words is well known. I will argue that this very ambiguity - and the resultant confusion - has been a major barrier to better methods and better research in the building sector. The words are used indiscriminately, as I will show. We have an epistemological problem, in that the complexity of the processes by which parts are aggregated in various stages into elements, components, parts, products, buildings and so on remains ill-described. The paucity of unambiguous terms to amplify and clarify these manifestations should tell us that the world of our concern - the ecology of people making things - has escaped adequate inquiry at least in the English language.

I will then argue that several of the principles of open building theory have relevance to the use of these two words, and conclude with examples in the real world in which industrialization and integration may have use in describing what we do in designing, constructing and adapting buildings.

How to describe building industry structure and dynamics?

Despite the fact that the building industry contributes very substantially to each country’s and the world’s economy, it is understudied [3]. By its nature, it is very complex and hard to account for. It is inextricably caught up in local cultural preferences, politics and regulations, real estate and labour markets, local geo-technical and climatic conditions, while also being part of local and regional product and service supply chains and the global finance industry. This “ecology” of production is difficult to map and explain [4]. In part this is because data about the behaviour of this industry at other than a gross aggregate level is difficult and expensive to obtain, and the data that is available is fraught with conflicting jurisdictions, collection and analysis methods, and problems of industrial secrecy.

Most literature on the building industry, at least since the 1960’s, has used the word “fragmented” to describe it’s structure, referring to what is widely thought to be its disorganization [5] [6]. Fragmented may make sense as a descriptor when the reference is to industries such as the automotive or aerospace industries, in which very few players now dominate (it was not this way at the dawn of the automobile age) and in which supply constellations are organized in alignment with their relatively consolidated and top-down industry structure.

But unlike these industries, the building industry is characterized by the very large number of parties who initiate building activities and regulate them, the equally large number of parties who supply parts and services to these initiatives and the variety of outputs matching the variety of those in control. And, unlike the automotive and aerospace industries, a very large number of the players in building processes are laypeople operating in the “informal” sector, as witnessed by the magnitude of sales at home project centres such as Home Depot and Lowes, and their equivalents in other countries, not to mention the ubiquitous informal sector in less developed countries.

“Disaggregated” is probably a better term to describe the “shape” of this economic sector. Disaggregated literally means "separated into constituent parts" [7]. The sense in which I mean this is that the building industry - its many agents and products, rules and processes - operates in ways fundamentally different from other more highly “aggregated” sectors in the economy, and behaves without an obvious "steering" mechanism other than the building market and culture as such.

When the conventional wisdom is that the building industry should behave in a way similar to the automotive or aerospace industries, it is little wonder that words such as “industrialized construction” and “integrated” will be in currency. But those industries are not suitable references, and therefore concepts such as “industrialized” and “integrated” need to be used carefully when brought to bear on building industry dynamics and used to explain or characterize the building industry or practices in it.

Industrialization and Prefabrication

Let us first examine *industrialization* [8]. Industrialization has to do with production in very large numbers of products of a general nature, parts that can be used by many players, acting autonomously with their own purposes quite distinct from the purpose of the producers. Examples abound, being an inevitable result of specialization, and pressures to reduce cost and improve quality. In the inventory of parts from which buildings are assembled today, most result from this process. There is good reason to think that this is not new, and precedes the industrial age. There has always been someone who, recognizing a general need, decided to make something that he expected others to want. From before mechanization, this source of entrepreneurial initiative has been known [9]. Now we harness machines and computers to help devise large catalogues of parts for the marketplace.

This business - rather than “technical” - view of industrialization sees the maker taking the initiative and assuming risk. After research and development, competitive positioning, experimental prototypes, investment in capital equipment and infrastructure, finding a place in a supply constellation, the producer decides if the risk will eventually earn a return on investment. The result is the production of relatively small and neutral parts suited to a range of users. These parts are “project independent”. Users, attracted to these products because of their utility to their individual purposes, decide to use what is already available, instead of making them (the buy vs. make decision).

Industrially produced, project independent parts are generally neutral enough that they can be tested and certified by nationally and internationally recognized testing bodies such as the UL (Underwriters Laboratory) [10], making local testing and public approval unnecessary. Today, building parts are produced in sophisticated factories, using well-organized production processes. In this process moulds, jigs, automated equipment, labour, and supply chains are in place using product templates, catalogues or libraries of parts (now stored as parametric elements), and so on. That is, the parts are designed even if parametrically, and production is undertaken at the risk of the producer.

It should be noted here that large, bulky, and complex assemblies for buildings (incorporating many subsystems of different kinds) require more costly research, more costly production processes, and thus require much larger and stable demand to produce a return on investment. The industrialized (project independent) production of these assemblies is thus rare, and when they are produced, they are always architecturally neutral; that is, they are hidden assemblies such as packaged heating and air conditioning units.

Construction, on the other hand, is the production of an artifact never seen before and never to be exactly repeated [11]. In construction, the user takes initiative, assumes the risk and reaps whatever profits result.

The image of a great basket of parts helps. The basket is filled with parts produced at the risk of the producer without knowing their downstream project application (industrialized production). The construction process involves reaching into the basket of available parts to select those needed for the artifact to be made, of whatever scale or complexity. The locus of initiative is, again, the distinction.

Prefabrication (“bespoke” production in the UK) is a variation on construction, in that the user takes initiative (places an order) and assumes risk (having provided the design) [12]. Unlike construction, prefabrication takes place at a distance from the site where the part will be used. It can, but need not, employ sophisticated means, labour saving methods, and information management. The result is project-dependent and is therefore constrained by the same factors as construction. Prefabrication is also not new, having been a mode of production well before the advent of machines and computers.

No Conflict between Industrialization, Prefabrication and Construction

There is, of course, no conflict between the most advanced industrialization processes and its products, and construction; or between industrialization and vernacular ways of building [13]. The famous “2x4 system” - used to build houses in the US since the 1830’s - is a case in point. This vernacular is fed by a vast industry making the parts - all produced in highly automated plants - and all “industrialized” (project independent). But few would say that this way of building constitutes “industrialized construction” [14].

While there is no conflict between these two processes, conflating industrialized methods of production and construction (or prefabrication) causes confusion. As noted above, the difference does not have to do with the use of sophisticated equipment. Robots can be found on the construction site and in factories. Hand labour is found in both. Prefabrication of roof trusses can be done by hand, or in highly automated plants, driven by sophisticated CAM (computer aided manufacturing) software, using products of industrialization but producing parts (trusses) ordered by their user. In such cases, the trusses are not examples of “industrialized construction” but of “prefabrication”, no matter how large the batch.

These are essentially business views, and usefully distinguish the matter of initiative, risk and control. While distinct operations and behaviours, they need each other today more than ever. Both complement the other. But they are different by definition and in practice.

Why the term "industrialized construction" has emerged at all is interesting. It is the same thinking that has fostered the emergence of the term "mass customization", an idea in currency that also conflates terms and processes unnecessarily [15].

A reading in the literature suggests that this confusion is largely an academic problem and that in practices that survive, the two loci of initiative sort themselves out. The efforts of even the most brilliant architects confusing these issues have fallen pray to ideologies that separate them from this reality [16]. Therefore the issue at hand is that the academic and research communities are out of step with the real world and are thus not able to be as helpful as they could be if theory and beliefs matched what is really happening.

The idea of integration has strong roots

Ortega writes, "The need to create sound syntheses and systemization of knowledge…will call out a kind of scientific genius which hitherto has existed only as an aberration: the genius for integration. Of necessity this means specialization, as all creative effort does, but this time the [person] will be specializing in the construction of the whole" [17].

This call from one of the 20th century's major philosophers may capture best the drive for that elusive wholeness that so many also in our field - the field of the built environment - continue to express. It is the wellspring and the root of the idea of integration. This search for "integration" has been widespread, especially in but not limited to the University [18].

One of the more recent of such searches is found in Christopher Alexander's magnum opus, titled The Nature of Order [19]. "This four-volume work is the culmination of theoretical studies begun three decades ago and published in a series of books -- including The Timeless Way of Building and A Pattern Language -- in which Alexander has advanced a new theory of architecture and matter. He has tried to grasp the fundamental truths of traditional ways of building and to understand especially what gives life and beauty and true functionality to buildings and towns, in a context which sheds light on the character of order in all phenomena."

The span of time of Alexander's work (C.A.1968-2008) corresponds closely to the heightened interest, found in the academic and government sponsored building industry literature, in the concept of "integration". While Alexander would now almost certainly reject many of the fundamental assumptions of those advocating integration, there is arguably something shared nonetheless – a sense of having lost the organic unity thought to have once obtained in the pre-industrial era. This is certainly a powerful idea. But it is also romantic wishful thinking today. I'd like to try to explain why.

Integration and Design Integration

"Integration" has several meanings, but the most common one is the idea that many things become "intermixed", have "equal participation" or are "combined to form a whole" [7]. Its use suggests the possible loss of identity of the parts to the whole.

Children in Waldorf schools around the world learn to experience the merging of two primary colours into a third one at an early age. They use the wet paper method. Each child is given a sheet of wet watercolour paper, a brush and two primary colours. The children are invited to apply one colour directly to the wet paper, then the other colour. Right in front of the child's eyes, the two colours merge and form a third colour. On the paper emerges the reality of three colours: the two original primary colours and the result of their merging. This may be one of the child's first ways to grasp the idea of two things losing their identity to a third reality. This seems to be one example of integration [20].

The word integration is found in the building sector in technology integration, product integration, and industrial integration. One additional phrase in currency in the architectural and engineering literature is design integration. What can this mean? What are its origins? In what context is this term found?

If by designing we generally mean what we do when we make a proposal for what should be built, by someone else, for someone else to use, we probably also have in mind some ideas regarding who is involved in these tasks – who takes initiative, who controls what, and so on.

Fundamentally, we distinguish or partition the act of designing from the act of making what is proposed. Of course, once the distinction is made, designing and making can be undertaken by one party, or by several parties. This is not new. Specialization brought us this distinction very early, always ruled by convention and tacit knowledge as well as specialized skills, tools and public oversight. I have participated in both, having practiced as an architect making drawings to instruct a builder what to do, and I have also built by my own hands what I have designed.

If that is at least a point of departure for “designing”, what is integration when the word is attached? In academic, governmental and some professional architectural and engineering discourse, we see the use of the phrase “design integration” or “integration of design and production”.

It is worth recounting a case that demonstrates how the phrase design integration has reached a state of uselessness. At a recent international conference on Design Management (CIB W96) in Copenhagen, a session was organized called Design Integration [21]. I was asked to be chair of that session, which allowed me to read all the papers. This reading revealed the following words or phrases associated with design integration:

- Concurrent engineering
- Multidisciplinary teams
- Introducing knowledge early
- Thinking in levels of abstraction
- Sharing of visions
- Group processes
- Interoperability
- Optimizing
- Collaborative participation
- Inclusion
- Sharing of knowledge and learning
- Lean construction
- Supply chain integration
- Value engineering

*The idea that problems can be subdivided into overlapping, interconnected segments that correspond to existing or emerging disciplines but are connected in a coherent and comprehensive manner (a phrase found in one of the papers)

These were the actual terms associated with “design integration”, found in the dozen or more papers I read. What are we to understand from this? Does design integration mean joining designers together somehow? If so, exactly how is this to be done? Is the joining done at the hip, or by brain links? Do we find partnerships, contracts, virtual networks, or the law as the operational devices of design integration? Does design integration mean a hierarchical relationship between parties, or a relationship of equals, or neither?

Experts in the building industry around the world have worked diligently for more than 50 years to put the concept of “design integration” into practice. It seems that the latest effort to accomplish “integration” will be found in building information modeling (BIM) and the recent IDS (Integrated Design Solutions) movement [22].

I would suggest that a resolution is possible by introducing the concept of control, one of the central concepts in Open Building. That is, we need to know what party (an individual or group) makes executive decisions. Thus, to make the phrase “design integration” useful, we must ask “Who controls what?” This is a decidedly political and business-related question that takes us outside our professional or “technical” expertise into a field of social, economic and cultural discourse and values.

Effective Terms of Reference

As mentioned above, the term “disaggregated” is a more apt term than “fragmented” when describing the organization and dynamics of the building sector. This means that a number of independent and geographically distributed parties are at play. The relations between these parties, their patterns of control, are key to understanding the dynamics of their interactions and their output.

There are many kinds of relations; we have teams, partnerships, collaborative structures, virtual corporations, vertically or horizontally organized networks and supply constellations. We would find it very strange and probably bad if one party (an individual or a company) claimed to be able to control everything! For a long time we have had specialization and it won’t go away. Rather, we experience more specialization as the world becomes more complex and fast paced.

It would be a bad idea if the building industry would model “integration” as we find it in the automobile or aerospace industries, for example. Do we really want a few giant companies controlling all the building activities, with tight, top-down supply chains, in the US, or in other markets? I think few would argue in favour of that, or in favour of abandoning the range of small, medium and large organizations that give the building industry tremendous agility, dynamism, resilience and innovative capacity.

Control and Dependencies

When we design a complex artefact like a building, we compose it from many parts. During the process of composing, we need to change parts, delete some, adjust them, or add new ones, as we learn more or as conditions outside our control change. It is normal that when we change one part, others are implicated. Soon the perturbations in the whole can become too complex to be controlled successfully when every part is subject to alteration upon the change of another part, and when manipulation of parts is distributed among a number of parties. To manage this complexity, we decide to fix some configurations - leaving them stable. These stable configurations become constraints on the manipulation of other configurations or parts. We follow this process until we think we are "done" with the designing or until the party requesting it gives approval.

It may be that "integrationists" want to eliminate such complex dependencies by unifying parts, so that the parts no longer have autonomous identities among which dependencies can occur. Along with this naturally goes a unification of control. Clearly, if we have a whole composed of two parts, the individual parts can be controlled by one party, or by two. The more parts we have, the more potential parties can take part in making and changing the artefact. When all parts are made into one (integrated - unified) clearly only one party can exercise control because the whole cannot be sensibly partitioned. The "one party" may be a group "acting as a whole" (by consensus or by vote) or it can be one individual who seeks out the advice of others but who has exclusive authority to act (control). We know the difference, however, which only goes to raise the question of how groups actually "work together" in making form.

Levels of Intervention

One way to avoid the trap of “integration” is to understand the idea of levels of intervention [23]. This is not a new idea – large infrastructures are always organized on levels - but is easily forgotten, and in any case constitutes an inevitable trend in the building sector.

For example, in large buildings, we see a tendency to separate a ‘base building’ from ‘fit-out’. This separation is also called “core and shell” and “tenant work”, or “support and infill”. Whatever the words used, the distinction is increasingly conventional - internationally - and is mirrored in the real property and building industries’ practices, methods and incentive systems.

For example, commercial office buildings have used this distinction for at least forty years. Tenants lease space in buildings in which the layout for each is custom designed and individually adaptable over time. Private and governmental institutions owning large administrative buildings likewise make that separation to accommodate ongoing relocation and reconfiguration of functional units. Large building companies have distinct, dedicated divisions to service both the construction of base buildings and the installation of tenant improvements or fit-out. Tenants may own their fit-out partitioning and equipment (usually called FF&E or Fixtures, Furnishings and Equipment) and can sell it to the next users, or may clear out the space when they leave (increasingly using parts prepared for disassembly or recycling), to be fitted out anew by the next occupant. This way of using built space already constitutes a substantial market, which, in turn, has given rise to a well organized industry serving the demands for tenant “fit-out”, including finance companies, product manufacturers, design firms, construction companies and a host of others among which are well known companies such as Steelcase, Haworth, Herman Miller, and Knoll, among others.

Another example is shopping malls. Developers build large structures giving much attention to public space but leaving retail space empty. Overall architectural, technical and space standards are established and documented in detailed tenant handbooks, enabling national or international retail chains (or local businesses) to lease space and bring in their own designers and fit-out services.

Why has this trend emerged? The answer lies in a convergence of three dominant characteristics of the contemporary urban environment. First is the increasing size of buildings, sometimes serving thousands of people. Second is the dynamics of the workplace and the marketplace where use is increasingly varied and changing. Third is the availability of, and demand for, an increasing array of equipment and facilities serving the inhabitant user. In that convergence, large-scale real estate interventions make simultaneous design of the base building and the user level impractical. Social trends towards individualization of use make functional specification increasingly personalized. Greater complexity and variety of the workplace demand adaptation by way of architectural components with shorter use-life, such as partitioning, ceilings, bathroom and kitchen facilities, etc.

The observed separation of base building from fit-out includes utility systems as well. Adaptable piping and wiring systems on the fit-out level, for example, connect to their counterpart and more fixed main lines in the base building, which themselves connect to the higher level infrastructure operating in the city.

Thus we see a significant contrast between what is to be done on the user level on the one hand and what is understood to be part of the traditional long-term investment and functionality of the building on the other. This is the reason for the emergence of the base building as a new kind of infrastructure.

The distinction here - between “levels of intervention” - is always useful when we compare infrastructure with what it is serving. In the case of buildings, the comparison has multiple dimensions, including the following, framed in terms familiar in the US office building sector if not more broadly:

BASE BUILDING	**INFILL or FIT-OUT**
Longer-term use	Shorter-term use
Public or common service related design	User related design
Heavy construction	Lightweight components
Long-term investment	Short-term investment
Equivalent to real estate	Equivalent to durable consumer goods
Long term mortgage financing	Short term financing

When this distinction is made in practice, it is usually the case that each level is under the control of a different “party” or agent. It is even then possible to say that each such “party” must “integrate” the work within their area of responsibility to maintain quality, schedule and cost. But the use of “integration” here is directly aligned with a pattern of control, rather than being a strictly technical definition. That is the key point: integration cannot be divorced from the exercise of control [24].

The Emergence Of A Fit-Out Industry

"Integration" or "integrated design" as a model for single-source or unified delivery of building technology or building processes thus may make sense, in particular situations. In open building theory, the most successful examples are evident at the "fit-out" level. It is well understood that industrial manufacturing is most effective and dynamic where individual users are directly served. Witness the automotive, electronics and telecommunications sectors. One example in the commercial sector is the emergence, over the past decades, of service providers that provide unified control of complete "slab-to-slab" fit-out. Steelcase pioneered this technology/service bundling, in their commercial office fit-out Pathways product, in the 1990's [25].

The potential market for residential fit-out is at least as large. Designing base buildings understood as 'infrastructures for living' will stimulate the evolution of a fit-out industry that will itself accelerate innovation and distribution of new domestic fit-out services and systems.

Residential application of the distinction between base building and fit-out, although based on the same principles as observed in office buildings, shopping malls and hospitals, is particularly important because it affects a very large market whose potential is not yet understood or exploited.

In Japan, a fit-out system, targeting the activation of post war residential apartments as well as newly built base buildings, has been launched in the market. Technical sub-systems and products that can be combined in full fit-out systems are increasingly available in the international building supply market, and in the Netherlands and Japan, for instance, there is evidence of continued commercialization efforts to develop marketable fit-out systems.

In general, the creation of a genuine fit-out industry is not a technical or industrial design problem. As noted above, necessary material subsystems and components like partitioning, bathroom and kitchen equipment, piping and wiring are available. What is needed is the introduction of installation teams modeled on the "work cell" familiar in automotive manufacturing, where, in the case of building processes, a trained team brings in all the ready-to-assemble parts – organized off-site in boxes and bundles – installs everything inside the empty space, and hands over a finished dwelling with a users manual, avoiding the disruptive sequencing of subcontractors. Backed up by sophisticated data and logistics management, this will combine efficiency with customization at a range of price points. It is important that the legal and economical frameworks needed for the emergence of such an industry are put in place by local and national government bodies, and by the financial companies that understand the market potential [26].

Roughly speaking, the cost of an integrated fit-out system for a modest apartment dwelling unit is in the order of the cost of the cars its occupants use. This shows the magnitude of the shift we are identifying – an entirely new industry of impressive scope, based on "industrialized" production of parts and delivering what is best called an integrated durable consumer good. In this perspective the trend towards base building infrastructure also allows the building industry to effectively come to terms with industrial production in its most creative mode.

Meeting The Sustainability Agenda

Base buildings that are well insulated and built for long-term and efficient performance are easier to build when freed from intricate and complex fit-out demands. Double-envelopes can be designed to meet the highest building performance standards, reducing heating and cooling loads while providing ample natural illumination. Fit-out components and parts, on the other hand, are those that consume energy and are particularly related to eco effects in buildings. This is even more so when facade elements become parts of fit-out packages. Because individual fit-out users are responsive to new products and services from the manufacturing sector, accelerated turn around cycles will boost the large-scale re-orientation of environmental construction to the demands of a carbon free ecology. In fact, the United States Green Building Council's LEED rating system already recognizes the distinction we discuss here [27].

Conclusion

The implications of the perspective put forward in this paper can be surmised. Many aspects of our work as architects and engineers and builders - in practice, research units and teaching - are involved. Adopting a perspective that includes the concept of control has been and will continue to be disruptive. However, if we don't adopt this perspective, we should anticipate a continued lack of effectiveness in dealing with relentless and ubiquitous forces at work in the built field. That is not to say that students will not continue to flock into the schools, or that creative and skilful architects and engineers will not continue to practice and practice successfully. But in a larger sense, our future depends on emerging from behind the shroud of such terms as *integrated design solutions* and *industrialized construction* and all that is embodied in these terms.

The problems in pursuing this shift of attitudes and perspective are not trivial. Necessary professional re-orientation may well determine the pace, direction and quality of change. Note that the practical examples of working with levels of intervention and in recognition of patterns of control cited above have emerged from sound economic reasoning and a willingness to respond to market forces, not from ideology. The time may have come to establish a more explicit platform for study and development of what seems to have come not as a new design idea, but as a new reality to be taken seriously.

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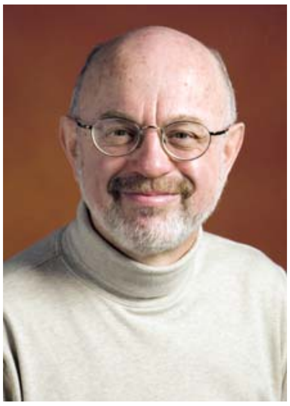
Author's Biography



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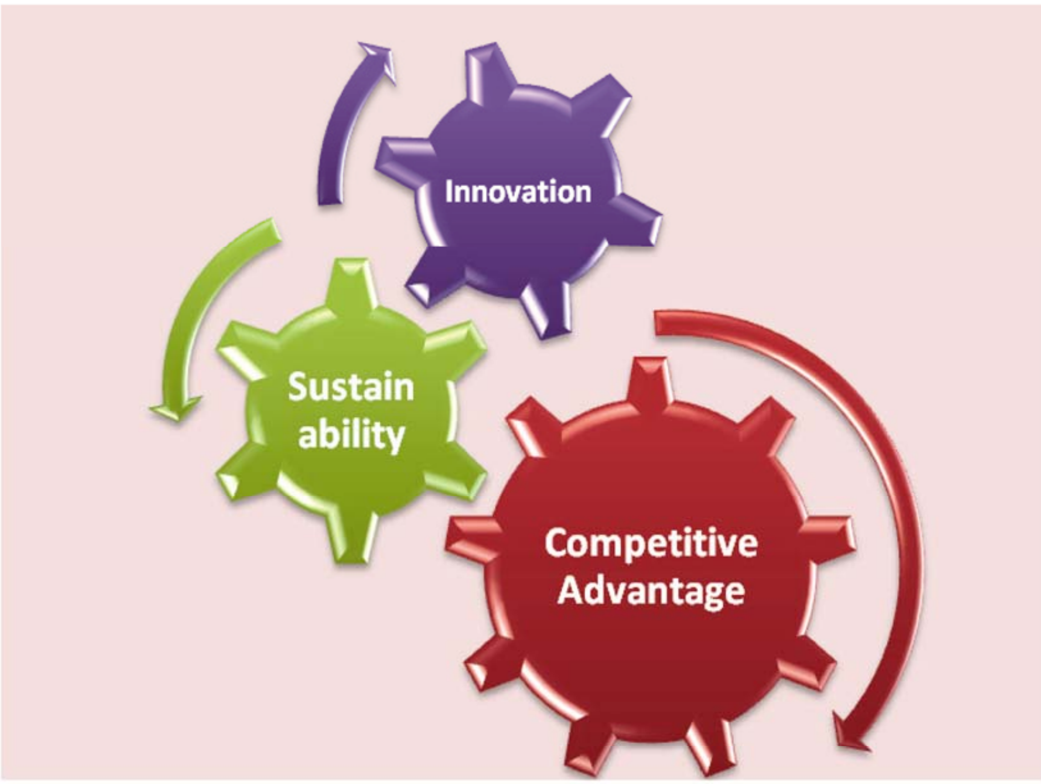
2

Incorporating Innovation and Sustainability for Achieving Competitive Advantage in Construction

Ayman Ahmed Ezzat Othman



Integration of Innovation and Sustainability: A Novel Approach for Achieving Competitive Advantage in Construction

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Abstract

Being one of the biggest industries worldwide, the construction industry plays a significant role towards social and economic development at national and international levels. It contributes towards providing communities with places for housing, education, culture, medication, business, leisure and entertainment. In addition, it constructs the infrastructure projects that are essential for these facilities to perform their intended functions. Furthermore, it increases the gross domestic product (GDP), motivates development of other industries and offers employment opportunities. Contrary, the construction industry is not only a very large consumer of non-renewable resources and energy, it is also a substantial source of waste, carbon emission and pollution as well as land dereliction and ecological destruction. The increasing recognition and the universal calls for sustainability have increased competition between construction professionals to deliver products that save the environment, enhance society and prosper the economy. In dynamic and ever-expanding industries like construction, achieving competitive advantage is a cornerstone for every organization wishing to remain in the market and compete for the future. This called for integrating innovation and sustainability to develop sustainable solutions, creative ideas and new approaches for escalating the competitive advantages of construction professionals. In order to achieve this aim, this chapter is divided into three sections to accomplish three objectives. Firstly, a literature review is used to investigate the concepts of innovation, sustainability and competitive advantage in construction. Secondly, case studies and examples are used to show how innovative ideas could help in increasing competitive advantage in construction and other industries. Finally, an innovative theoretical framework is developed to facilitate the integration of innovation and sustainability as an approach for achieving competitive advantage in construction. This research highlighted the need for innovation in delivering sustainable projects that enable construction companies to maintain their competitiveness. In addition, it identified the drivers and barriers of innovation in construction. Adopting the developed framework will increase the completive advantage of construction professionals through integrating innovation and sustainability.

Keywords: innovation, sustainability, competitive advantage, novel approach, construction industry, framework

Introduction

In spite of the crucial role that the construction industry plays towards achieving national and international strategies for social and economic development, it has a major impact on the environment. On one hand, it contributes towards increasing the GDP, stimulating growth of other industries and creating job opportunities (Field and Ofori, 1988; Mthalane et al., 2007). In addition, it provides societies with facilities and infrastructure projects that meet their needs and fulfil their requirements (Friends of the Earth, 1995; Roodman and Lenssen, 1995; Khan, 2008). On the other hand, around 3 billion tonnes of raw materials and 40% of the total global economy are used in manufacturing construction materials worldwide. Furthermore, the construction industry is accountable for about 50% of the material resources taken from nature, 40% of energy consumption and 50% of total waste generated. Large amounts of energy are consumed during the procurement of materials, construction activities and operating artificial heating and cooling systems (Anink et al., 1996; Othman, 2007). This called for the construction industry to be more sustainable. The rapid political, economic, legal, technological and competitive changes in the business environment necessitated that every industry has to innovate in order to remain in market and compete for the future (Othman, 2008). Today's competitive environment entails that companies have to understand the needs of current generations and offer them efficient and effective solutions that achieve their objectives without compromising new generations from achieving their own needs. Innovation and new technology are essential components of competitive advantage for many organizations. Different organizations face imperative competitive challenges due to the quick speed and unpredictability of technological change. Industries which depend on highly sophisticated technologies and firms that are engaged in multinational competition are particularly vulnerable to the need for continuous and rapid modification of their products' features, and the ways in which they conduct business. Because of the limited natural resources on the planet and due to the huge consumption of materials and energy, construction professionals have to consider sustainability issues when performing their activities in order to be competitive. Innovations and new technology provide a way of increasing the competitiveness of the construction industry through developing smarter materials, equipment and techniques that save the environment, enhance society and prosper the economy.

Aim and Objectives

This chapter aims to investigate the integration of innovation and sustainability principles as an approach for achieving competitive advantage in construction. In order to achieve this aim, three objectives have to be accomplished:

- Building a thorough background of the study topic through reviewing the concepts of innovation, sustainability and competitive advantage in the construction industry.
- Presenting case studies and examples of innovative ideas that increased competitive advantages of companies operating in construction and other industries.
- Developing an innovative theoretical framework integrates innovation and sustainability towards achieving competitive advantage in construction. The development of the framework is based on the results of the literature review, cases studies and the practical solution that the integration of both principles can do towards increasing competitive advantage in the construction industry.

Background

Innovation

Overview and Definitions

The term "innovation" refers to a new idea, method or device (Oxford Dictionary, 2009). It is the creation, development and implementation of a new product, process or service, with the aim of improving efficiency, effectiveness or competitive advantage (Digital Strategy, 2009). Innovation is a mindset, a pervasive attitude, or a way of thinking focused beyond the present into the future vision. Innovation is not a modern concept. Joseph Schumpeter is believed to be the first economist who recognised the importance of innovation in the 1930's (Rogers, 1983). It is increasingly seen as a result of an interactive process of knowledge generation and knowledge application (Toedtling and Lehner, 2006). It is an important topic in the study of economics, business, design, technology, sociology, and engineering. Innovation is often synonymous with the output of the process. However, economists tend to focus on the process from the origination of an idea to its transformation into a useful product, to its implementation; and on the system within which the process of innovation unfolds. Since innovation is also considered a major driver of the economy, especially when it leads to increasing productivity, the factors that lead to innovation are also considered to be critical to policy makers (Physorg, 2009). Although terms like creativity and change are used interchangeably with innovation, invention is different to innovation, whereby the first is the generation of new ideas whilst the latter is the application of new ideas (Winch, 1998).

Types of Innovation

There are diverse views with regard to the different types of innovation. Tidd et al. (2005) argued that there are four types of innovation; hence the innovator has four pathways to investigate when searching for good ideas. These types of innovation are:

- **Product innovation**
  Introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics. Product innovations can utilize new knowledge or technologies, or can be based on new uses or combinations of existing knowledge or technologies.

- **Process innovation**
  Implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software. Process innovations can be intended to reduce production costs, expedite service delivery or increase quality. Just on time is a good example.

- **Positioning innovation**
  Using a product to perform a function different to its intended purpose such as “Lucozade” used to be a medicinal drink but it was repositioned as a sports drink.

- **Paradigm innovation**
  Major shifts in thinking cause change. During the time of the expensive mainframe, Bill Gates and others aimed to provide a home computer for everyone.

A slightly differing view to the above and based on the current theories of innovation, Slaughter (1998) distinguished innovation as:

- **Architectural innovation**
  A significant alteration made to components which have a substantial impact with other components and the process.

- **Incremental innovation**
  Alterations made on an existing technology which generally stems from the firm implementing the technology.

- **Radical innovation**
  A completely brand new idea or process which is articulated to enhance the performance of an industry.

- **System innovation**
  Diffusion of several independent innovative components used to compile a new product, process or technique.

- **Modular innovation**
  An important change made to a factor in technology which does not interfere with other factors within the technology.

The innovation process

The innovation process encompasses several systematic steps, beginning from problem/requirement analysis to idea generation, idea evaluation, project planning, product development and testing to finally product marketing. The steps may overlap each other. These steps could be categorised into 3 broad phases, which represent a simplified innovation process, see Figure 1 (Tiwari et al., 2007).

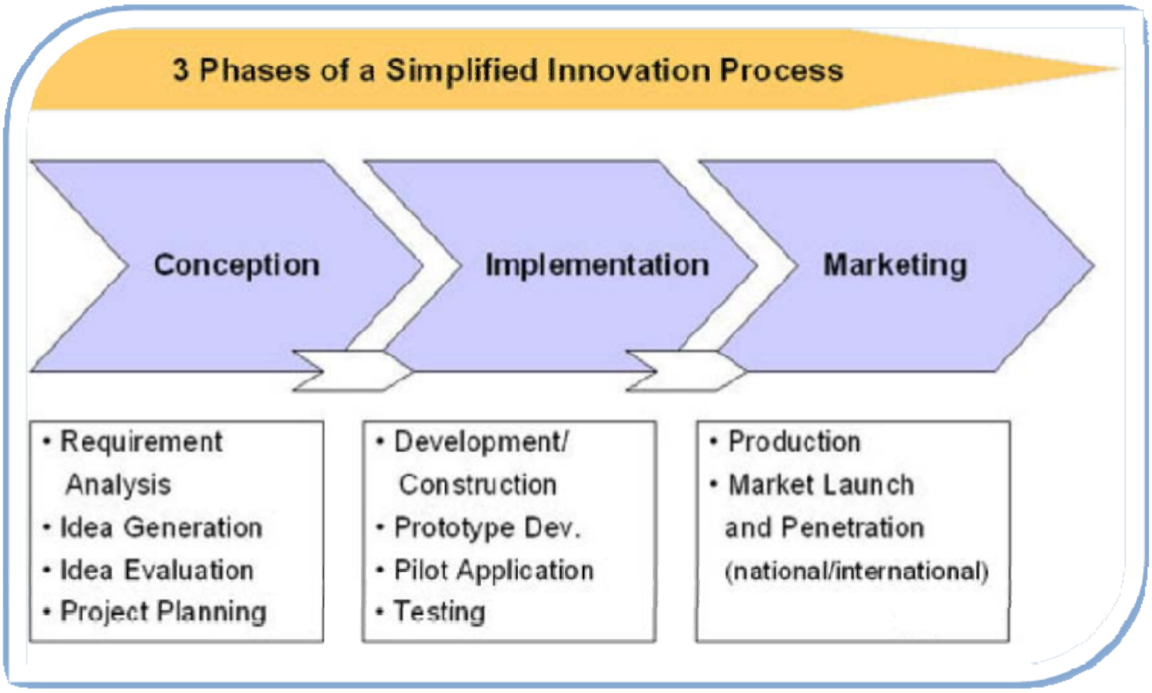

Figure 1. Three phases of a simplified innovation process

Innovation and Uncertainty

Although innovation usually adds value, it has negative impact and involves a certain level of uncertainty. Radical Innovation involves the maximum level of uncertainty on four major fronts: Technical, Organisational, Market and Resource.

(1) Technical uncertainty
This is concerned with the development of a product that possesses the right specification; the availability of technology and trained personnel needed for developing products with those specifications and the availability of these technologies elsewhere.

(2) Organisational uncertainty
This is concerned with the impact of the new technology on the organisation's vision, mission and structure; the adaptability of the new technology by employees and the reaction of the organisation as a whole to the development of this innovation.

(3) Market uncertainty
This is concerned with identifying the type of customers who will use the product of the innovation process and the ability of the produced product to meet the customers' needs and achieve their satisfaction.

(4) Resource uncertainty
This is concerned with the role of management towards providing enough financial resources for the development of these products; the availability of adequate technology; the level of outside assistance required (TBS, 2009).

Drivers of Innovation in Construction

Drivers of innovation are factors that have the ability to encourage and promote the inclination to innovate. Drivers are the key influences in the construction industry which bring about and motivate innovative ways of approaching construction processes. Since the construction industry is such a diverse sector, there are various ways innovation takes place. Innovation occurring from various aspects can recognise drivers in construction innovation from different levels in the construction sector such as industry level (Pries and Janszen, 1995), institutional and firm level (Winch, 1998) and construction project level. Drivers emerge from an increase in global competition and restrictive environment legislation (Manseau and Seaden, 2001), to improve the efficiency and effectiveness of the construction industry (Manley *et al.*, 2005). Furthermore, another major contributing factor that drives innovation is R&D programmes. These programmes are mainly supported and funded by the government, therefore having the ability to carry on producing innovative methods and procedures (Koskela, 2002).

Bossink (2004) has identified different levels in the industry from which drivers may occur:

- **Environmental Pressure**
  Influences from the external environment that force and encourage institutions to innovate.

- **Technological Capability**
  Technical aspects within the institutes that facilitate the development of innovative products and methods.

- **Knowledge Exchange**
  The exchange of information and knowledge within institutes to promote innovation. The intensity of innovation knowledge is complex and difficult to acquire alone, but by sharing knowledge within institutes, participants can evaluate channels of knowledge flow and identify any blockages.

- **Boundary Spanning**
  This aspect encourages all organisations and companies to interact with each other to produce innovative methods and procedures that will benefit all. Organisations are main motivators which administers the flow of knowledge movement and the way innovation learning occurs.

The Role of Project Stakeholders in Innovation

The construction process is complex and fragmented with a variety of participants interacting with each other (Winch, 1998). The participants will be discussed under the following headings namely: Client, Professional Team and Contractor.

The Client

The construction client initiates and ultimately pays for the project. The client knows exactly what is needed in the project (Leiringer, 2001) and thereby indicating the purpose of the project and its intended use. The involvement of the client is vital for innovation to be successful (Nam and Tatum, 1997). Many well recognised institutions acknowledge that clients play an important role in encouraging innovation as they are the main motivator for innovation in construction (Egan, 1998; Winch, 1998). Professional clients work with numerous projects which assist them in acquiring a certain level of technical competence and skills that enable them to understand the advantages and disadvantages of an innovative solution (Nam and Tatum, 1997). Occasional clients on the other hand can recognise diverse solutions, create specific requirements on the solution, reduce risk or access certain resources. Leiringer (2001) identifies a third client classification namely: inexperienced clients. These clients do not know exactly what they require, and this has a negative impact on the attitudes regarding appreciation of the product or process by the client. Therefore additional attention is given to clients that lack the knowledge of the industry so that clients are able to specify their needs more clearly to the relevant participants and appreciate the end product or process.

The Professional Team

The professional team of any construction project usually comprises an architect, engineer, quantity surveyor and project manager. Table 1 illustrates the said professional team and their respective percentage contributions to encouraging innovation, as carried out in an international case study by Manley (2006).

Table 1. Improving Performance in the Building and the Construction Industry (Manley, 2006)

Encouragers of Innovation			
Large/Repeat Clients	59%	Trade contractors	27%
Architects	55%	Other suppliers	26%
Engineers	51%	Organisations that set industry standards	26%
Manufacturers	46%	Quantity surveyors	19%
Building designers	44%	Funders	15%
Main contractors	43%	Government regulators	11%
Developers	38%	Letting agents	7%
Project managers	38%	Insurers	5%
One-off clients	27%		

Table 1 shows that architects and engineers contribute considerably towards encouraging innovations, and therefore, the relationship between these two consultants is an important factor for innovation in construction (Manley, 2006).

The Contractor

Studies have shown that contractors play a significant role in innovation. They do not merely implement innovations introduced by suppliers as they are also at the source of the innovation process. Since contractors implement products and have full access to building site information, they are able to come up with innovative solutions. Contractors also generally create solutions that are not present in the market place. These kinds of contractors are prepared to use new products in order to maintain a competitive advantage over their competitors.

Benefits of Innovation in Construction

Innovation is intended to improve the performance of organizations in the construction industry and achieve the objectives of its stakeholders. The benefits of innovation in the construction industry are (Manley *et al.*, 2005; Blayse and Manley, 2004; Gunnigan and Eaton, 2008):

- Reducing construction cost and time as well as reducing injury rates.
- Improving productivity, increasing competitiveness and competitive advantage, marketing growth and achieving social objectives such as affordable housing development.
- Enhancing design buildability and economy as well as improving communication and learning.
- Reducing operational and maintenance costs as well as maximising additional opportunities for use of the facility which will generate future income.
- Partnering and Alliancing between project stakeholders helps increasing productivity, achieving client satisfaction and improving quality.

Barriers to Innovation in Construction

A barrier to innovation is a circumstance or obstacle that prevents the implementation of innovation in construction. There are currently many reasons as to why the level of innovation is low in the construction sector:

- The short term of projects which are won in most instances on price and the opportunity or motivation for industry stakeholders to invest in R&D initiatives for innovation is minimal.

- The patterns of the construction industry cycle follow that of the economic cycle, during a recession, profits for companies are reduced, and as a result, this hinders the implementation of innovation.

- The construction industry is project-based and does not produce repetitive products. The implementation of construction methods, changes with every site according to the scope and objectives of the project. In addition, the fragmented nature of the industry makes the products of construction more complex. Consequently this hinders the implementation of innovation in construction (Leiringer, 2001; Gann and Salter, 2000).

- Nam and Tatum (1997) and Budiawan (2003) argued that the slow adoption of new technology and innovation is a major factor in the construction industry. Participants in the industry stated that the tendering process in construction is too short to adopt innovative ideas. Furthermore, when the construction stage is reached, it is too late to adopt innovative ideas as the processes have already been priced.

- The industry is predominantly made up of small firms which hinders the ability to innovate (Sexton and Barrett, 2003). Small firms have more factors limiting innovation (Reichstein et al., 2005), for example they tend to focus mainly on those activities that directly affect them and have no strategy on managing technical external changes (Gann, 2000).

- Budiawan (2003) stated that the risks attached to implementing innovation are higher in the construction industry, as a trial-and-error approach is not acceptable. If the resulting effect of implementing innovation is a failure, it affects the company’s reputation and credibility. As a result, construction firms are more averse to innovation.

- The conventional method of managing construction projects poses another obstacle in the execution of innovation in construction (Mohamed and Tucker, 1996).

- Government statutory regulations and procurement methods adopted also have a significant impact on innovation in construction (Gann and Salter, 2000).

In an Australian case study by Manley (2006), key barriers facing the construction industry were identified. The results of which are represented in Figure 2.

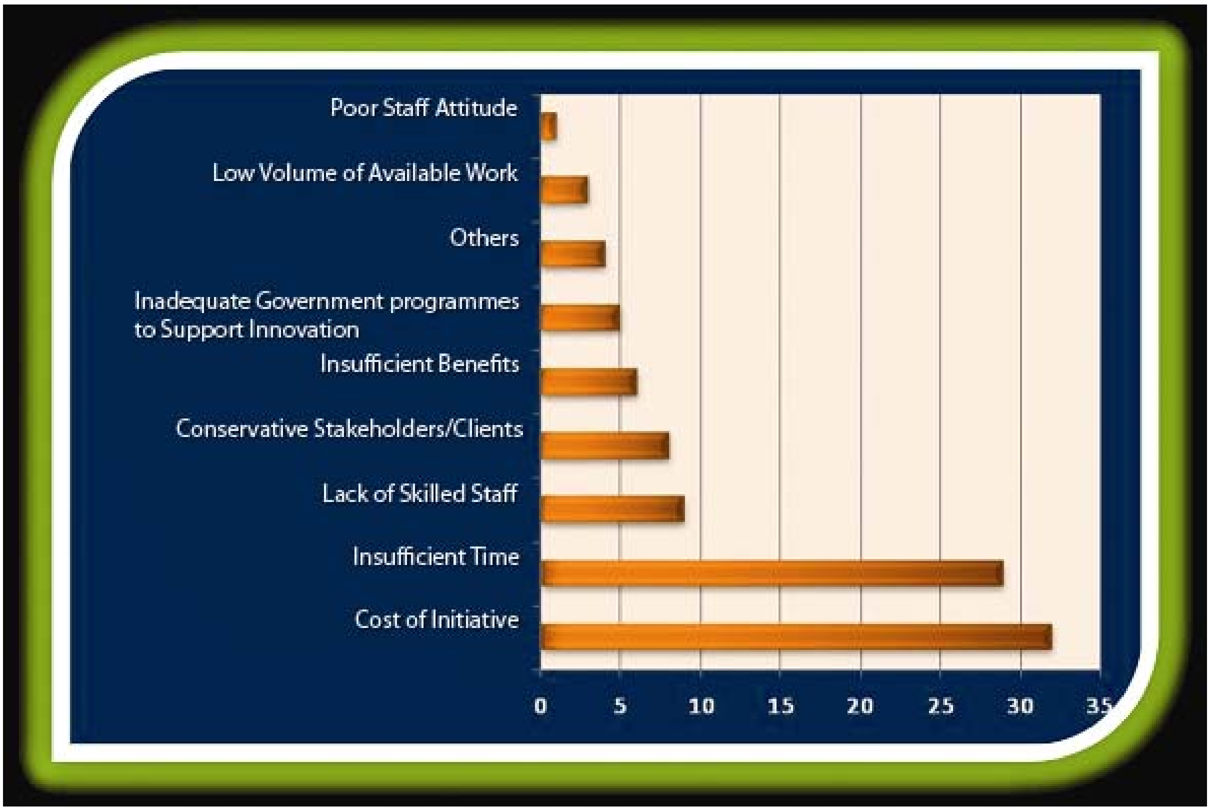

Figure 2. Barriers to innovation in the Australian Building and the Construction Industry (Manley, 2006)

Sustainability

Overview and Definitions

Sustainability, in a broad sense, is the capacity to endure. It has become a wide-ranging term that can be applied to almost every facet of life on Earth, from a local to a global scale and over various time periods. The existence of more than 70 different definitions for sustainability (Holmberg and Sandbrook, 1992) highlighted its significance and showed the efforts made by different academic and practical disciplines to define and understand its implications to their fields. Yet, all definitions agree that it is essential to consider the future of the planet and find innovative ways to protect and enhance the Earth while satisfying various stakeholders' needs (Boyko et al, 2006). There is now abundant scientific evidence that humanity is living unsustainably. This is obvious in using non-renewable resources, land dereliction, waste generation, water contamination, and energy consumption for instance (Othman, 2009). Returning human use of natural resources to within sustainable limits will require a major collective effort. Since the 1980s, sustainability has implied the integration of economic, social and environmental spheres to meet the needs of the present without compromising the ability of future generations to meet their own needs (United Nations General Assembly, 1987).

Efforts towards living more sustainably can take many forms from reorganising living conditions (e.g., ecovillages, eco-municipalities and sustainable cities), reappraising economic sectors (green building, sustainable agriculture), or work practices (sustainable architecture), using science to develop new technologies (green technologies, renewable energy), to adjustments in individual lifestyles.

The challenge is about finding the balance between environmental considerations, society requirements and economic constraints (Hui, 2002).

Dimensions of Sustainability

Figure 3 shows the three different dimensions of sustainability.

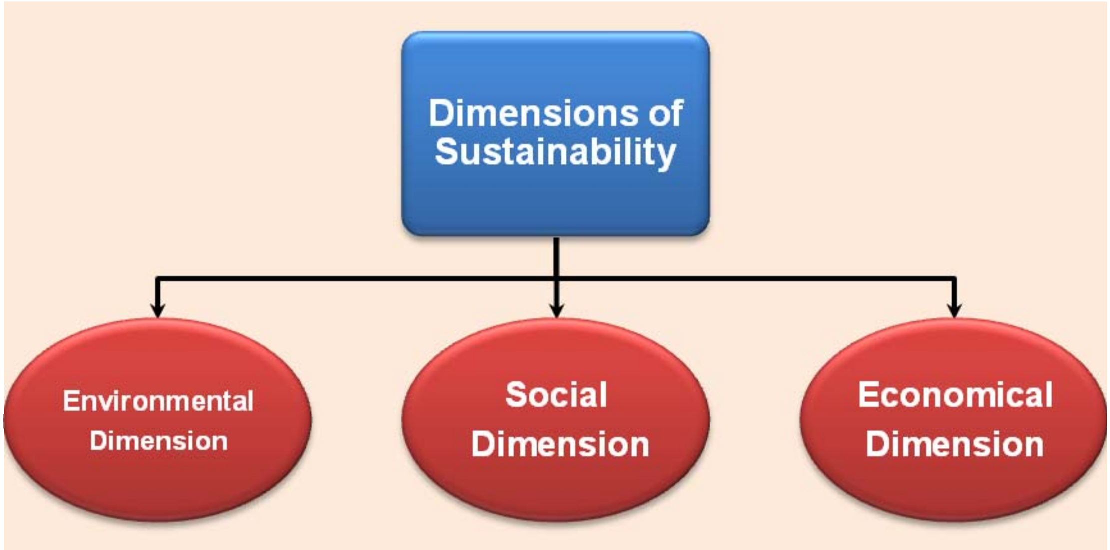

Figure 3. Dimensions of Sustainability

(1) Environmental Dimension of Sustainability: This dimension focuses on:

- Reducing waste, effluent generation, emissions to environment.
- Reducing impact on human health.
- Using renewable raw materials.
- Eliminating toxic substances.

(2) Social Dimension of Sustainability: This dimension focuses on:

- International and national law.
- Workers health and safety.
- Urban planning and transport.
- Local and individual lifestyles and ethical consumerism.
- The relationship between human rights and human development.
- Corporate power and environmental justice.
- Global poverty and citizen action.
- Impacts on local communities and quality of life.
- Benefits to disadvantaged groups (e.g. disabled and low earners).

(3) Economic Dimension of Sustainability: This dimension focuses on:

- Integrating ecological concerns with social and economic ones.
- Improving quality of life.
- Providing opportunities for local businesses.
- Increasing market share due to an improved public image.
- Creating new markets and opportunities for sales growth.
- Reducing cost through improving efficiency and reducing energy and raw material inputs.
- Creating additional added value.

The Principles of Sustainability

There are three principles of sustainability, (see Figure 4). Understanding these principles helps design and construction teams perceive their roles towards saving the environment, prospering the economy and enhancing society.

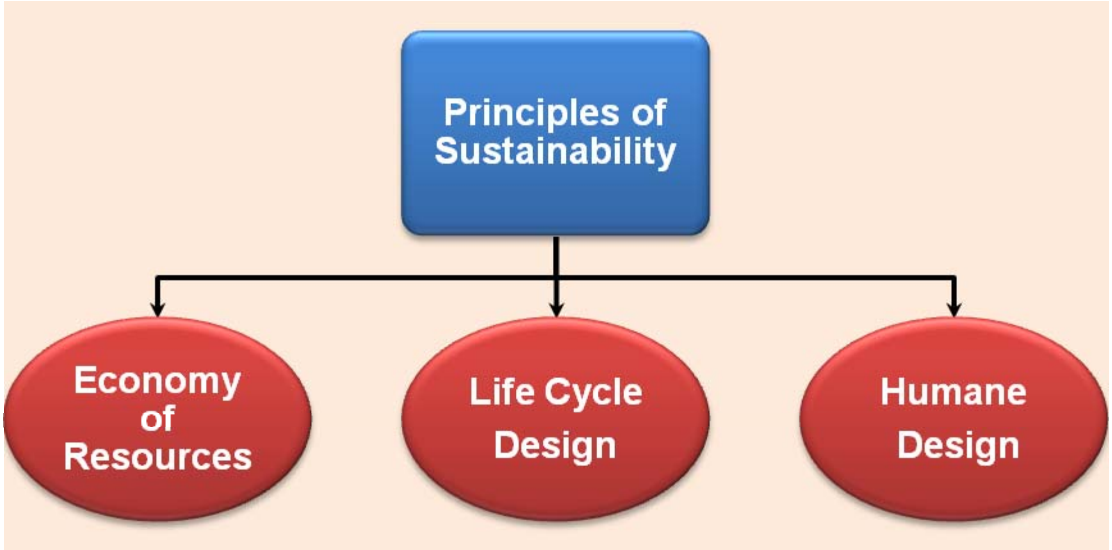

Figure 4. Principles of Sustainability

(1) Economy of Resources
This principle is concerned with the reduction, reuse, and recycling of natural resources that are input to a building. The strategies to achieve this principle are: energy conservation, water conservation and material conservation.

(2) Life Cycle Design
This principle analyses the building process and its impact on the environment throughout the project life cycle.

- Firstly, during the pre-building phase, the sustainable design strategy focuses on waste reduction, pollution prevention, recycled content, embodied energy reduction and use of natural materials.
- Secondly, during the building phase the sustainable design strategy focuses on energy efficiency, water treatment/conservation, use of non- or less-toxic materials, renewable energy systems and increasing building's life.
- Finally, at the post-building phase the sustainable design strategy focuses on reducing construction waste by recycling and reusing building materials.

(3) Humane Design
This principle focuses on the interactions between humans and the natural world. The strategies to accomplish this principle are: preservation of natural conditions, urban design and site planning as well as design for human comfort (Kim, 1998).

Competitive Advantage

Competitive advantage is an advantage over competitors gained by offering consumers greater value, either by means of lower prices or by providing greater benefits and service that justifies higher prices (Porter, 1985). It is a status in which one company is able to receive profits above that of the industry average, or even another firm. Many competitive advantage types are unsustainable, as competitors will eventually attempt to replicate what the first company has succeeded in doing. However, a sustainable competitive advantage is possible when other companies cannot duplicate what the one holding the advantage has been able to do.

Environmental Analysis

There are 5 steps, which enable managers to understand the environment and its impact on the organisation.

(1) Assess the nature of the environment

- ❖ Simple / static condition
    - Raw materials producers are example of this environment
    - Technical processes are fairly simple
    - Competition and market are fixed overtime
- ❖ Dynamic condition
    - The rate of change is fast
    - Managers identify the possible future changes and how it could affect their organisations and build alternative options to respond to these changes.
- ❖ Complex
    - The company faces a diversity of environmental influences.
    - Requires a significant amount of knowledge to handle them.

(2) Audit environmental influences on the organisation

The influences which affect the organisation come from the industry environment and the macro environment:

- ❖ The industry environment
    - Suppliers
    - Competitors
    - Customers
- ❖ The macro environment
    - Government
    - Technology
    - The national and international economy
    - Social structure
    - Demographic structure

(3) Structural analysis of the competitive environment

This analysis aims to analyse the factors that directly affects the competitive capability of the organisation. There are 5 forces that influence organisation competitiveness.

- ➢ New entrants
- ➢ Power of buyer
- ➢ Supplier power
- ➢ Substitute products and services
- ➢ Competitors

(4) Identify the organisation's strategic options

All organisations are in a competitive position in relation to each other. Therefore, it is very important to understand the nature of their relative positioning and its implications in strategic terms. There are three methods for analysing the organisation's competitive position

- ➢ **Competitor analysis**
    - What are the objectives of the competitors?

- What resources and strengths do they have?
- What is their record of performance?
- What is the current strategy of competitors?
- What are the assumptions underlying competitors' approach to their strategy development?

➢ **Strategic group analysis**

This analysis can build an understanding of the position of an organisation in relation to the strategies of other organisations. The aim is to define clearly the groups of organisations which follow similar strategic characteristics, similar strategies or competing on a similar basis.

➢ **Market segment**

Because of the different buyers power and interests, it is very important that every organisation breaks the market into segments and know precisely which segment it operates in.

(5) Identify the key opportunities and threat

- What are the key forces at work in the industry?
- Are there underlying forces?
- Is it likely that the key forces will change and if so what?
- How do particular competitors stand in relation to these competitive forces?
- What can be done to manage the competitive forces affecting the organisation?
- Are some market segments of the industry, or even other industry, more attractive?

Business Competitive Strategies

Michael Porter suggested four "generic" business strategies that could be adopted in order to gain competitive advantage. These strategies are: Differentiation, Cost Leadership, Differentiation Focus and Cost Focus. These strategies relate to the extent to which the scope of businesses' activities are narrow versus broad and the extent to which a business seeks to differentiate its products. The differentiation and cost leadership strategies seek competitive advantage in a broad range of market or industry segments. By contrast, the differentiation focus and cost focus strategies are adopted in a narrow market or industry.

(1) Differentiation

This strategy involves selecting one or more criteria used by buyers in a market - and then positioning the business uniquely to meet those criteria. This strategy is usually associated with charging a premium price for the product - often to reflect the higher production costs and extra value-added features provided for the consumer. Differentiation is about charging a premium price that more than covers the additional production costs, and about giving customers clear reasons to prefer the product over other, less differentiated products.

(2) Cost Leadership

With this strategy, the objective is to become the lowest-cost producer (with acceptable quality) in the industry. If the achieved selling price can at least equal (or near) the average for the market, then the lowest-cost producer will enjoy the best profits. This strategy is usually associated with large-scale businesses offering "standard" products with relatively little differentiation that are perfectly acceptable to the majority of customers. A low-cost leader will also discount its product to maximise sales, particularly if it has a significant cost advantage over the competition which can further increase its market share.

(3) Differentiation Focus

In this strategy, a business aims to differentiate within just one or a small number of target market segments. The special customer needs of the segment mean that there are opportunities to provide products that are clearly different from competitors who may be targeting a broader group of customers. The important issue for any business adopting this strategy is to ensure that customers really do have different needs and wants - in other words that there is a valid basis for differentiation - and that existing competitor products are not meeting those needs and wants.

(4) Cost Focus

Here a business seeks a lower-cost advantage in just one or a small number of market segments. The product will be basic - perhaps a similar product to the higher-priced and featured market leader, but acceptable to sufficient consumers. Such products are often called "me-too's".

The Relationship between Innovation, Sustainability and Competitive Advantage

Achieving competitive advantage in construction is a cornerstone for any company wishing to remain in market and compete for the future. This necessitates that companies search for new strategies, techniques and processes to keep them competitive. Because of the negative impact of the construction industry to the environment, it is essential that companies working in the construction field strive to deliver sustainable built environment through saving the environment, enhancing society and prospering the economy. These goals will energise competition between construction professionals and will be better accomplished by integrating innovation and sustainability as an approach for achieving competitiveness in construction. The relationship between innovation, sustainability and competitive advantage is cyclic as shown in Figure 5.

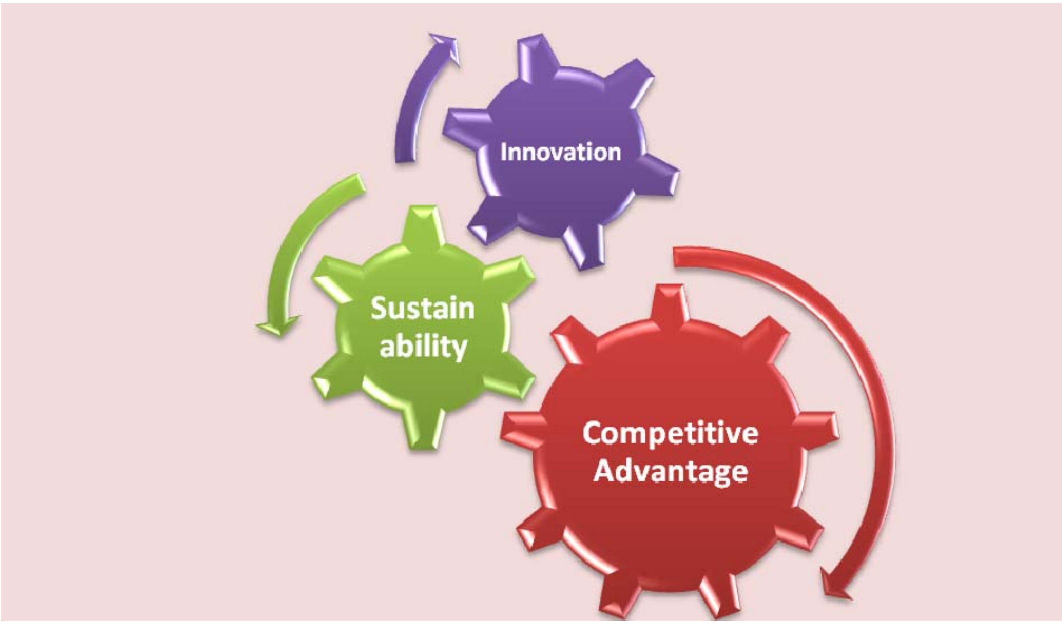

Figure 5. The relationship between sustainability, innovation and competitive advantage

The Role of Market Assessment in Pulling Innovation and Pushing Competitive Advantage

Market Assessment is used to enable organisations and institutions to do a market study on a product, process or technology they plan to develop. A better assessment of the market potential for a technology could be very useful for better positioning a technology. In addition, market assessment plays an important role in directing organisations either to adopt innovation as an approach for increasing their competitiveness or not. Firstly, when the market is static, no new entrants and the level of technology is simple, organisations tend not to utilise innovation and their competitive advantage remains fixed overtime. In dynamic markets which are characterized with fast rate of change, new entrants and fierce competitors, organisations have to innovation in order to remain in market and compete for the future. Finally, in complex markets that have a number of diverse influences (i.e. political, economic, environmental...) and knowledge represents a cornerstone to make prudent decisions, organisations not only have to pull innovation to keep them competitive, they have to sustain their competitive advantage and push it forward throughout the time via continues research and development to improve and maintain their competitiveness as well as protect their new technology and advancement from being imitated.

Case Studies and Examples of Competitive Advantages in Construction and other industries

The following are some case studies and examples of innovative ideas that helped companies in construction and other industries to competitive.

(1) The Portakabin Group

The Portakabin Group is part of one of the leading private family owned businesses in the UK. It is involved in the hire and sale of interim and permanent accommodation.

Portakabin has achieved competitive advantage through innovative product development. 30% of its sales revenue is generated by products that have been launched or re-launched in the last three years. Portakabin Limited, an important Group member, specialises in producing modular buildings, operating 45 hire centres across the UK, employing over 1,300 people and increasingly developing European operations. Buildings are manufactured and fitted out in a factory environment, while foundations are prepared on-site. The customer's modules are taken to the site, craned into position and linked together, see Figure 6. Architectural features such as lifts, stair towers or cladding are added on-site.

Figure 6. Craned Modules

In terms of market positioning, Portakabin is located at the top end of the market with quality products and premium pricing reflecting high value for money. Portakabin operates in an extremely competitive market with 20 major international competitors in addition to local rivals. Portakabin is the market leader with 15.4% of the overall UK market. In Europe, Portakabin has 3% of the market and competes with the world's biggest provider GE Capital, as well as major continental companies such as the French company Algeco - the European market leader. The UK market is mature, so growth is challenging to achieve. However, Portakabin must protect and build its UK market leadership and this need, coupled with a concern for customers, drives its current exciting new product and service development strategy. Portakabin's commitment to its customers is summed up in its charter, which includes:

- answering calls within four rings
- a response to enquiries within 24 hours
- the building to be provided to the agreed contract sum
- giving a rectification response within 48 hours
- including customers in a customer care programme.

In addition, if their building is not delivered on time Hire customers will receive a week's free hire for every day the building is late, up to a maximum of four weeks, whereas Sales customers will receive an additional six months warranty on their buildings (The Times 100, 2009).

At the three different aspects of sustainability, Portakabin utilized innovation capabilities to be competitive.

- Firstly, at the economic aspect, Portakabin delivers projects on time and within budget, reduces project duration by 50% though using modular building methods and increases product quality through close quality control of the entire construction process.

- Secondly, at the environmental aspect, the company achieved better building performance through manufacturing buildings to very tight tolerances, using cutting edge software to ensure that every building produced has carbon emission rates which will either meet or exceed the requirements of Building Regulations. Exceeding Building Regulations relating to air permeability requirements by 70% which resulting in exceptional energy efficiency performance for reduced energy consumption. Furthermore, the company increased its competitiveness through using Ozone friendly materials, recycling materials and reducing noise and pollution as well as waste.

- Finally, at the Social aspect, through factory-based construction Portakabin offers an intrinsically safer working environment than a traditional construction site (Portakabin, 2009).

(2) Cemex

As one of the top building materials companies in the world, Cemex works to provide high quality and reliable service to customers and communities around the world. It advances the well-being of those it serves through continuous effort to pursue innovative industry solutions and efficiency advancements and to promote a sustainable future. The company continuously works to increase its competitiveness through innovation and sustainability. To achieve long-term sustainable growth, Cemex improves its operational excellence and efficiency, follows high ethical standards, and offers innovative products and services for a sustainable, energy-efficient construction industry. The company is committed to ensuring good corporate governance, providing a safe, healthy, and fair workplace for its employees, seeking ways to reduce the environmental impact of its operations and products, and bringing about positive change in our society, see Figure 7.

Figure 7. Smart idea to advertise a fast drying concrete in Germany (Notcot, 2009)

(3) Dell Computers Corp.

Dell was founded in 1984 by Michael Dell. Dell has a broad product development scope, ranging from home PCs to products for businesses such as notebooks, network servers and workstations. The market for PCs targeted for all ages such as kids, teenagers, corporate and institutional customers. The company was based on a simple concept that Dell could best understand customers' needs and efficiently provide the most effective computing solutions. The key components of its strategies are quick-moving, direct distribution channels and build to order, customization concept. As far as this particular strategy plan is concerned, Dell will develop and provide various choices for different customers to cater their needs and satisfactions, the strategies of Dell computer corporation. Dell has a number of distinctive competences. Dell was the first PC manufacturer to cut out the middleman and sell PCs direct. The strategy of Dell is using direct sales as the channel of distribution. Dell achieves its competitve advantage through its ability to bring to the market the computer system that is desired by the customer at the most competitive price. Its superior design attracted many consumers and also other competitive rivals like IBM, Compaq and Hewlett Packard. As a result, Dell reduces customers' prices by avoiding expenditures associated with the retail channel, such as higher inventory carrying costs, obsolescence associated with technology products, and retail mark-ups. Dell believes the most efficient path to the customer is through a direct relationship. However, the company is probably as well known for its innovative business model as it is for its products. Direct customer relationships provide a constant flow of information about customers' plans and requirements and enable Dell to continually refine its product offerings. More importantly, Dell is the low price leader in the PC market, Dell can consistently under price rivals by reducing its value chain and also support programs tailored to customer needs such as customization, service and support, and latest technology. Further, Dell's flexible, build-to-order manufacturing process enables them to achieve faster inventory turnover and reduced inventory levels.

Dell Computer Corp. was able to use the Internet to trim costs and boost sales, both of which were becoming increasingly difficult to do in the nearly saturated personal computer (PC) market of the late 1990s. The firm started to sell PCs via the Internet in 1996. It became possible for customers who previously had placed custom orders via the telephone to place them on Dell's Web site. Customers could select configuration options, get price quotes, and order both single and multiple systems, (see Figure 8). The site also allowed purchasers to view their order status, and it offered support services to Dell owners, (see Figure 9). Within a year, Dell was selling roughly $1 million
worth of computers a day via the Internet. Even more importantly, nearly 80 percent of the online clients were new to Dell. With the more automated Web-based PC purchasing process, Dell found itself able to handle the growing sales volume without having to drastically increase staff. Cost savings also were achieved as the firm's phone bill began shrinking. Dell's business model, which allowed for easy tracking of customer purchases, also allowed the firm to keep inventory at a minimum. In 2001, Dell usurped Compaq Computer Corp. as the world's largest PC maker.

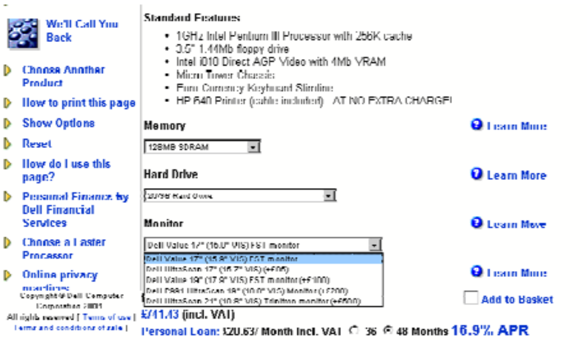

Figure 8. Placing & Configuring orders via Dell Website (Managing Change, 2009)

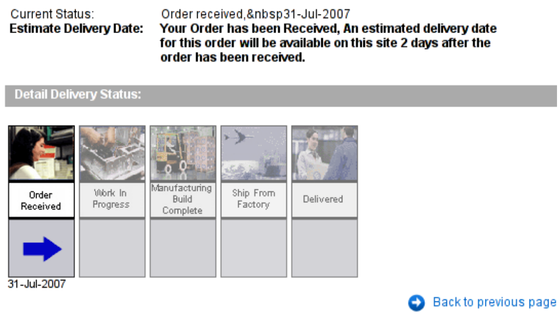

Figure 9. Following up Orders Status via Dell Website (Planet Free Software, 2009)

Utilising technology helped Dell to develop a sustainable solution that increased its competitive advantage such as:

- No inventory of completed computers and with just-in-time supply lines, it has little inventory of components (e.g. hard drives).
- Quickly capitalise on components from lower cost suppliers.
- Quickly capitalise on new PC developments such as DVD drives.
- Negative cash conversion cycle such as keeping inventory for 5 days, manage receivables to 30 days and push payables to 59 days (Free Encyclopaedia of Ecommerce, 2009; Mega, 2009).

(4) Nike

Founder and CEO of Nike said “Business is war without bullets”. Nike Inc. was incorporated in 1968 under the laws of the state of Oregon, USA. The general business activities can be described as design, development, and global marketing of high quality footwear, equipment and accessory products. Nike is the largest seller of athletic footwear and athletic apparel in the world. The Nike swoosh is one of the most recognizable business logos on earth. It is more than a symbol of great brand marketing. Nike has revolutionized the way companies approach the athletics market. The company digs into any niche related to sports, including technological breakthroughs, retailing, sports management and sports promotion. Nike deals in a very consumer orientated market. This means that the demand for the Nike's goods heavily depends on the popularity of the various fitness activities. The company continuously adjusts their product mix in order to meet demands. It manages its business carefully, leading in aggressive marketing styles and innovative products. In its products, Nike is committed to provide quality and innovative services and products internally and externally. It utilizes innovation and technology capabilities to be competitive in market through producing sustainable products that are lighter, more durable, and more functional. Furthermore, the company identifies focused consumer segment opportunities and establishes and takes care of relevant emotional ties with these consumer segments.

Nike focused on the male consumer and was dedicated to serious athletes. Nike's shoes were firmly fixed as performance shoes with new design and technology. It has a healthy dislike of its competitors. At the Atlanta Olympics, Reebok went to the expense of sponsoring the games. Nike did not. However Nike sponsored the top athletes and gained valuable coverage. Nike's ability to find great athletes who represented something that exceeded sports and who were able to reach people on many levels would play itself out over and over again in Nike's future and prove to be one of Nike's biggest competitive advantages. Towards sustainable economy and generating job opportunities, Nike has no factories. It does not tie up cash in buildings and manufacturing workers. This makes a very lean organization. Furthermore, Nike is strong at research and development, as is evidenced by its evolving and innovative product range. They then manufacture wherever they can produce high quality product at the lowest possible price. If prices rise, and products can be made more cheaply elsewhere (to the same or better specification), Nike will move production (Marketing Teacher, 2009; Mega, 2009).

(5) Vodafone

Vodafone is a leading international mobile communications company with interests in 27 countries and partnership agreements with a further 40 countries. It has over 71,000 employees throughout the world and in 2008 had more than 289 million customers. In the UK, more than 19 million people use Vodafone services. Vodafone's **vision** is 'to be the world's mobile communications leader' and a key component of this is to ensure that customers trust and admire the company. It achieves this by taking a responsible approach to the way it conducts its business. This enhances its reputation and builds customer loyalty. Vodafone's business strategy and its corporate responsibility strategy are interlinked. Vodafone believes that long-term commercial rewards come from doing business in a sustainable way.

Vodafone's approach to business is two-fold:

- Providing product extension - new features, dimensions and services in saturated markets. These are areas like the UK, USA and Europe which have sophisticated users who want and expect new functions from their mobiles. Developing new ways of delivering products and services helps to keep existing customers and attract new ones. For example, 3G technology has improved the ability and quality of transferring voice and data. Very fast internet speeds allow extended services such as video calling, music downloads, mobile television and email messaging.
- Looking for opportunities in emerging markets. These include some of the world's more remote areas, including parts of Africa, where many people do not yet have access to a mobile phone. The less developed infrastructure in these areas makes traditional landline telecommunications difficult. Vodafone is committed to providing these markets with the technology to develop communication that will help both economically and socially. There are now more than four billion mobile phones across the world and 64% of all users live in a developing country.

Vodafone uses technological capabilities of the mobile phone to bring values to the social and economic development of both developing and developed countries. The impact of mobile technology on developed markets over recent years has been immense and has focused on providing added value to customers through new and improved functions and features. By comparison, the impact of technology on emerging markets such as Kenya has provided a real lifeline both to individuals and to small businesses. The mobile phone has helped economic development in emerging economies. With growth in the provision of mobile phones, Vodafone has enabled great improvements in facilitating the flow of money and information, which is vital for economic growth. By improving Kenya's telecommunications infrastructure and by providing the M-PESA system, Vodafone has enabled more people to access and transfer money. This has also helped socially by helping people to take advantage of employment opportunities away from their hometowns and villages (The Times 100, 2009).

Research Methodology

The above mentioned aim and objectives called for a research strategy that could gather data sufficiently rich to investigate the integration of innovation and sustainability principles towards achieving competitive advantage in construction. The research methodology designed consisted of three interrelated activities, namely data collection, data analysis and action required (see Figure 10). During the data collection activity different sources are used to accomplish the first and second objectives. This included textbooks, academic journals, conference proceedings, dissertations and thesis, government publications and related websites. In addition, creative case studies and examples that utilised innovation and sustainability to achieve competitive advantage are presented. During the data analysis activity, quantitative and qualitative techniques are used to analyse the collected data. As an action for improving the competitive advantage of the construction industry, an innovative theoretical framework is developed and the strategies that support its application are outlined. The validity and reliability is of importance to this research. The study depended on facts rather than subjective information which increased the reliability and validity of collected data and research findings.

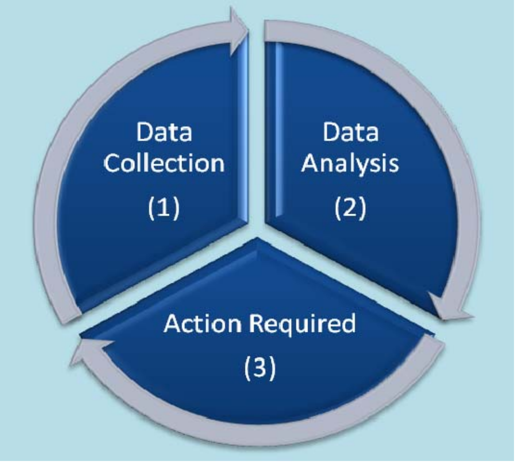

Figure 10. The Research Methodology

An Innovative Theoretical Framework for Achieving Competitive Advantage in Construction

Definition and Justification of Developing the Framework

Framework is defined as a structure for describing a set of concepts, methods and technologies required to complete a product process and design (EDMS, 2007). The Competitive Advantage Framework (CAF) (hereinafter referred to as "the Framework" or the "CAF") is a proposed framework developed by this research to facilitate the achievement of competitive advantage in construction through using innovation as an approach for delivering sustainable built environment. The justification of developing the framework is three fold:

- Reducing the negative impact of the construction industry on the built environment through utilizing technological capabilities to produce advanced durable, environmentally friendly, non-toxic, easy to maintain, efficient, recyclable and cost-effective materials and equipment. In addition, the framework is essential for eliminating waste, reducing energy consumption and generating alternative energy resources.
- Enhancing the performance of the organizations operating in the construction industry by escalating their competitiveness and achieving the satisfaction of the industry stakeholders.

- Supporting the government initiatives towards achieving their strategies and plans for social and economic development.

The Aim and Objectives of the Competitive Advantage Framework

The Competitive Advantage Framework is a business improvement tool designed to integrate the concept of innovation and sustainability as an approach for achieving competitive advantage in construction. This aim could be achieved through accomplishing a set of interrelated objectives as follows:

- Identifying the root causes that hinder integrating innovation and sustainability as an approach for achieving competitive advantage in construction.
- Establishing improvement objectives.
- Generating, evaluating and selecting the best alternative that will achieve these objectives at the most cost-effective manner.
- Implementing the selected alternative, monitoring its execution and feeding back concerned parties with comments and lessons learned.

Description of the Competitive Advantage Framework

The framework consists of four steps, namely: problem identification, objectives establishment, alternatives examination and implementation and feedback. Towards putting the framework in a practical way, every step was explained in detail through showing the input, tools and techniques needed to achieve the intended output (see Figures 11 & 12).

Problem Identification

The "Problem Identification" function is a fundamental activity of this framework as it enables construction professionals to identify the root causes that obstruct the integration of innovation and sustainability towards achieving competitive advantage in the construction industry. It is of prime importance to build an effective team (including a competent team leader) that will carry out the improvement study. A balance between the need for participants who represent various areas of expertise and interest has to be achieved. The diverse background knowledge of team members plays a vital role in helping the team members to understand and accomplish the study objectives. The study team should contain between six and twelve full time participants to maintain optimum productivity (Norton and McElligott, 1995). Conducting an early orientation meeting will help in establishing strategic issues like study duration, resources required and assigning responsibilities to team members. Senior management support will facilitate the provision of needed resources and the adoption of study decision. Data collection methods (i.e. literature review, survey questionnaire and interviews) and data analysis techniques (i.e. quantitative and qualitative) have to be defined and utilised. Brainstorming techniques, team consensus and evaluation matrix have to be used for identifying the root causes and rank them according to their importance (see Figure 13).

Objectives Establishment

To enable construction professionals to adopt the appropriate decision, the objective of improving the performance of the construction industry through achieving competitive advantage has to be adequately defined. This could be achieved through utilising innovation capabilities towards delivering sustainable built environment. Brainstorming technique and team consensus will be used to generate and select objectives that address the identified problem. An evaluation matrix will be used to rank these objectives according to their significance. In addition, this function will result also in defining the criteria to be used to measure the improvement of the construction organisations through achieving competitive advantage, (see Figure 14).

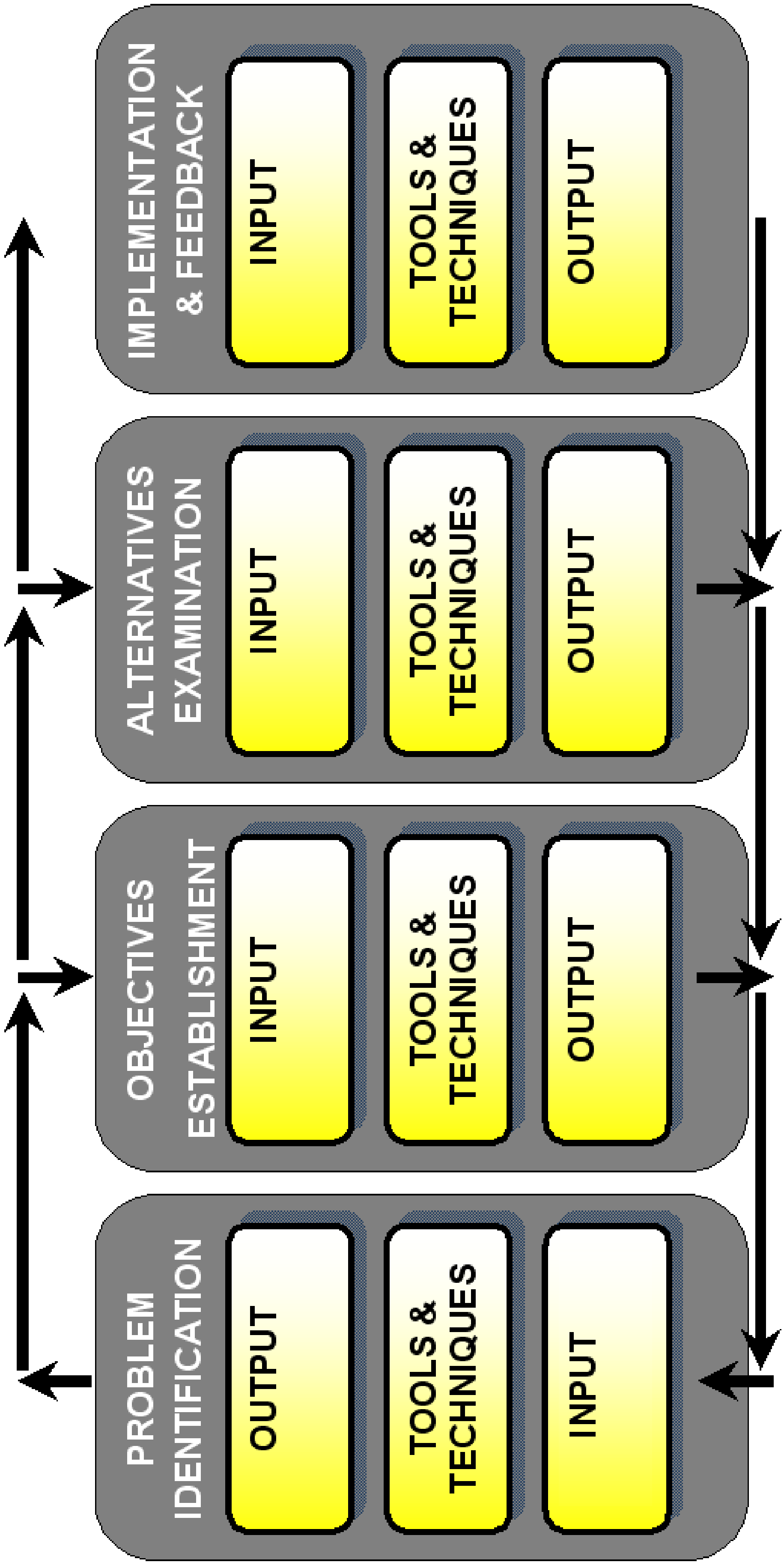

Figure 11. The Competitive Advantage Framework

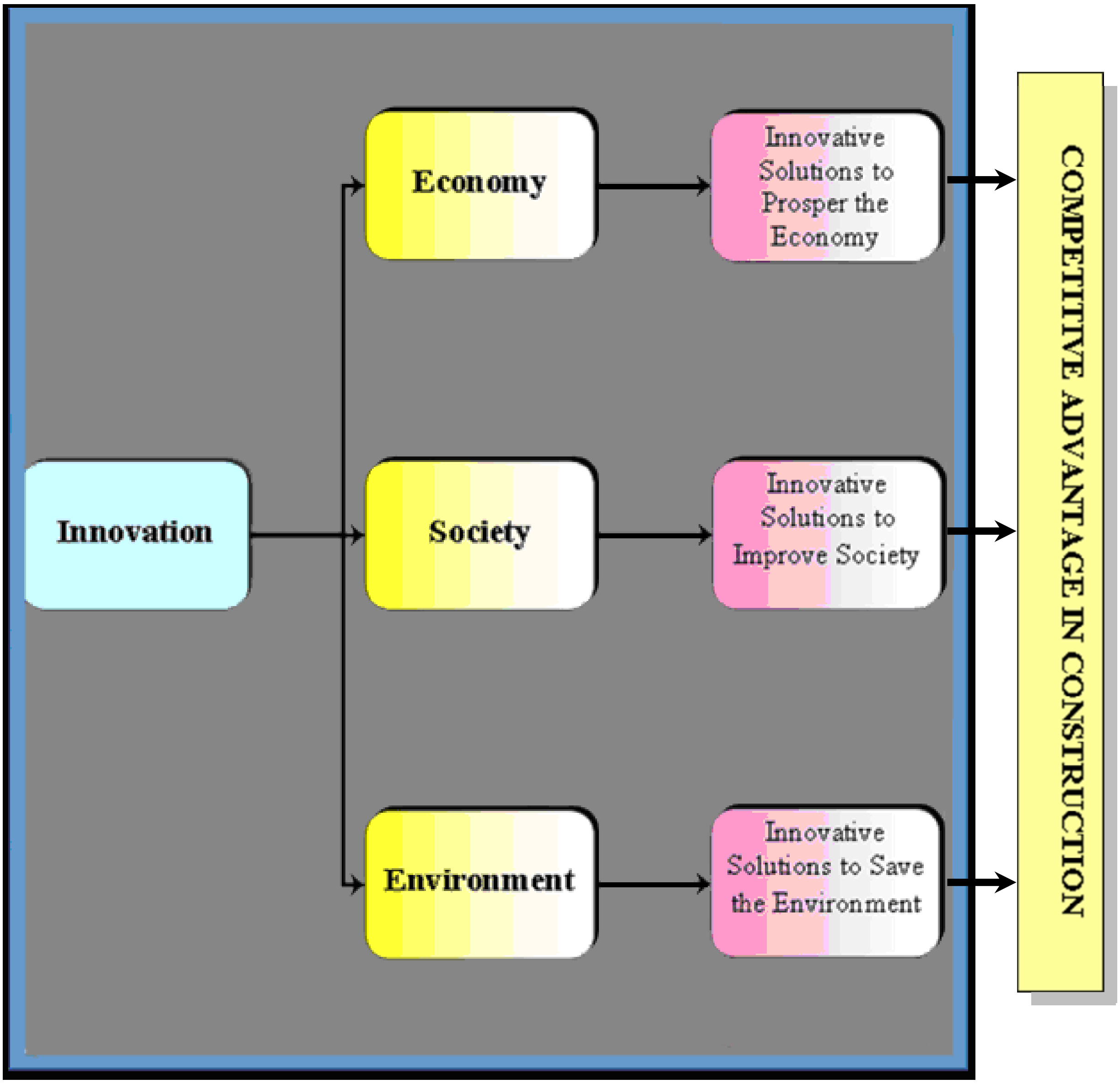

Figure 12. Integrating Innovation and Sustainability towards Achieving Competitive Advantage in Construction

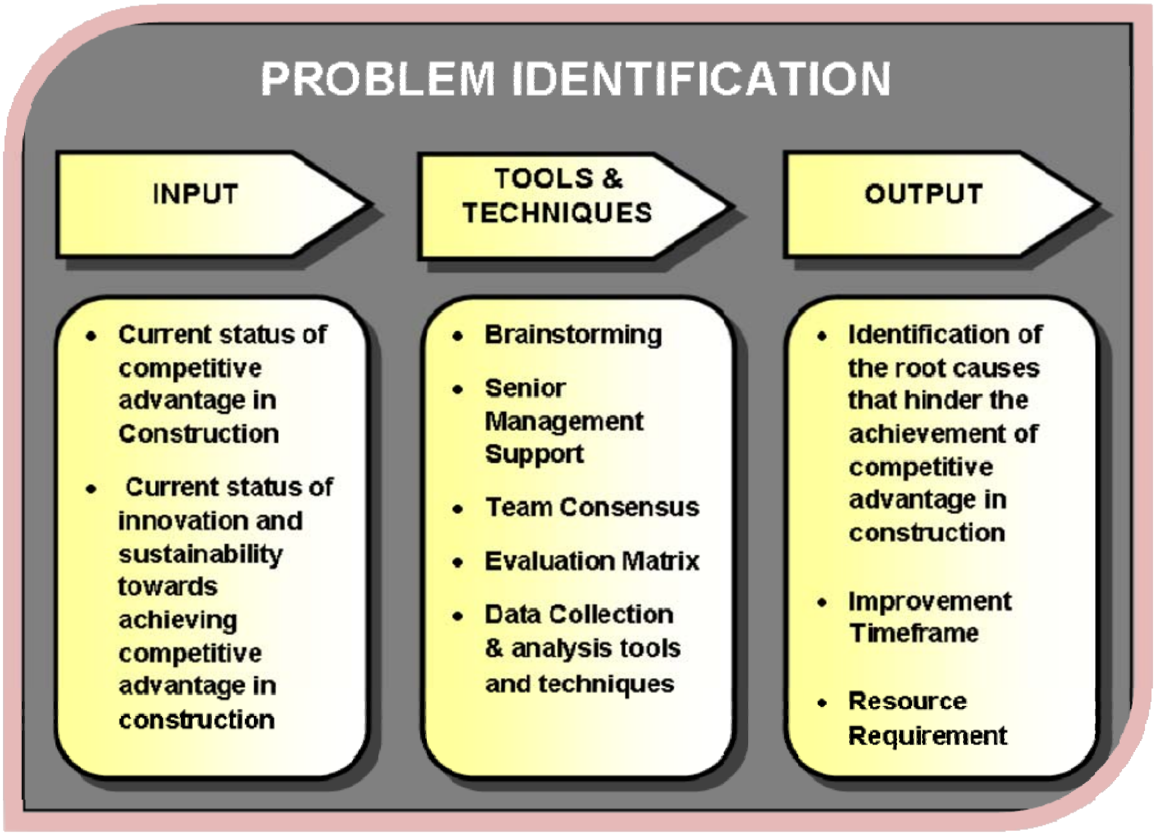

Figure 13. Problem Identification

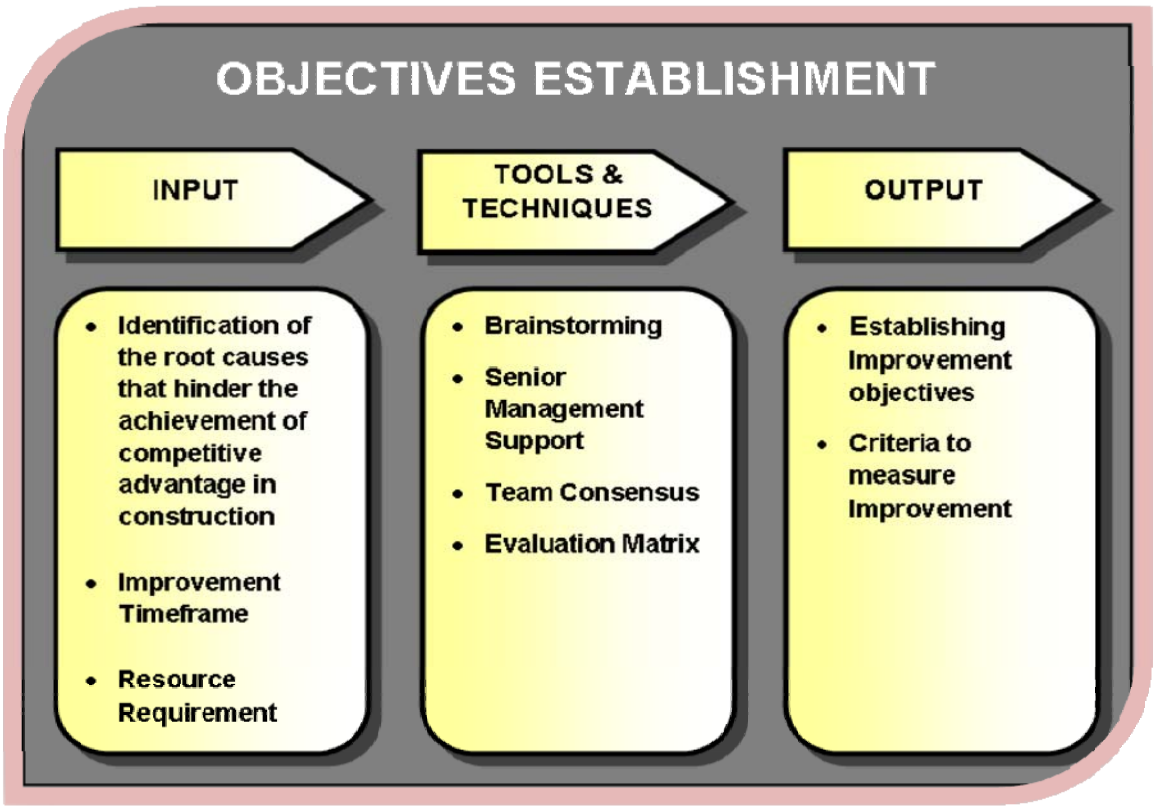

Figure 14. Objectives Establishment

Alternatives Examination

After the improvement objectives have been defined and ranked according to their importance, this function aims to generate and evaluate alternatives to better achieve these objectives. Brainstorming techniques will be used to generate and record a large number of ideas without evaluation. The rules for brainstorming are as follows:

(1) The problem under study should be described to the team in advance.

(2) A positive environment should be established by the team leader prior to embarking on idea generation.

(3) The group should be relatively small and should consist of members from diverse backgrounds.

(4) Illogical ideas and freewheeling are encouraged.

(5) Quantity and not quality ideas are encouraged.

(6) Judgement of ideas is prohibited.

(7) The combination and improvement of ideas is encouraged (Norton and McElligott, 1995).

In addition, during this function the desire for the judgement of ideas, which was suppressed earlier during alternatives generations, is released. The evaluation matrix will be used to evaluate generated alternatives through allocating importance weights to these alternatives, so that only the best ideas will be selected for development. The support of senior management will facilitate the adoption and implementation of the selected decision, (see Figure 15).

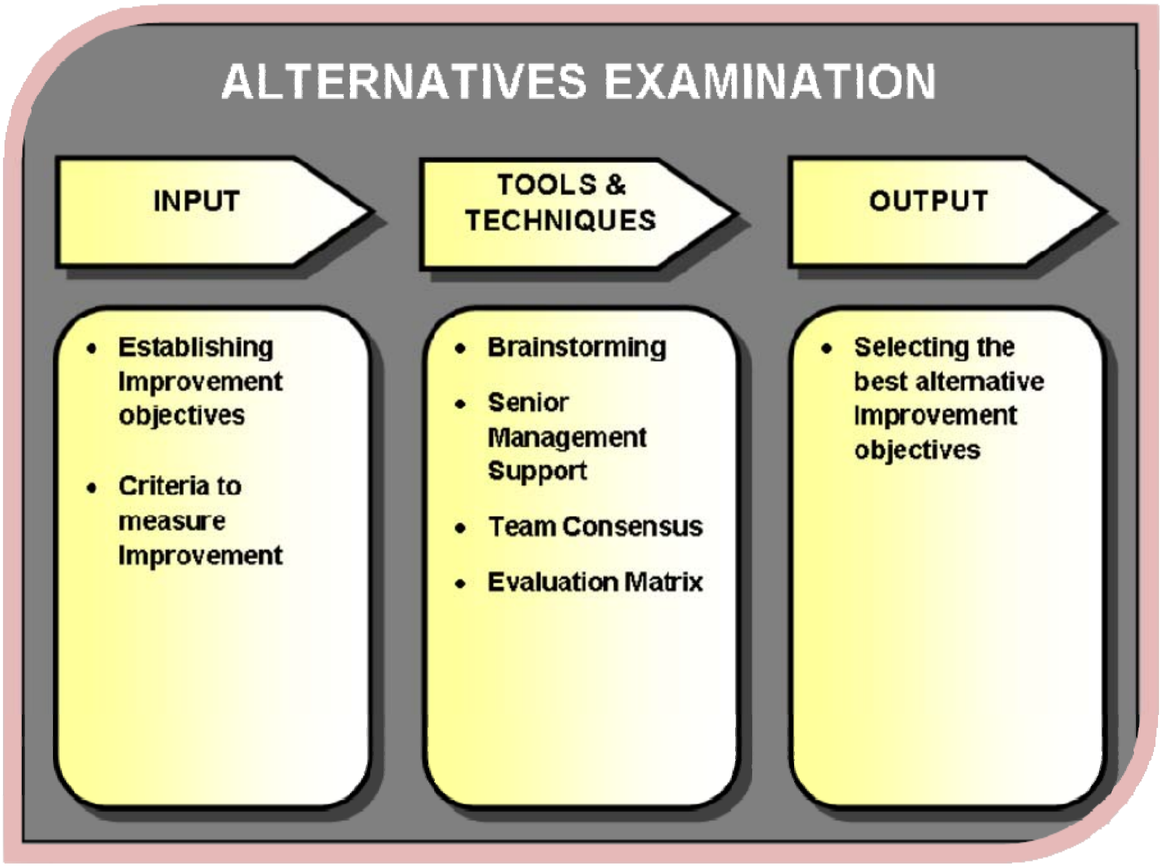

Figure 15. Alternatives Examination

Implementation and Feedback

Within this function, the best alternative selected in the previous function will be implemented. This necessitates developing implementation plans that enable the integration of innovation and sustainability towards achieving competitive advantage in construction. The implementation plans may require that employees involved in the integration process be trained and equipped with all technologies and techniques required to guarantee the successful implementation of the selected alternative. Comments and feedback from the implementation team will enable taking corrective actions if plans were not implemented as planned. Furthermore, this will help in improving the performance of the construction industry in future improvement project, (see Figure 16).

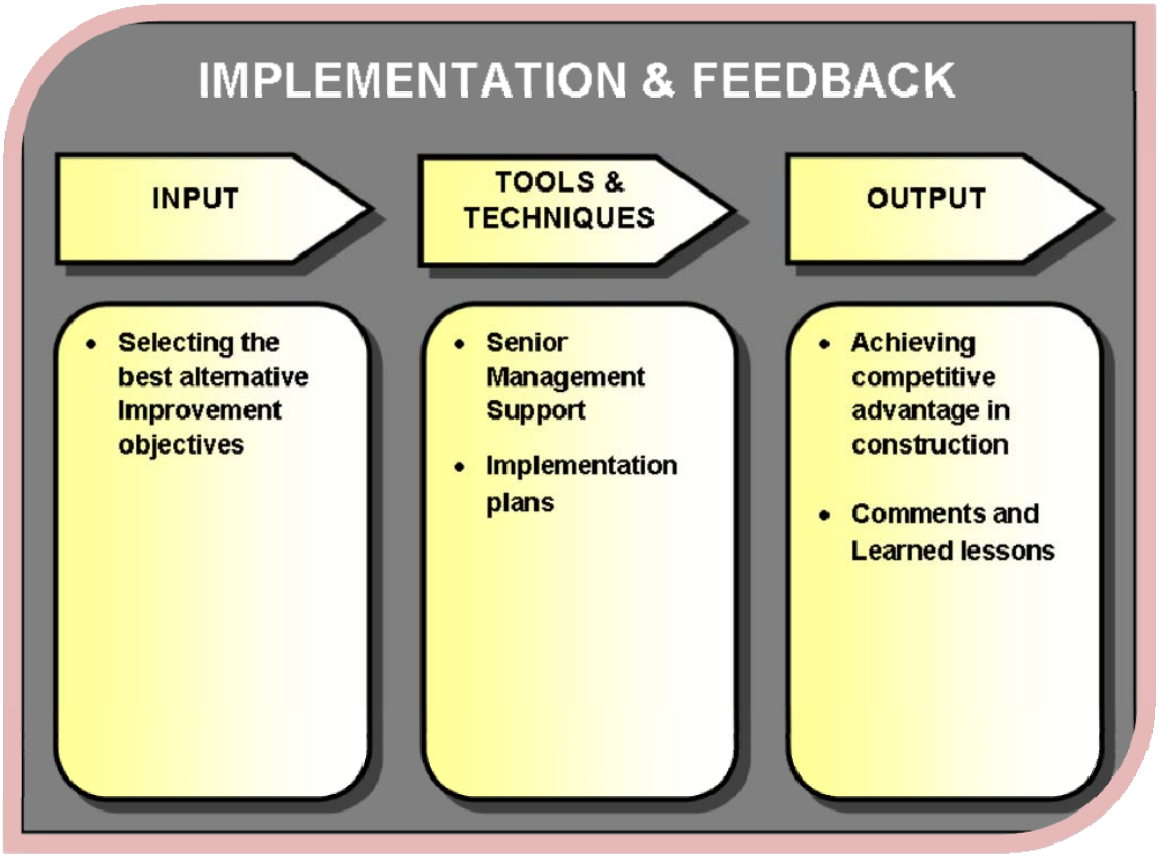

Figure 16. Implementation and Feedback

Limitations of the Competitive Advantage Framework

Although the framework is theoretical and looks generic, it establishes the steps and set the rules that construction organizations have to follow in order to utilize the capabilities of innovation and technological advancement towards delivering sustainable built environment. In addition, the effective application of the CAF depends to a large extent on the willingness and encouragement of the senior management in construction organizations to adopt the framework to increase their competitiveness. On the other hand, if the senior management does not have the desire and tended not to use the framework, then its adoption will be limited. Since the adoption and application of the framework is a long-term strategy and due the tight time schedule in construction projects, this framework might not be welcomed by some sectors of the industry.

In order to overcome these limitations and increase the opportunities of adopting the framework, the benefits of the framework should be presented and explained to senior management of construction organizations in order to convince them with the role, which the framework could play in sustaining their competitiveness. Due to the limited timeframe and resources, it was not possible to apply and evaluate the framework, hence the CAF needs to tested and validated in a real business environment.

Results

- In spite of the positive role that the construction industry plays towards social and economic development, it has a negative impact to the environment in terms of consuming non-renewable resources and energy, generating waste and pollution as well as land dereliction.

- The universal call for sustainability has increased the competition between construction professionals and organisations working in the construction sector towards delivering products that save the environment, enhance society and prosper the economy.

- Case studies and examples of innovative and competitive companies in construction and other industries are essential for educating construction professionals and showing them successful stories and the practicality and possibility of integrating innovation and sustainability to achieve competitive advantage in construction.

- Maintaining competitive advantage in an ever expanding industry, like construction, and making it sustainable through continuous improvement, research, development and market research is a cornerstone for remaining in market and competing for the future.

- The developed framework is generic, theoretical and time consuming. Hence, its benefits have to be presented to senior management in construction companies in order to provide resources and allow the time needed to test, validate and then adopt the developed framework.

Conclusions

In spite of the vital contribution that the construction industry makes towards social and economic development as well as achieves national and international development programmes, it has a negative impact on the environment. The scarcity of non-renewable resources, energy consumption, pollution and waste necessitated that construction professionals strive to produce projects that save the environment, enhance society and prosper the economy. This increased the competition between organisations working in the construction sector and forced them in the direction of finding innovative ideas, new technologies and creative approaches that generate sustainable solutions. Achieving competitive advantage is a key factor for any company wishing to successfully remain in market and compete for the future. The research work presented in this chapter adds value to the original body of knowledge through establishing the link between innovation, sustainability and competitive advantage and developing a theoretical yet innovative framework that puts the integration between innovation and sustainability in a practical way to achieve competitive advantage in construction.

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3

Integrating Affordable Housing and Sustainable Housing: Bridging Two Merit Goods in Australia

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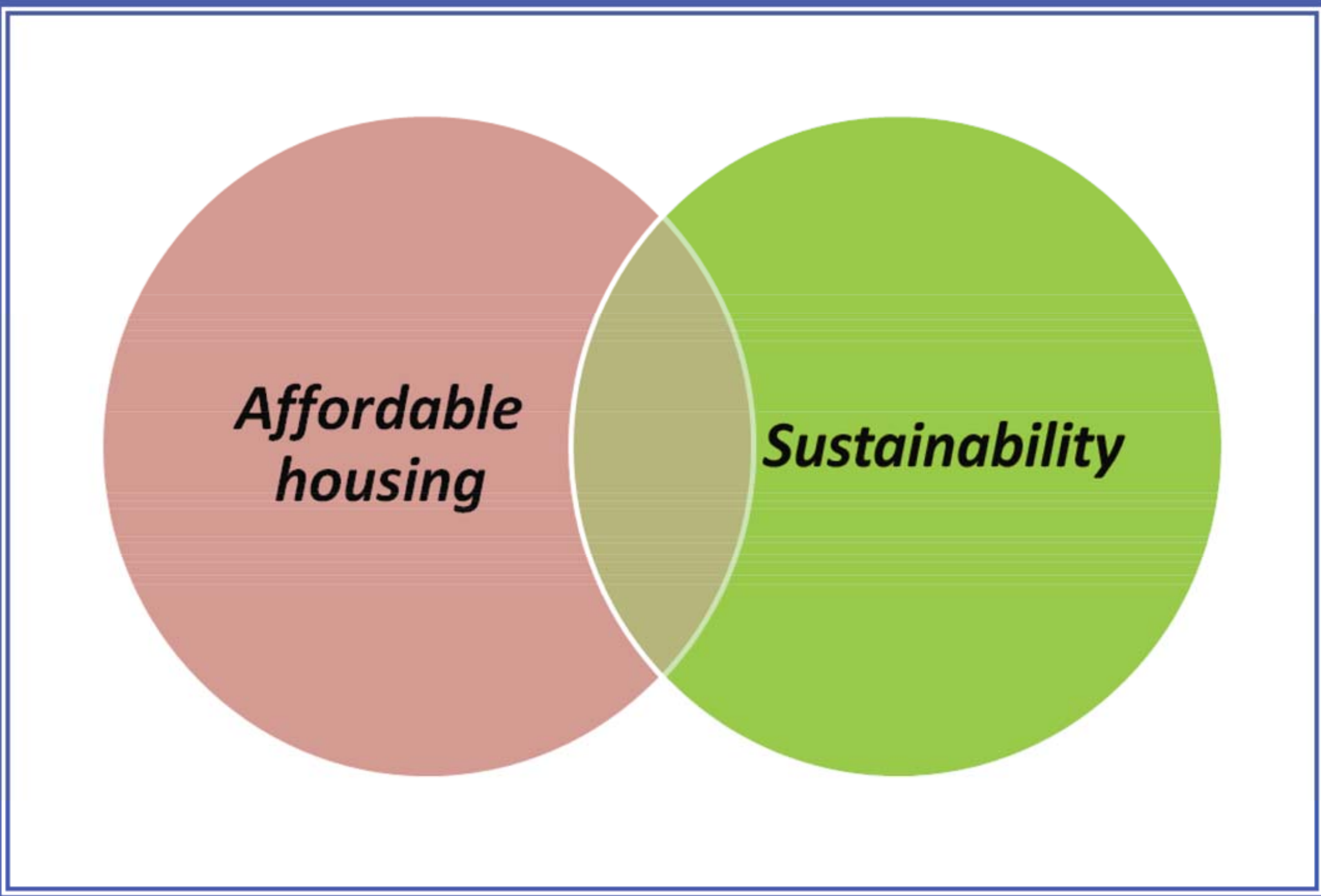

Integrating affordable housing and sustainable housing: bridging two merit goods in Australia

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Abstract

Interest among planning and policy makers in environmentally sustainable housing has risen in recent years as a response to the global goal of attaining sustainable development. In Australia, there has long been concern that the market might under-provide affordable housing and, more recently, concerns have been raised over the capacity of the market to provide sustainable housing. Governments in Australia have intervened through subsidies, tax incentives and more direct forms of support for the provision of affordable and sustainable housing. Providing environmentally sustainable housing is thus perceived to be a "merit good" in Australia. That is, a good that has social merit but one that is underprovided by markets. Contemporary housing policy debate in Australia has emphasised the need to respond to a growing housing affordability challenge. Affordable housing might also be seen to be a merit good in Australia. Nevertheless there has been a reluctance to consider housing sustainability in the same context as housing affordability.

This chapter addresses the debate over affordable and sustainable housing in Australia by drawing on learnings from the Ecocents Living research project to suggest a conceptual basis to understand the issues at hand. Ecocents Living is a project that seeks to integrate the concepts of affordable and sustainable housing into a model to guide industrial implementation of sustainable and affordable housing. It is argued that the concepts of sustainable housing and affordable housing have synergies that warrant consideration and the further development of an embryonic model for integrating sustainable and affordable housing is offered in this chapter.

Keywords: sustainable housing, affordable housing, Australia

Introduction

Housing affordability is a relatively recent policy concern for Australia. Since the Second World War, Australians have enjoyed high rates of home ownership and relatively low housing costs, facilitated by cheap and plentiful land for urban development (Beer et al. 2007).

However, there has been a sustained decline in housing affordability in Australia in recent decades. Real house prices (i.e. inflation adjusted) in Australia have averaged an annual increase of 2.7% between 1960 and 2006, while over the same time period, real household incomes have risen a modest 1.9% per annum (Beer et al. 2007).

The Australian Government (2008) estimated that in 2007, more than one in five rental households were experiencing housing stress. In commenting on the impact of the global financial crisis and the recessionary impacts on Australia, Braddik et al. (2009) noted that while dropping interest rates may improve housing affordability, a larger problem remains in maintaining affordability in the light of a nationwide undersupply of housing. The shortfall between housing supply and demand appears to be widening, with a recent study estimating that Australia will have a shortage of 250,000 dwellings by the middle of 2010 (ibid).

Interest in environmentally sustainable housing has risen dramatically in recent years as one response to the global goal of attaining sustainable development. This trend in policy, regulation and practice, rests on an assumption that reducing the environmental impact of housing will have long-term social benefits. Sustainable housing discourse and practice is focused on the application of principles in the design of homes and the methods and materials used in construction (Randolph et al. 2008).

Affordable and sustainable housing thus has a difficult mandate. Such housing should attain best practice in increasing sustainability by demonstrating features exemplified in the relatively small number of iconic green housing developments whilst seeking to provide homes that are affordable. The Australian experience of increasing affordability is that such housing tends to be poorly located on cheap land and built to minimise construction costs, resulting in lower environmental performance and questionable social acceptability (Arman et al. 2009).

Methodology

The objectives of this research were addressed by summarising theoretical expositions of the concepts of sustainability and sustainable housing. This was undertaken in relation to a discussion of how sustainable housing is typically delivered, through a review of the role of regulation. Learnings from the *Ecocents Living* project are offered to suggest a model that, with further development, might integrate affordable housing and sustainable housing. The model is summarised in conclusion.

Background

Sustainability

Sustainable development is a policy goal linked to the 1987 World Commission on the Environment and Development report *Our Common Future,* which incorporates the most commonly cited definition of sustainable development:

> *Development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (WCED 1987 p.43).

The World Development Report 2003 notes that this definition does not clarify the notion of needs nor address the associated implications. Moreover it asks:

> …does the Brundtland definition imply that well-being (utility) should not fall below some minimum for any subsequent generation? Does it imply that each generation should enjoy a constant level of well-being? Alternatively, should well-being be nondeclining for each future generation?' (World Bank 2003 p.14)

This lack of clearly articulated definition of sustainability creates problems for its operationalisation. Further, the lack of clarity potentially facilitates interpretations of sustainability by different interest groups to meet predetermined goals (Kates et al. 2005). Thus, by suggesting that it is possible to simultaneously meet economic, social and environmental goals, the tensions that otherwise exist are not debated. Thus, as Davidson (2005a) argues, “we might not be able to provide the solutions which ensure a genuinely sustainable future”.

Ultimately, the decision about the particular ecological system selected is a societal one. In general, definitions of sustainability describe the concept in terms of maintaining conditions for future generations. The interpretation of ‘maintaining conditions’ varies, and can include potentially conflicting interpretations, such as maintaining productivity of economic systems and maintaining natural capital stocks. The interpretation of ‘maintaining conditions’ will depend on the prevailing ideology in a given society, and will generally emphasise maintaining one condition over another.

Maintaining the productivity of economic systems is emphasised in the Brundtland definition. It is often referred to as a definition of weak sustainability, derived from a neoliberal concern with maintaining economic growth. Clapp and Dauvergne (2005 p.60) also note that the Brundtland Report offers a strategy ‘palatable to all’, though they acknowledge that it does suggest redistribution between the rich and poor, a proposition that some neoliberal economists might find contestable. The Brundtland definition has also been critiqued as being as passive as it is vague and failing to define the needs or identify the mechanisms required to achieve an environmentally sustainable society (Norgaard; Redclift; Solow; cited in Castro 2004 p.196).

At the other end of the ideological spectrum, often referred to as strong sustainability, is the argument for maintaining natural capital stocks. The World Conservation Strategy (IUCN 1980) provides an example of an ecological emphasis to sustainability. It offers a strategy that aims to achieve sustainable development through the conservation of living resources. The objectives of the strategy included the preservation of essential ecological processes and life support systems, and genetic, species and ecosystems diversity (Clapp and Dauvergne 2005).

How sustainability is understood tends to influence the outcome of plans, policies and regulations directed at achieving sustainability.

Sustainable housing

There are multiple conceptualisations of sustainability which seek to resolve the ambiguity about what actions should occur to achieve sustainable outcomes. The triple-bottom-line (TBL) approach is a widely used model in government and corporate circles that seeks to understand sustainability in terms of its economic, social and environmental attributes (Kates et al. 2005). McManus (2005) portrays the TBL as a hierarchical model, whereby economic development has social constraints limited by ecological capacity. TBL has been applied to the analysis of the sustainability of housing in studies by Chiu (2004) and Blair et al. (2004).

In these studies the Brundtland definition has been modified to suggest that sustainable housing is:

> Development that meets the *housing* needs and demands of the present generation without compromising the ability of future generations to meet their needs and demands (Chiu 2004, p.65; See also Priemus 2005 p.6)

This definition is ambiguous in terms of what physical development form is envisaged. In this sense Neumayer argues that development is economically sustainable “if it does not decrease the capacity to provide non-declining per capita utility for infinity”, whereby current and future utility is provided by a stock known as capital, whether it be natural capital, human capital or man-made capital (Neumayer 2003 p.7). Development is sustainable when the *capacity* to provide utility, rather than the utility itself, is maintained. Thus, the importance lies in maintaining the capital for future generations, which will in turn provide their utility. It is noteworthy that it is a highly anthropocentric definition, in that nature has no value independent of human value (Neumayer 2003).

In studying economic sustainability in the context of intergenerational equality, Yates et al. (2007) suggest that housing is sustainable when future generations can enjoy, and therefore afford, the same housing standards as current and past generations. In terms of housing affordability this process might be measured by monitoring the incidence of housing stress. In this sense, Yates et al. (2007) refer to housing policy and suggest that sustainability exists when “all obligations, current and future, can be met without changing current policy setting” (Yates et al. 2008 p.7).

Social sustainability is not as well understood as economic and environmental sustainability. Chiu (2004) argues that social sustainability is regularly interpreted from three perspectives. The development-oriented interpretation emphasises social acceptability, in noting that development is socially sustainable when it keeps to social relations, customs, structures and values. The environment-oriented perspective suggests that development is sustainable when social conditions, norms and preferences required for people to support ecological sustainable actions are met. Finally, the people-oriented interpretation of social sustainability emphasises maintaining levels of social cohesion in society and preventing social polarisation and exclusion.

In terms of housing, these conceptual understandings suggest that the social sustainability of housing encompasses (Chiu 2004 p.69):

- The social preconditions required for the production and consumption of environmentally sustainable housing;
- Equitable distribution and consumption of housing resources and assets;
- Harmonious social relations within the housing system;
- Acceptable quality of housing conditions.

The term “environmentally appropriate” has a myriad of interpretations, depending on whether the environment is perceived to have intrinsic value, or value only because of its use to humans (Payne and Raiborn 2001). Again the interpretation is dependent on the societal value of the environment. It has been suggested that environmental sustainability depends on preserving a series of inter-related dynamic equilibriums (Pirages 2005):

1. Between human populations living at higher consumption levels and the ability of nature to provide resources and services
2. Between human populations and pathogenic microorganisms
3. Between human populations and those of other plant and animal species
4. Among human populations

Human activities and behaviours regularly alter these equilibriums. For example, increases in human populations tend to degrade the resources and services provided by natural capital, with implications for future consumption. Considering such equilibriums demonstrates that the debate over sustainability should consider inherent tensions, which alter the equilibriums, a notion argued by Davidson (2005a). Indeed Davidson (2005a) argued that sustainability should not be thought of as an end goal but as a dynamic process.

Winston and Eastaway (2007) suggest that housing is one of the more neglected aspects of sustainability despite its potential to make a positive contribution. They go on to suggest that the environmental impacts of housing depend on:

- Land and associated impact on wildlife, landscape and amenity
- Access to public transport
- Previous land uses
- Density and associated access to services
- Construction materials as some hardwoods are unsustainably sourced from tropical forests
- CFC’s which are embodied in some air conditioning, refrigeration and insulation
- Energy consumption
- Water consumption

- Waste generation

In this sense a society with strong environmental ethos will impose more stringent environmental benchmarks and standards on housing development than a more conservative society that believes economic growth can not be limited by ecological limits.

The role of building regulation

Regulation of the construction industry is a mechanism that might deliver sustainable housing outcomes where market mechanisms are inadequate to reduce the environmental impact of buildings. Regulations and building codes relate to the unique characteristics of the building sector in terms of its product, production processes and the way the product is used (OECD n.d.). Further, as argued by Chiu (2004 p.71), while regulation and codes typically reflect social and cultural norms of a society, “they require efforts and commitments from the governments to formulate and enforce them”.

Building regulation has a long history and there is evidence of it in ancient Babylon, ancient Rome, medieval and industrial Europe (Zillante 2007). Such regulation responded to issues of basic quality and workmanship prior to the industrial age, and to sanitation and public health concerns in the latter. More recently, building regulation has considered issues of environmental sustainability as well as life safety and property protection.

The commitment to attaining sustainable development as per the Brundtland definition has been worked into more practical frameworks to facilitate tangible outcomes. For example, the CIB Agenda 21 on Sustainable Construction sought to be a “global intermediary between those general agendas in existence, i.e. the Brundtland Report and the Habitat Agenda, and the required national/regional Agendas for the built environment and the construction sector” (CIB n.d.). The CIB agenda is a conceptual framework that establishes clear links between the global sustainability discourse and the construction sector and it is envisaged that this will assist in defining detailed measures in various local contexts.

In the case of Australia, the Building Code of Australia (BCA) contains a set of technical rules for the design and construction of buildings, which are given legal effect by building regulatory legislation in the State and Territory governments. The system of a national code has created consistency in building regulation, whilst allowing for variations in climate, geological and geographical conditions. The goal of the BCA is to “enable the achievement of nationally consistent, minimum necessary standards of relevant, health, safety (including structural safety and safety from fire), amenity and sustainability objectives efficiently” (ABCB 2009)

The technical provisions related to the design and construction of buildings and structure consider matters including structure, fire resistance, access and egress, services and equipment, and energy efficiency as well as certain aspects of health and amenity. The BCA is performance based which facilitates cost savings in building construction by allowing innovative or alternative materials, forms of constructions or designs and allowing site-specific designs which ensure that the “intent of the BCA is met while still allowing acceptable existing building practices” (ABCB 2009).

The BCA is limited to technical components of the design and construction of buildings, and other aspects of construction, such as administrative provisions, procurement, planning, occupational health and safety, consumer protection are outside its scope. Some issues, such as durability, adaptability, have a non-mandatory route and instead of being addressed in the building code, are addressed in ABCB guidelines. Some issues are not at all addressed by the building code (e.g. waste management issues, design for disassembly, re-use of materials).

Changes to the building code are often requested by the Council of Australian Governments (COAG). Energy efficiency measures for housing were first introduced to the code in 2003. More recently, COAG has requested that the energy efficiency requirements be amended in the 2010 edition of the BCA to require all residences meet a 6 star rating “subject to continued effectiveness”.

Thus, to summarise, while sustainable development is a contested concept at a conceptual level, it is better understood and applied to housing when delineated into economic, social and environmental sustainability. In terms of environmental sustainability, there is an ongoing trend in Australia to address certain issues through mandatory standards in the building code.

Affordable Housing

Affordability could be simply defined as ability to pay. However, this definition is limited and does not take into consideration whether the consumption of the good or service would seriously compromise the consumer's ability to consume other goods and services. Affordability, therefore, needs to relate to the price and consumption of a particular good or service, such as housing relative to disposable income. Incorporating disposable income ensures there is a mechanism, such as the percentage of income spent on the product, to determine if there will be enough income left to buy other essential goods and services (Davidson 2005b).

The variables associated with housing affordability and their related contributing factors include:

- Price: market competition; access to public housing.
- Usage: demographics; household needs; supply of suitable housing; and opportunity cost of consumption.
- Disposable income: Commonwealth support payments; government grants and/or concessions; support from welfare agencies.

Affordability like sustainability is a complex concept involving the consideration of a number of variables. For example, household needs in relation to style of housing and location differ between a couple with children who might require more rooms, or a retired couple wishing to live near family and support networks. Satisfying household needs varies depending on the price of housing stock, which is in turn influenced by the availability and price of private rental accommodation or public housing, and variables in the housing market. Usage and price of housing is also dependent on disposable income.

Australians have historically enjoyed high rates of home ownership and relatively low housing costs, facilitated by cheap and plentiful land for urban development but Australia today is in the midst of a housing affordability crisis (Beer et al. 2007). House price growth has continued to outstrip income growth to the point that more than one million low and middle income households are now experiencing housing stress (Australian Government, 2008), defined as occurring when more than 30% of household incomes are spent on housing costs for the bottom 40% of income groups (Australian Government 2008; Yates et al. 2007).

Housing stress is affecting large numbers of home purchasers, but is also felt in the rental sector. A recent study by Yates et al. (2007) found that 65% of low-income private rental households were experiencing housing stress in Australia.

Another recent international study (Cox and Pavletich in AMP.NATSEM, 2008) comparing housing affordability in the developed world ranked no Australian urban area as ‘affordable’ and 25 of Australia’s 28 urban areas as ‘severely unaffordable’. Although this level of affordability was also found in New Zealand and the United Kingdom, most developed countries had a much smaller proportion of ‘severely unaffordable’ urban areas. The United States, for example, had only 30 ‘severely unaffordable’ areas out of 129 studied (Cox and Pavletich in AMP.NATSEM, 2008).

Beginning in the early 1990s, State Governments in Australia have implemented policies that favour urban consolidation over growth on the periphery (Forster 2006). Strategic planning in cities like Melbourne, Adelaide and Perth now incorporates urban growth boundaries that restrict land sales and set limits to further development on the periphery (Forster 2006). Such policies are coupled with plans to develop high density housing around transit oriented developments on train and tram lines, which it is hoped will discourage car use through the development of self contained urban centres combining shops with transport nodes. State Governments in Victoria and South Australia have also mandated affordable housing targets in new urban estate developments that demand that a certain proportion of all new developments are deemed to be affordable. In South Australia, for example, 15% of all new housing in estates under development must be affordable. Likewise Housing SA, the state housing authority responsible for social housing builds homes that can only be sold to low income earners. However such measures have only a minor impact on the supply of affordable housing and have little effect on the supply of rental properties. As Yates and Wulff (2005) note, the private rental market cannot be relied upon to provide affordable housing opportunities when the supply is inadequate and the limited stock is poorly distributed.

Moreover, such policies do not negate the pressure on land prices presented by urban growth boundaries, as observed by Forster (2006). Day (2005) argues that urban consolidation policies have driven up the price of land in Australian cities while the cost of constructing a home has largely remained the same since the 1970s. Housing affordability has also been affected by asset price inflation triggered in part by the introduction of a First Home Owners Grant to new home buyers by the Howard Government in 2000, and rising incomes associated with the economic boom in Australia that began in the late 1990s and continued until the global financial crisis in 2008. The First Home Owners Grant has been supplemented by grants to first home owners by State Governments and in some states, tax concessions on stamp duty and associated costs of home purchase.

Merit goods

An Australian cultural milieu that places a social premium on home ownership but in an environment where affordability is in decline has been encouraged by significant support from the Australian and State Governments for new home owners, which has feared that markets will not supply housing that is sufficiently affordable to the majority of the population. In this sense home ownership in Australia might be considered to be a merit good that should be provided or at least strongly encouraged by governments. Merit goods differ from socially desirable public goods such as law and order, parks, street-lighting, defence etc., which are generally provided from the general revenue because the market cannot efficiently provide and distribute non-excludable goods through the price mechanism.
Merit goods while similar to public goods are those that are deemed socially necessary but can be provided by the market but not necessarily in the right quantity or at an affordable price. Education is generally considered to be a merit good and in some countries, health care. Such goods if left to the market might be unevenly distributed in the community. For example, people who cannot afford to educate their children privately will not do so, or choose not to do so if there are other matters that they wish to prioritise.

Home ownership in Australia is considered to be highly desirable by governments and the community alike as it is held to provide social equity and is bound up in Australia's cultural identity (Gleeson 2008). Australia's identity as a suburban home owning nation is referred to by Gleeson (2008 p 2655) as 'The Great Australian Dream', which is under challenge from a poorly grounded critique of 'sprawl' perpetuated by urban planners. This critique warns that unless higher urban densities are achieved Australians will be condemned to obesity, poverty, loneliness and many other maladies. Concerns over 'sprawl' have influenced the imposition of urban growth boundaries and other measures that place upward pressure on the cost of land and hence undermine the cultural aspirations of Australians to ownership of a detached house on a quarter acre block. As Forster (2006 p.180) suggests, such policies 'reduce the affordability of conventional housing, while forcing increasing numbers of households into higher density dwellings that they show little sign of actually desiring'. The Dream remains but it is becoming increasingly unattainable, placing political pressure on governments struggling to find new ways to provide a merit good that is culturally tied to Australian's concept of themselves as a home owning nation.

The critique of the Great Australian Dream is allied to more grounded concerns over the sustainability of our cities in relation to pressing debates over climate change. The Stern (2006) and Garnaut (2008) reports have drawn attention to the unsustainability of doing nothing about climate change and other environmental issues. Australian Commonwealth and State Governments have begun to mandate stricter building codes to ensure that new homes are more energy efficient and environmentally sustainable. Stricter building codes are allied to generous tax rebates and subsidies for the installation of solar panels in housing and environmentally sustainable water heating systems. Such systems are not cost effective for average income earners to install without a subsidy. In essence governments have positioned environmentally sustainable housing as a merit good. It is a good that is not efficiently provided by the market, at least not in the quantities that will make a difference to climate change, but nevertheless has significant social merit, thus attracting a subsidy from the state.

Affordable housing and sustainable housing might fall under the common rubric of a merit good in Australia and are increasingly considered in a single context. However, this raises the question of how might affordable housing be made sustainable in a practical sense to achieve congruent social, cultural and environmental objectives?

Ecocents Living Project

The *Ecocents Living* research project was undertaken to identify a suite of built forms for housing that are both affordable and environmentally sustainable. The project was supported by the South Australian Department of Families & Communities and the Hindmarsh group of companies. Innovative housing solutions were to be investigated which might have valuable demonstration potential and could contribute to a diverse portfolio of responses across a number of target groups, tenures and locations.

The main aim of the research was to identify relevant building systems from a suite of affordable and sustainable housing projects that are consistent with South Australian government policy. At the outset of the project, it was agreed that certain aspects would be considered in the research such as:

- Environmentally sustainable housing including energy efficient design, sustainable materials, water conserving technologies and life cycle approach
- Innovative procurement and construction methods such as prefabrication techniques and efficiently manufactured building systems
- Adaptability to changing life cycle needs and different target groups, tenures and locations with particular relevance to rental housing.

The research methodology was to triangulate data on affordable and sustainable building systems based on the best international and national knowledge and experience. This included:

- A review of the international and national literature on affordable building systems
- A review of the international and national literature on sustainable building systems
- Inspection of identified affordable/sustainable building developments of interest
- Identification of key performance indicators
- Consultation with key informants on affordable and sustainable building systems
- Identification of systems that are both affordable and sustainable in the Australian context and targeted to include rental housing projects.

Comparison of existing examples of affordable and sustainable housing

The early findings from the review of literature had indicated certain characteristics of affordable and sustainable housing and it was necessary to test the relevance of these using recent and/or progressive housing developments. This would contribute to the following aspects of the methodology:

- testing of the characteristics and, where necessary, supplementation so that they more fully represented affordable and sustainable housing
- development of the essential characteristics into a range of performance indicators
- introduction and development of metrics into the performance indicators
- formation of benchmarks indicating current and future levels of performance

- identification of possible models for affordable and sustainable housing

The selection of the recent and/or progressive housing developments was carried out to include:

- several South Australian housing developments which had some affordable and sustainable housing characteristics
- reference to interstate developments to provide a national perspective
- two overseas developments to give an international comparison

These developments are summarised in Table 1

Table 1. Housing developments selected for analysis

Name	**State/ Country**	**Location**	**Development Size**
Inspire	South Australia	Noarlunga, 30km to south of Adelaide CBD	28 dwellings – Stage 1
Lochiel Park	South Australia	Campbelltown, 8km to north east of Adelaide CBD	100 dwellings when complete
Christie Walk	South Australia	Adelaide CBD	24 dwellings of various forms
Mawson Lakes	South Australia	12km to the north of Adelaide CBD	4,000 homes by 2010
Aldinga Arts Eco Village	South Australia	45km to the south of Adelaide CBD	Currently 55 homes mainly owner- builders
Landcom NSW designs	New South Wales, Australia	Various across NSW	Various depending on particular project
K2 Melbourne	Victoria, Australia	5km to the south east of Melbourne CBD	96 apartments
BedZED	United Kingdom	14km to south of London CBD, near Mitcham	99 dwellings
Oxley Park	United Kingdom	70km to north west of London	145 houses

Results of research

Initially, the nine developments were analysed using the characteristics identified from the literature review which included measures of environmental, economic and social sustainability. Specifically, environmental characteristics consisted of energy efficiency, water efficiency, construction materials and construction methods. For economic sustainability, financial procurement methods used for the development projects were considered as well as purchase (or rental) costs. Dwelling size, adaptability (for occupants with disabilities), community acceptability and whether the design of the development was intended for outer or inner city locations were the social characteristics.

This initial analysis resulted in the necessity to define performance indicators and to introduce sub-indicators where appropriate and these are described as follows:

- Energy efficiency encompasses all measures to reduce a dwelling's energy use and greenhouse gas emissions. Sub-indicators were energy star ratings, use of photovoltaics and solar water heating, and solar passive design.
- Water efficiency encompasses water conservation, storage and water sensitive urban design techniques. Sub-indicators were rainwater storage, water efficient appliances and grey water re-use.

- Construction materials relates to the selection and use of materials. Sub-indicators were the use of low embodied energy materials, re-use and recycling of materials, and use of components with low volatile organic content.
- Construction methods relate to innovative methods and techniques and include internal thermal mass, pre-fabrication and alternative building techniques.
- Financial procurement was deemed an indicator not to be ranked but rather a statement of how the dwellings are financially delivered.
- Affordable housing in terms of both purchase cost and rental cost as defined by the Department for Families and Communities (SA government).
- Dwelling size. Increasing floor areas can unnecessarily reduce affordability and environmental sustainability whereas minimum floor areas are required for health and well-being. Floor area requirements can be specified according to the number of occupants.
- Appropriate density was deemed an indicator not to be ranked. Rather, it reflects the suitability of the dwellings to low, medium and high density developments.
- Adaptability is used to describe a structure that has been constructed to allow modification at minimum cost, to suit the changing needs of the people in the house.
- Social acceptability is defined as the acceptability of a development to the surrounding community.
- Desirability of a dwelling refers to how it exceeds the consumers' expectations. The desirability of a dwelling is typically reflected in its market value and interest from buyers and renters.
- Suitability is an overall ranking or score based on the sum of the performance indicators.

As the project unfolds these performance indicators will be refined by further consideration of other research and by consultation with key informants. The key informants will include state and local government experts, builders and developers, architects, community housing representatives and affordable housing residents. Consultations will enable contemporary metrics and benchmarks to be developed for each performance indicator and sub-indicator. An example of this is 'Social acceptability' which might be measured by a quantification of formal actions (e.g. submissions to a development assessment panel) or informal behaviour (community perception and local responses).

The initial conclusions from the research carried out so far show that the indicators for *environmental* sustainability are quite well developed with substantial knowledge available on measurement and benchmarking of performance. However, it is likely that the benchmarks will need to be raised with time as higher levels of performance become desirable. Whereas the measurement of *social* sustainability is subject to some interpretation and contemporary indicators will require further development. A comprehensive range of indicators and benchmarks will enable the identification of housing models which can provide affordable and sustainable outcomes across the full range of requirements.

An integrated approach to affordable and sustainable housing

Learnings from the research suggest how environmental sustainability, housing affordability and social sustainability might converge in conceptual and practical terms to provide meritorious housing.

The model in Figure 1 is an illustration of a combined system comprising core sustainability objectives and core objectives of affordable housing. The overlapping areas suggest the thrust of the convergence.

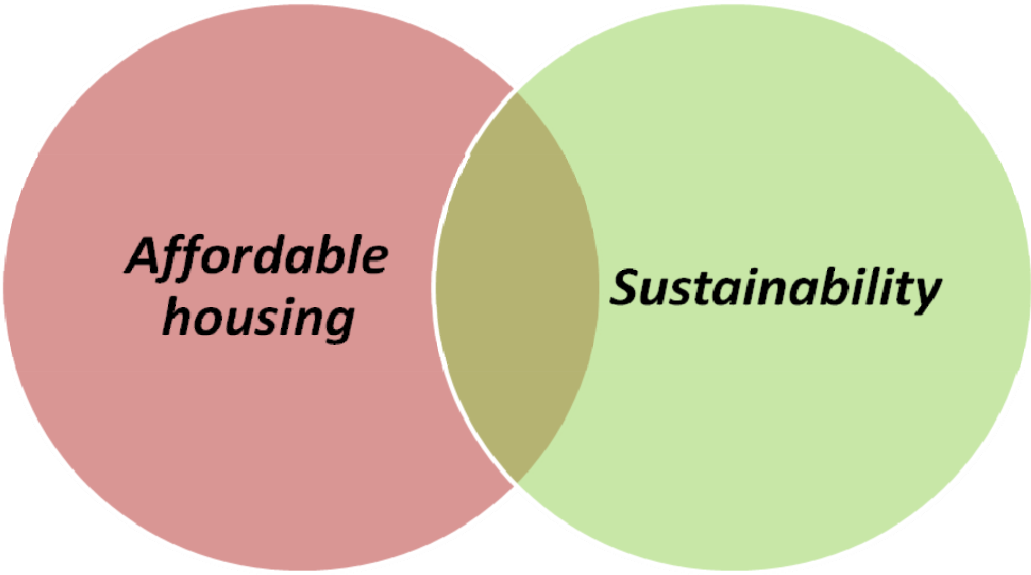

Figure 1. Overview of the convergence of sustainable and affordable housing systems

Common areas of convergence are typically in the economic and social components of sustainability, whereas difficulties are encountered in integrating environmental sustainability with affordable housing as environmentally sustainable housing is thought to only be attainable with additional cost. More specifically, mutually supporting objectives of sustainable housing and affordable housing include a focus on economic viability, social acceptability, improving equality and the role of technology in providing innovative solutions.

A fully integrated system of affordable and sustainable housing is illustrated in Figure 2 below, where it is proposed that integration will only occur when affordable housing is a secondary objective to achieving truly sustainable housing.

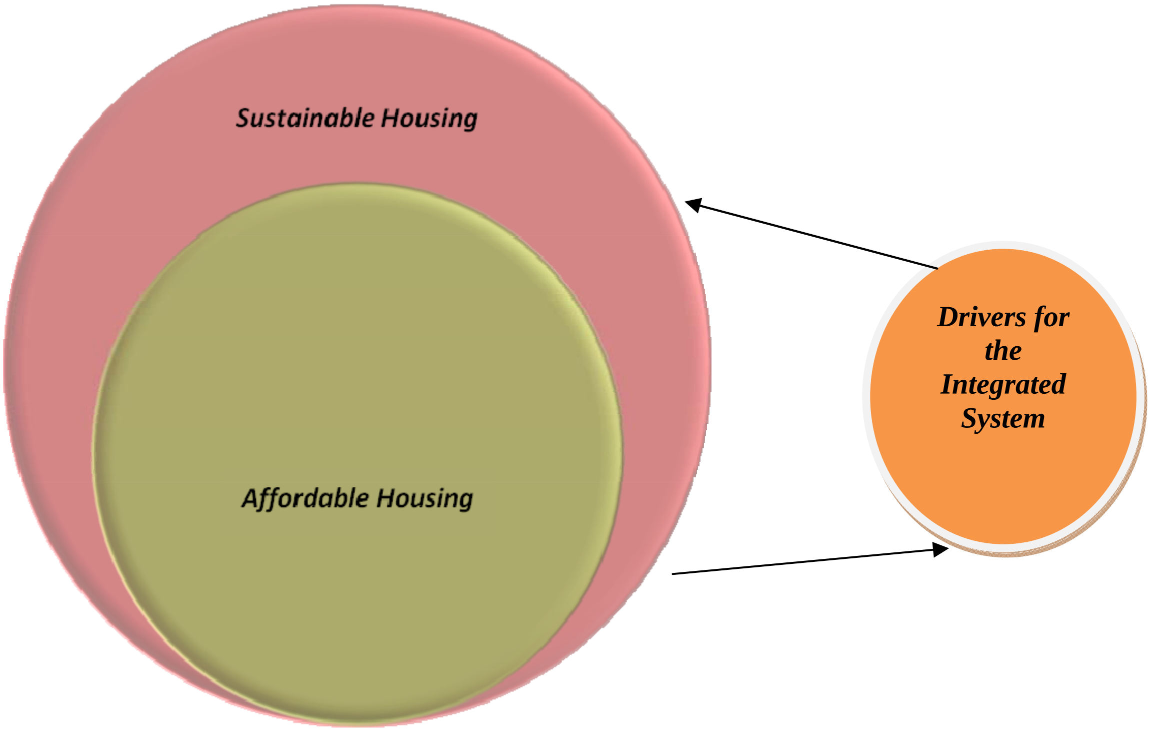

Figure 2. Overview of integrated sustainable and affordable housing and key drivers

However, an integrated model of sustainable and affordable housing might need to be underpinned by key drivers or enablers. There is a cardinal need to identify what needs to be in place to bridge the gap between the separate components of sustainable housing and affordable housing. In identifying the factors conducive for the affordable housing aspects, attention should be paid to the structural problems in Australia's housing systems, such as a growing gap between housing supply and demand. Other key drivers are generic factors in the broad environment such as the political environment which in essence governs housing policy.

Conclusion

This chapter has addressed the debate over affordable and sustainable housing in the Australian context and discussed work on an embryonic model that might offer conceptual and practical direction for the construction of affordable and sustainable housing. It has been argued here that sustainable housing and affordable housing, at least in the Australian context, are merit goods with a degree of conceptual convergence albeit with evident tensions. Convergence was discussed in relation to the Ecocents Living project, a research project that is seeking to develop a conceptual and practical model to guide the development of affordable and sustainable housing. Illustrations were offered of areas where the objectives of sustainable housing and affordable housing converge but where there are also evident tensions. It has been suggested that integration might only be achieved when affordable housing is a secondary objective to achieving truly sustainable housing. Albeit attention should be paid to structural issues such as the relationship between housing supply and demand and generic factors in the broad environment, which include the political environment and its impact on environmental and housing policy. The model discussed here is embryonic and we welcome contributions to a debate on how the integration of sustainable and affordable housing might be advanced.

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George Zillante is Associate Professor and Head of Building at University of South Australia. He has qualifications in Architecture, Urban & Regional Planning, Building Surveying, Business Administration and Construction and has worked (and continues to work) at the professional level in those fields. Over the years George has done a lot of work in the field of Building Legislation and this has resulted in his appointment to many Government Committees including, inter alia, Chair of the South Australian Building Advisory Committee, member of the South Australian Development Policy Advisory Committee, member of several Australian Building Codes Board Committees as well as representing the Australian Construction Industry on the International Association for the Professional Management of Construction. This interest in Building Legislation led George to establish the Centre for Building & Planning Studies at UniSA in 1993 and has resulted in several research projects dealing with the impacts of legislation on development and, more recently on bushfires and Government Policy responses to the impact of bushfires and Organisational Change. George is also a member of several Professional Bodies (RICS, AIBS, AIB, ACCE etc) and serves on a number of Education and Accreditation Committees.

Dr Stephen Pullen is a building scientist with over fifteen years experience in the study of sustainability of construction materials, buildings and the urban environment. He commenced research into embodied energy in 1993 and in 1997/1998 participated in the ARC supported project at the University of Adelaide called *Design of Environmentally Responsible Housing for Australia*. In 2003/2004, he was a Chief Investigator in the ARC Linkage project at the University of New South Wales on *Water and Energy profiles for Sydney: Towards Sustainability.* He is also a Chief Investigator in the recently awarded ARC Linkage project on an *Integrated Model for the Assessment of Urban Sustainability*. As part of his PhD studies, he developed a model of the urban environment which spatially represents embodied energy consumption and may be used for scoping reductions in the life cycle energy of buildings including the refurbishment of existing buildings.

Dr Lou Wilson is a sociologist at the University of South Australia. Lou teaches courses in social planning and research methods and has research interests in affordable housing, social inclusion, social cohesion, social capital and sustainability. He is currently a member of three research teams investigating these topics on projects supported by the Australian Research Council, the South Australian Government and private industry partners.

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Michael Arman is a research associate at the University of South Australia. His study and profession background is in Urban and Regional Planning where he has worked on a variety of urban, natural resource management and social planning projects on behalf of local and state government, and non-government bodies at a leading Adelaide-based consultancy. At the University of South Australia, Michael has been a key researcher in an industry-sponsored project considering how to integrate the concepts of sustainability and housing affordability. Michael also has research interests in the social impacts of urban planning. Recent publications include an article published in Ecological Economics, and two refereed papers presented at international conferences.

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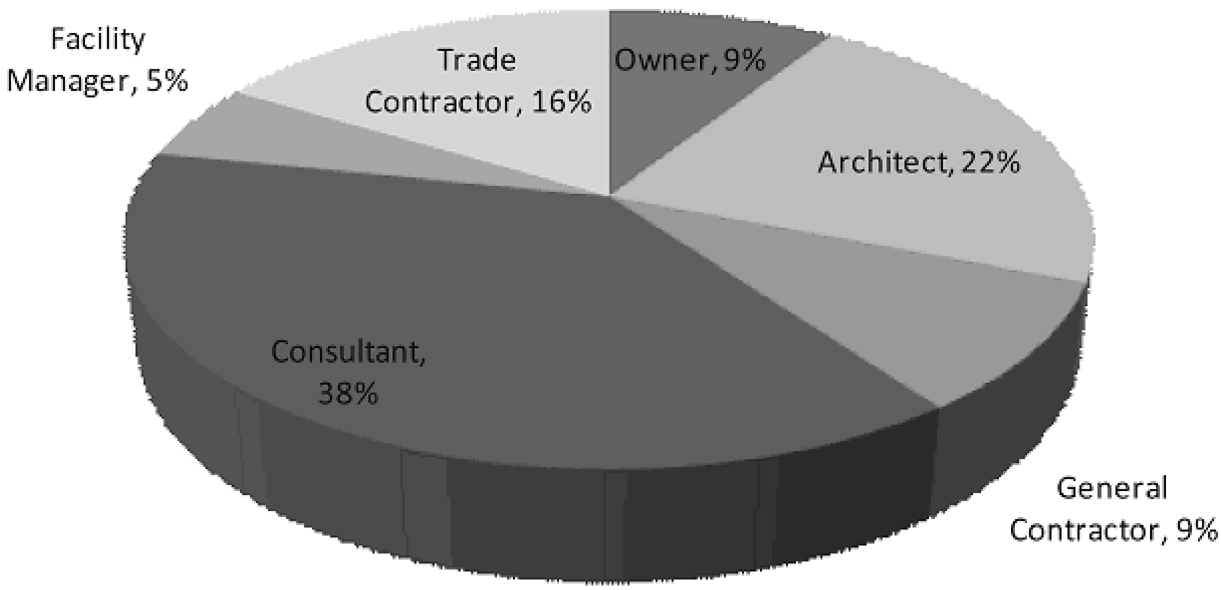
Relationship Between AEC+P+F Integration and Sustainability

Angelica Ospina-Alvarado, Daniel Castro-Lacouture, Kathy Roper



Relationship between AEC+P+F Integration and Sustainability

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Abstract

Sustainability is increasingly becoming a very important performance indicator when evaluating the success of a construction project. In order to attain a truly sustainable project it is necessary to understand it as a whole system whose subsystem interactions should be optimized. To optimize the synergies between project subsystems it is necessary to reconsider the process with which projects are traditionally planned, designed, constructed, maintained and operated. Traditional project delivery systems do not suit the needs of a sustainable project, because the process is very fragmented, different team members are brought into the project after major decisions are already taken and their input is very limited, communication and information exchange is very poor, and contract language inhibits cooperation. A sustainable project requires a process that fosters interdisciplinary collaboration and integrates the team, project systems and the business structure. It requires a process based on early participation of key project members, transparency, open information exchange and communication, as well as collaborative decision making, among others. This chapter presents a framework that explains the associations between an integrated project delivery system and the different sustainable construction criteria, showing the implication of the project process on the sustainability of a project.

Keywords: AEC+P+F (Architecture, Engineering, Construction + Planning + Facility Management Integration, sustainability, integrated project delivery, sustainable construction

Introduction

Sustainable construction is the process of planning, designing, constructing, maintaining, and operating building projects, with the goal of minimizing overall environmental impacts and maximizing the benefits to the final users and to the surrounding community. In order to develop a sustainable project it is necessary to rethink design, construction and operation aspects of energy, water and resource use, indoor air quality, recycling programs, alternative transportation access, landscaping strategies, construction waste management, construction site planning and management, wastewater management, and maintenance, among others.

In order to attain a truly sustainable project it is important to maximize synergies between the different project systems and components, reaching important efficiencies and minimizing unnecessary costs. In addition it is necessary to plan and design with the end user in mind, the operation and maintenance activities, and the construction. This will enable inputs from the selection of materials and systems to be transformed to outputs in the form of a sustainable project. To achieve this, it is necessary to require the early and active involvement of all major stakeholders, including the owner, architect, engineers, planners, specialty consultants, contractor, key trade contractors, final users, and facility managers.

Current practice based on a traditional project delivery method is not very well suited to develop integrated sustainable projects nor to improve the overall performance of the project and the completed building. The current process is very fragmented and is built upon a culture of adversarial roles; the different processes are carried out by various stakeholders who are not contractually responsible to each other and who are often brought into the project after all major decisions have been made. The information exchange between the different parties is limited; the wording on contracts promotes little cooperation or innovation and puts pressure on local optimization. Therefore it is not possible to develop synergies between systems and between project phases.

The practices and relationships between the different stakeholders are mainly determined by the project delivery system and by the contracting structure selected by the owner. A sustainable project requires a delivery method that differs from the traditional one and fosters interdisciplinary collaboration that integrates project participants, business structures, and systems and construction practices. The AEC+P+F (Architecture, Engineering, Construction, plus Planning, plus Facility Management) integrated approach to the delivery process requires early involvement of key project participants, transparency on project relationships, enhanced information exchange, collaborative decision making, open communication, encouragement of participation and innovation, among others. Project integration can be a catalyst to achieve building sustainability.

Objectives

This chapter demonstrates the importance of project delivery system in the sustainability of a project. It proposes a framework to explain the mutual associations between AEC+P+F integration and sustainable construction and operation, studying the implications of project delivery methods on sustainability. Through the use of a matrix that presents the interactions between the different sustainability objectives and goals, project lifecycle activities in an integrated project, and project participants who should be involved, it is shown how to achieve an integrated, efficient and effective sustainable project. The matrix takes into consideration the main project phases of the integrated project delivery approach and the main project participants. The matrix aligns the project lifecycle phases on the horizontal array, and sustainability objectives and goals on the vertical array. The intersection cells are populated with the project participant who is necessary in each phase in order to maximize a sustainability objective.

Background

The construction industry has traditionally measured the performance of construction projects in terms of initial costs, productivity, time, safety and quality. However, changes in project challenges and owner characteristics, such as the awareness of the impact of the project on the environment and its users, have made the performance and success factors of the project evolve to include not only traditional performance indicators, but also new indicators such as lifecycle costs of the project, sustainability, customer satisfaction, elimination of disputes, and long time relationships among the project team (Tang 2001, Whaley 2009, Rooney 2006, Rahman and Kumaraswami 2004). Therefore, sustainability as a success factor for a project is becoming an important indicator of its overall performance. Sustainability as an indicator measures the performance of the project in terms of the reduction of negative impacts on the environment and the increase in benefits to the final user and the surrounding community.

Augenbroe and Pearce (1998) have identified several aspects that have to change within the industry, as a response to sustainability. Some of those aspects encompass the inclusion of energy conservation measures, solid waste reduction programs, sound use of materials and resources, healthy levels of indoor environmental quality, water consumption reduction strategies, development and implementation of strict policy and regulations in terms of land use and urban planning, and evaluating the feasibility of a project in terms of its lifecycle cost instead of its initial cost. However, even if some of the strategies mentioned before are carried out, the project would not be truly sustainable until it is understood as a holistic integrated system (Busby Perkins & Will and Santec 2007) and the project delivery system evolves towards a more integrated one where each project team member can maximize his or her participation on the project (Tang 2001, Sun y Aouad 2000, AIA National y AIA California Chapter 2007).

Sustainability and the Construction Industry

The construction industry is one of the main contributors to depletion of natural resources in the world (Bentivegna et al. 2002). Currently this industry consumes around 43% of the energy, 72% of the electricity, 17% of the water, and 32% of the materials and resources; in addition it produces 40% of green house emissions, 40% of solid wastes, soil loss, reduction on air quality, and has a high negative impact on biodiversity. In response to high impact this, emerges the concept of sustainable construction.

With the aim of defining what is sustainable and what is not, to standardize its measurement and to avoid green washing, different rating systems have been developed. Across the world there are several sustainable project rating systems such as BREEAM (Building Research Establishment Environmental Assessment Method) in the United Kingdom, CASBEE (Comprehensive Assessment System for Built Environment Efficiency) in Japan, LEED (Leadership in Energy and Environmental Design) in the United States, and Green Star in Australia, among others. The authors selected LEED in order to define the sustainability criteria on this project.

LEED is a certification system that measures the sustainability of the project using six main categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, environmental quality, and innovation in design. Within each category there are some prerequisites or aspects that must be met in order to have a sustainable project, and some credits or aspects that could be or could not be met depending on the characteristics and goals of a specific project. The credits are associated to a number of points, and the certification level is determined according to the number of credits achieved by the project. The credits and prerequisites have been established according to the sustainability criteria defined in consensus by the construction industry in the United States (USGBC 2007).

Construction Industry Integration

The construction industry has several characteristics which are preventing it from achieving improvements on its overall project performance and sustainability. Some of these characteristics include a fragmented supply chain: each portion of the work is done by different parties that are usually not contractually responsible with each other, the communication and information exchange between the different parties is very poor and is characterized by a lack of information exchange standards, and relationships and team work is based on a culture of adversarial roles, lack of transparency and mistrust. There is a false belief that each project is different, preventing the transfer of knowledge from one project to the other. In addition the knowledge and ideas of the contractor and subcontractors are often lost, because they join the project when most important decisions have already been taken. The contract wording is based on remedies and penalties and its main intention is to transfer risk from one party to other party, which usually is not the most appropriate party to bear the risk; therefore, it limits the possibility of cooperation among different parties and their innovation capacity. There are not common project goals and objectives and the compensation structure is based on individual performance; therefore each party works in its own best interest and not in the best interest of the project. Often the interests of one party could be to the detriment of another party or the interest of the project itself. In addition there is no room for innovation and the focus is in local optimization (Matthews and Howell 2005, Sun and Aouad 2000, Forcada Matheu 2005, O’Connor 2009, Zaghloul and Hartman 2003, Tang 2008, Sullivan 2009, Skal 2005, Rooney 2006, Rahman and Kumaraswami 2004).

There are some drivers that are leading the industry towards a more integrated approach to delivering the projects. Sustainability is gaining more importance as a project success factor. There are important challenges in terms of generational, cultural and market changes. International competition has increased and several governments are supporting integration. There are very important advances in technology. Projects are more complex; owners are more experienced, knowledgeable and have higher expectations. Success and performance factors are evolving; the market is looking for increased collaboration and for a reduction in litigation (Tang 2001, Sun and Aouad 2000). There are different approaches to project delivery systems and contracting structures around the world that are heading towards achieving an integrated project. For instance in the United States the American Institute of Architects is leading the development of the integrated project delivery (IPD) (AIA National and AIA California Chapter 2007) and a coalition formed by different construction industry stakeholders released the ConsensusDocs contract documents for collaborative projects in 2007 (O'Connor 2009). On the other hand in Australia, the United Kingdom and other parts of the world the relational contracts, the alliancing and partnering structures are other platforms that support project integration and team collaboration (Rooney 2006, Rahman and Kumaraswami 2004, Skal 2005).

The principles of project integration are: respect, trust and ethics among project team members in order to build a culture of collaboration; the project and the entire team should agree common goals and objectives set early in the process where the best interest of the project primes; the benefits and rewards should be linked to the performance of the project; there should be a collaborative decision making process; research, innovation and creative thinking should be encouraged; all key stakeholders should be part of the team early in the process when they can contribute more to it; the team should be formed not only by the client, designer and contractor, but also by the facility manager, the subcontractors, the suppliers, and other players depending on the nature of the project; enough time and resources should be allocated to the planning and schematic or conceptualization phase in order to make the major definitions; a culture of open communication, accountability and on time conflict resolution should be built among the team; technology should be used to standardize information exchange; top management and the client should be committed to the process; risk should be shared and when necessary should be allocated to the party that can handle it and has the capacity to bear it; the team selection process should be based on contribution potential and previous experience; adequate training should be available for the different stakeholders of the project; and integration should be vertical and horizontal (AIA National and AIA California Chapter 2007, Tang 2001,O'Connor, Whaley 2009, Skall 2005, Rooney 2006, Rahman and Kumaraswami 2004).

For integration to take place, it is necessary to understand the project as a continuous flow, not separate phases carried out by different parties. The project has to be analyzed from its conceptualization and planning, design, implementation and construction, start up, and operation perspective. All the definitions and decisions should be moved to the first stages of the project, when making changes is less expensive and there is greater possibility to influence the project (AIA National and AIA California Chapter 2007, Rahman and Kumaraswami 2004, Tang 2001). In addition, risks have to be identified as a team early in the process in order to avoid them, minimize them and handle them appropriately. Risks should be shared by the team and when needed should be allocated to the party that can better bear them (Rahman and Kumaraswami 2004).

Project integration would led to benefits in terms of project performance, not only in regard of enhancing project sustainability, but also in terms of overall cost and duration reduction, team relationships and productivity improvement, quality enhancement, and risks and safety issues reduction. Risk can be reduced since more details will be identified and discussed earlier in the project, along with the ability for all team members to suggest risks to be included in a risk log for mitigating issues during project execution (Tang 2001).

Methodology

This chapter proposes a framework to explain the influence of each project team member on the optimization of the interaction between the different phases and activities of an integrated project and the sustainability criteria in order to maximise the overall sustainability of the project. The framework is based on the development of a matrix that visually represents the intersection between each project activity and each sustainability criterion showing the team member(s) that could maximise the interaction. In order to determine the activities of the construction process, the phases of the integrated project delivery were used, that is conceptualization, criteria design, detailed design, implementation documents, construction, and operation and maintenance. These phases were expanded into 48 specific activities. The specific activities were placed on the vertical axis of the matrix. In order to define the sustainability criteria the six categories of the LEED rating system were used, that is sustainable sites, water efficiency, energy and atmosphere, materials and resources, environmental quality and innovation in design. These categories are composed of 65 different prerequisites and credits for LEED 2.2 version, and these items were used as the sustainability criteria. The sustainability criteria were placed on the horizontal axis of the matrix. The intersection cells were populated with the team members that have an influence on it; therefore these team members had an important influence not only on the activity but on the sustainability criteria. The matrix does not include all possible team members; however it includes the main team players, which are O-owner, A-architect, S-engineer or specialty consultant, C-general contractor, T-trade contractor, and F-facility manager. In order to populate the matrix, a comprehensive study of the *LEED NC 2.2 Reference Guide* (USGBC 2007) and the *Impact of LEED® NC Projects on Constructors from Michigan State University*" (Syal 2007) took place. The participation of each team member was calculated as a percentage compared to the participation of all team members. Those participations are aggregated for each project phase and each LEED category or sustainability criteria group.

The matrix is very extensive; therefore it is not possible to present it in this chapter. An excerpt is presented in Figure 1; it presents the design section of the matrix, for the different sustainability criteria used.

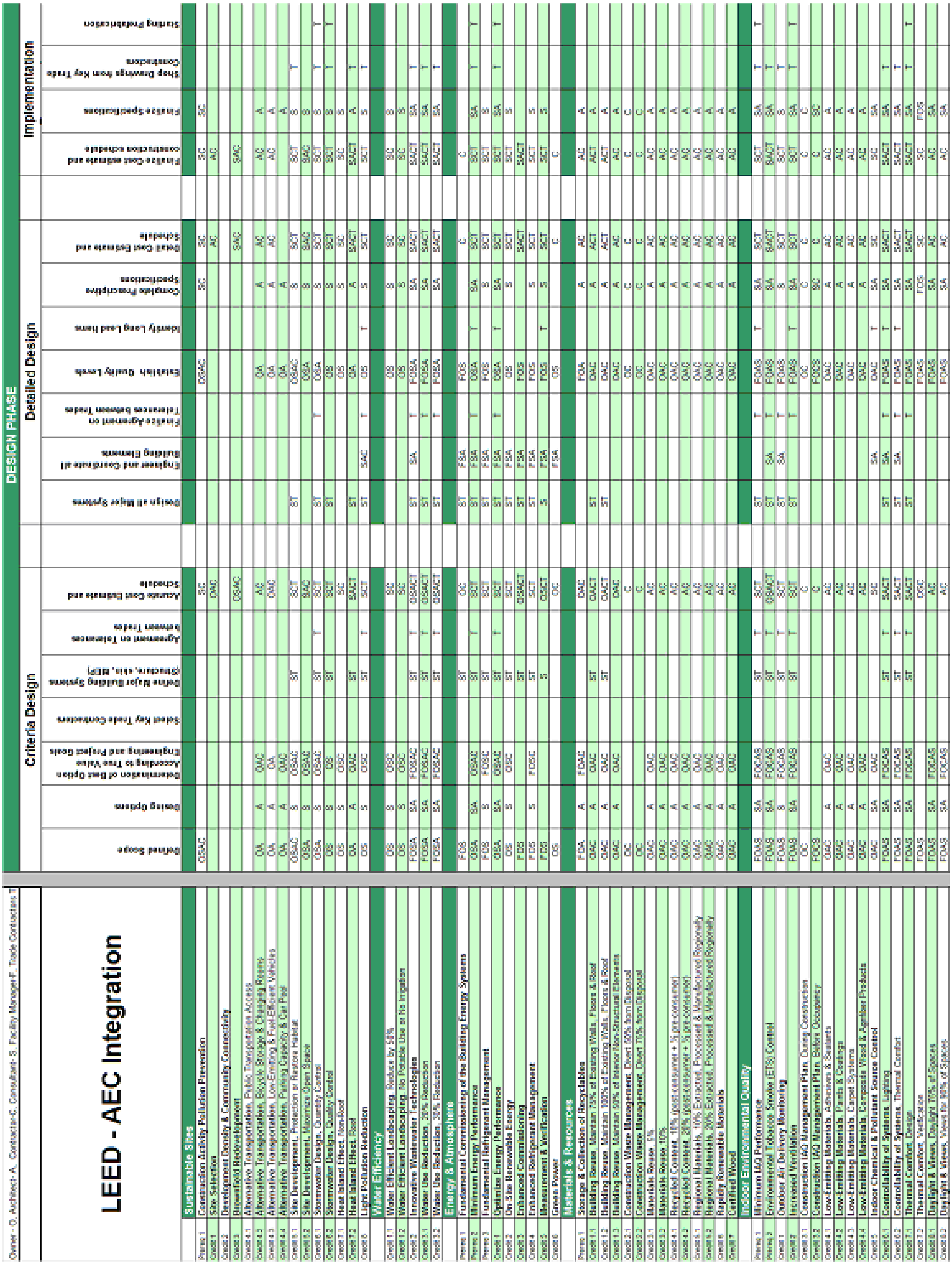

Figure 1. Design section from the complete matrix

Results

The matrix is used to determine the observed participation distribution of the different team members on the intersection between activities of the project and sustainability criteria. The observed participation is aggregated based on project phases and sustainability categories. Figure 2 presents three pie charts comparing the participation of project team members during the design phase for the water efficiency category. The pie charts are examples of the representation of team participation on that phase and category; however the percentages of participation have been calculated for all phases and categories and the description is presented below.

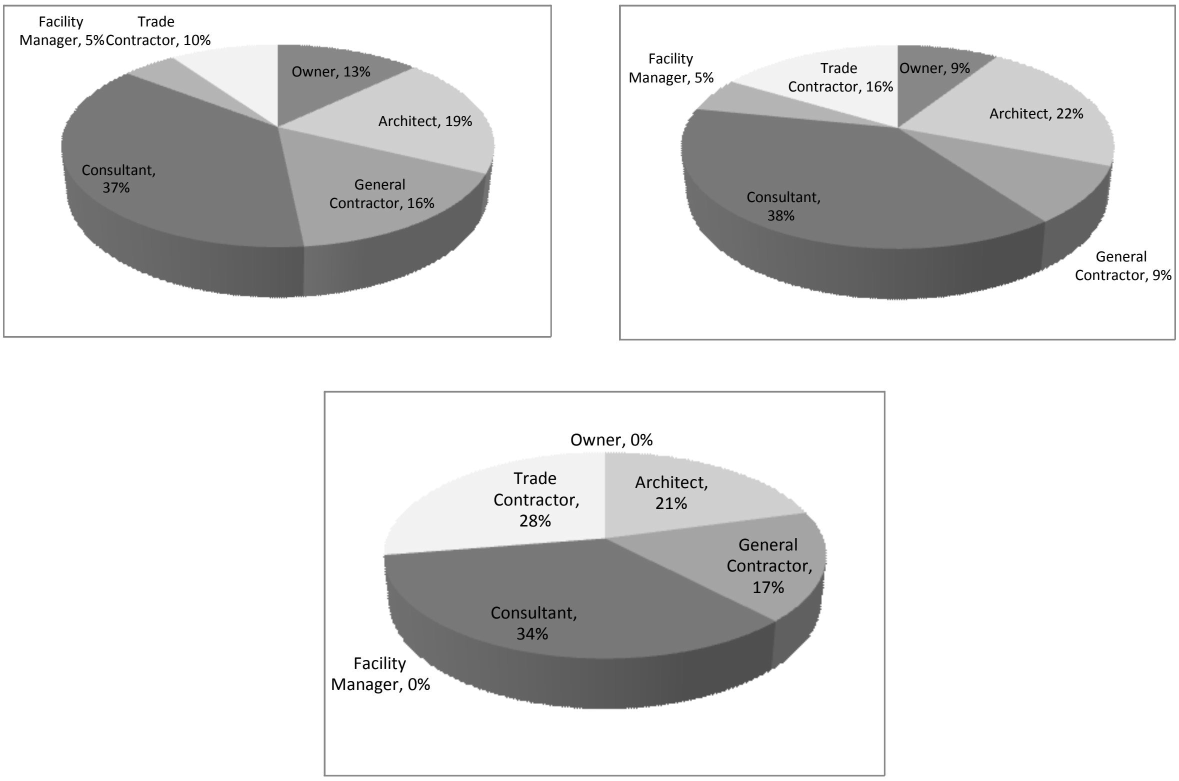

Figure 2. Team participation: I Criteria Design, II Detailed Design, III Implementation Documents Water Efficiency Category

During the conceptualization stage, team members should determine the goals and objectives of the project, the different responsibilities of each team member and how these responsibilities are going to change and evolve throughout the project, and how the activities are going to be carried out. For the sustainable sites sustainability criteria and conceptualization stage activities, the base on the matrix, the observed participation distribution of team members is: owner 26%, architect 25%, engineer or specialty consultant 24%, general contractor 14%, trade contractor 0%, and facility manager 11%. The owner, architect and engineers or specialty consultants are the main players. The contractor and the facility manager have a secondary role and the trade contractor is not yet part of the team. The main objectives of these sustainability criteria are to locate the project on the right site and to minimize impacts on the selected site, not only during construction but also during operation. To achieve those objectives the entire team should define the goals and the communication strategies of the project, and should evaluate the associated risks and allocate the risk. In addition the owner, architect and engineers or specialty consultants should define the scope of work in order to maximize the sustainability criteria.

For the water efficiency sustainability criteria and conceptualization stage the participation distribution of team members according to the matrix is owner 23%, architect 21%, engineer or specialty consultant 27%, general contractor 10%, trade contractor 0%, and facility manager 18%. The main objectives of these criteria are to reduce the water consumption and to reduce the generation of waste waters from potable water. The main team players are the owner, the architect and the engineer or specialty consultant as well. However, the role of the facility manager takes more importance because the final user opinion is very important on defining water efficiency strategies.

For the energy and atmosphere sustainability criteria and conceptualization stage the participation distribution of team members based on the matrix is: owner 29%, architect 18%, engineer or specialty consultant 27%, general contractor 11%, trade contractor 0%, and facility manager 14%. The main objectives of these sustainability criteria are to optimize the energy efficiency of the different systems installed on the project and to reduce the atmospheric emissions generated either by the project or by the generation of energy used by the project. The key project participants are the owner and the engineers or specialty consultants, because they must make the most important definitions; however participation of the architect and facility manager is important as well. Within these sustainability criteria input from the engineers and specialty consultants is higher compared with previous criteria, because they should make the major definitions. The architect acts as a support for engineers and specialty consultants. The owner receives important feedback from the facility manager; however he/she remains the major decision maker. The participation of the general contractor at this point is very similar to his/her participation on previous sustainability criteria, and deals especially with preliminary programming and estimating.

On the other hand, the participation of team members on the intersection of the materials and resources sustainability criteria and the conceptualization stage activities is different from the participation presented on previous sustainability criteria. Their participation distribution according to the matrix is owner 27%, architect 30%, engineer or specialty consultant 6%, general contractor 29%, trade contractor 0%, and facility manager 8%. The main objectives of these sustainability criteria are to reduce the consumption of raw material, especially non-renewable material and to minimize the generation of construction wastes and project waste during operation. The main decision makers are the general contractor, the architect and the owner. The participation of the general contractor becomes crucial; because of his/her knowledge in terms of materials availability. The role of the engineer and specialty consultants is reduced, because the lead designer on these matters will be the architect. The main input from the facility manager is in regard to the operation requirements of the collection of recyclables facilities.

In terms of the participation of team members on the interaction between environmental quality sustainability criteria and the conceptualization stage, the distribution is owner 23%, architect 22%, engineer or specialty consultant 19%, general contractor 18%, trade contractor 0%, and facility manager 17%. These sustainability criteria seek to guarantee a healthy and comfortable environment for the final users of the facility and deals with three main components: design of building systems that provide adequate ventilation and comfort, provide the final users with clean air, and provide the final users with the possibility to control their own environment. The owner's and the facility manager's input deals with the requirements from the final users in terms of environmental quality. The architect and the general contractor are involved in the decision making process for selecting low-emission materials, and the engineers and specialty consultants are involved in the definition of building lighting and HVAC systems.

During the conceptualization stage major decisions have to be taken in terms of the innovation criteria that the project will have. All project team members play a crucial role in these definitions.

On a traditional delivery system process project, during the planning or conceptualization stage, the only project participants who are part of the team are the owner and sometimes the architect. Similar to the engineers and specialty consultants, the general contractor and the facility manager are not yet part of the team, so an important portion of the knowledge and experience required in order to make decisions that optimize the synergies between the building systems and components, is lost in the process. In addition, if the facility manager is not part of the team, many decisions will not be made with the final user and operator of the project in mind and several changes will have to be made, when the facility starts operation.

The design phase is divided into three stages: criteria design, detailed design and implementation documents. The criteria design stage main objectives are to evaluate different design options and to select the most appropriate for the project, to finalize the definition of scope of work, and to define the basis and criteria of design according to the owner's project requirements. Ideally the subcontractors should come on board at this stage. Afterwards, the detailed design main objectives are to finalize the design and to reach agreement on tolerances between subcontractors. Finally the main objectives of the implementation documents stage are to determine the construction means and methods and to start the process of shop drawings and prefabrication. The role of each team member will change throughout the design process.

For interaction between the sustainable sites sustainability criteria and the criteria design activities the team participation distribution based on the matrix is: owner 14%, architect 24%, engineer or specialty consultant 34%, general contractor 21%, trade contractor 7%, and facility manager 0%. Those percentages change when entering the detailed design as follows: owner 12%, architect 21%, engineer or specialty consultant 35%, general contractor 16%, trade contractor 16%, and facility manager 0%. And for the implementation documents the participation is owner 0%, architect 20%, engineer or specialty consultant 31%, general contractor 25%, trade contractor 24%, and facility manager 0%. During the criteria design the participation of the owner is very important to finalize the scope definition and on the selection of design alternatives. During the detailed design his/her main role is on the establishment of required quality levels. On the other hand for the period of implementation documents the owner does not have much contribution because major definitions and decisions have already been made. The participation of the facility manager is not very significant for the interaction of sustainability criteria and the design phase. On the other hand, the participation of the architect is high at the beginning of design but is reduced throughout the process, because he/she is not the main designer for most of the building systems, and the architect acts as support for the engineers or specialty consultants. The role of the engineers or specialty consultants is very important because they are the main designers in terms of sustainable sites sustainability criteria. Contrary to the traditional construction process, all engineering systems are completely defined and the knowledge of engineers and specialty consultants is included in the schematic design; therefore the sustainability of the project is optimized.

Another important difference compared to a traditional project is the early input from the general contractor and the trade contractors, which influence the sustainability of the project. Their participation allows truly finalizing the design before construction starts, because most design inconsistencies are detected during constructability reviews of the design phase; therefore changes to design during the construction phase will be reduced. In addition prefabrication can start before actual construction begins, allowing a quicker and leaner process.

In terms of the interactions between the water efficiency criteria and the design phase, the team participation based on the matrix should be during the criteria design: owner 13%, architect 19%, engineer or specialty consultant 37%, general contractor 16%, trade contractor 10%, and facility manager 5%; during the detailed design owner 9%, architect 22%, engineer or specialty consultant 38%, general contractor 9%, trade contractor 16%, and facility manager 5%; and during the implementation documents owner 0%, architect 21%, engineer or specialty consultant 34%, general contractor 17%, trade contractor 28%, and facility manager 0%. The participation is very similar to the participation on the interaction between sustainable sites sustainability criteria and the design phase. The owner has a greater participation during the criteria design but his/her participation is reduced on the implementation documents. The participation of engineers and specialty consultants is important and is very constant throughout the design phase, because they are the main designers of the plumbing and irrigation system; therefore they should participate when the determination of scope is being finalized, the definition of bases or criteria of design and the final design of the system. The participation of the general contractor and subcontractors is very similar to their participation on the past interaction. The architect plays a role of support for the engineers and specialty consultant and helps on the selection of sanitary artefacts. The participation of the facility manager is higher compared to that defined in the sustainable sites sustainability criteria because he/she plays an important role in the scope definition and on the establishment of required quality levels.

The participation of the different team members on the intersection of the energy and atmosphere sustainability criteria and the design phase is for the criteria design stage: owner 18%, architect 8%, engineer or specialty consultant 39%, general contractor 18%, trade contractor 11%, and facility manager 6%; for the detailed design stage: owner 8%, architect 41%, engineer or specialty consultant 38%, general contractor 12%, trade contractor 23%, and facility manager 4%; and for the implementation documents stage: owner 0%, architect 8%, engineer or specialty consultant 36%, general contractor 25%, trade contractor 31%, and facility manager 0%. The owner has higher participation during the criteria design phase because he/she should be part of the selection of energy systems and on the definition of some components such as renewable energy systems. The owner participation is reduced afterwards; his/her main role is on the definition of quality levels requirements. The main role of the facility manager is in regard to the definitions of the measurement and verification system. The role of the architect is of support to engineers and the specialty consultants, because the most important designers of the energy systems are the specialty consultants.

For the interaction between the materials and resources sustainability criteria and the design phase, the participation distribution of team members during the criteria design is: owner 15%, architect 44%, engineer or specialty consultant 2%, general contractor 35%, trade contractor 4%, and facility manager 1%; during the detailed design: owner 16%, architect 42%, engineer or specialty consultant 4%, general contractor 30%, trade contractor 7%, and facility manager 1%; and during the implementation documents: owner 0%, architect 57%, engineer or specialty consultant 0%, general contractor 33%, trade contractor 10%, and facility manager 0%. The participation of the team members on this interaction differs compared to the participation on previous sustainability criteria. The architect is the major decision maker and receives important input from the general contractor. During the first stages of design the owner participates on the selection of design options and on the establishment of quality levels. The facility manager has very small participation and it is regarding space for collection of recyclables during operation. The participation of engineers is low and deals with reuse of existing building structural components or selection of structural material.

Regarding the intersection of environmental quality sustainability criteria and the design phase, the participation distribution of team members during the criteria design is: owner 13%, architect 29%, engineer or specialty consultant 24%, general contractor 22%, trade contractor 8%, and facility manager 5%; during the detailed design: owner 10%, architect 26%, engineer or specialty consultant 27%, general contractor 14%, trade contractor 16%, and facility manager 7%; and during the implementation documents: owner 1%, architect 28%, engineer or specialty consultant 26%, general contractor 22%, trade contractor 22%, and facility manager 1%. The role of the owner is very important compared to other sustainability criteria especially during the first two stages of design, because these criteria deal with user wellbeing. The facility manager plays a role in those stages as well, especially on the determination of comfort levels. Within these sustainability criteria, both the architect and engineers and specialty consultants play the main roles as designers throughout the process. The general contractor has a higher participation at the beginning of design, his/her participation decreases at the middle stage, and increases again during the elaboration of implementation documents. The participation of subcontractors is very similar compared to their participation to achieve the energy and atmosphere sustainability criteria.

In a conventional process, usually only the owner and architect participate during the schematic design phase; therefore the definition on major engineering systems is done later in the process, when achieving synergies between them becomes very difficult. In addition, the knowledge of engineers and specialty consultants is lost on the development of the architectural design. Moreover, the construction team comes on board when the design is supposed to be finished; therefore their knowledge is completely lost on the design, and major design problems appear late in the construction phase, when changes are very expensive and solutions to those problems cannot be optimal. In a traditional project process the procurement takes a long time after the design is concluded; therefore sometimes prefabrication options are reduced.

In an integrated project the construction process should be very smooth, because of the previous coordination and detail finalization; therefore the changes should be reduced. The optimum participation of team members does not vary significantly on the interaction of each sustainability criteria group and the construction phase activities. For the sustainable sites sustainability criteria the team participation should be: owner 7%, architect 4%, engineer or specialty consultant 8%, general contractor 37%, trade contractor 36%, and facility manager 8%; for the water efficiency should be: owner 5%, architect 8%, engineer or specialty consultant 12%, general contractor 31%, trade contractor 31%, and facility manager 13%; for the energy and atmosphere should be: owner 8%, architect 4%, engineer or specialty consultant 22%, general contractor 26%, trade contractor 25%, and facility manager 16%; for the materials and resources should be: owner 6%, architect 5%, engineer or specialty consultant 0%, general contractor 39%, trade contractor 44%, and facility manager 7%; and for the environmental quality should be: owner 7%, architect 8%, engineer or specialty consultant 19%, general contractor 27%, trade contractor 27%, and facility manager 12%.

During construction, participation of the architects, engineers and specialty consultants should be very low and in terms of resolution of inconsistencies in design. Their main participation should be in the commissioning and acceptance stage. In the sustainable sites sustainability criteria the main players are the general contractor and the subcontractors; the participation of the owner, facility manager and design team should be mainly at the acceptance phase. In the water efficiency sustainability criteria the participation of the team is very similar to their participation in the sustainable sites sustainability criteria; however the participation of the owner and facility manager should be greater at the acceptance phase. In the energy and atmosphere the participation of the owner and the architect is low and mainly affects the acceptance stage. The general contractor and subcontractors play a very important role, not only on the implementation of the project, but also during training of the facility manager and final users. The role of the specialty consultants and the facility manager is higher during the commissioning and acceptance process, because an important amount of equipment, components and systems should be tested at this point. On the other hand, on the materials and resources sustainability criteria the main role is the general contractor and subcontractors, the participation of other team members is very marginal. In the environmental quality sustainability criteria, the participation of team members should be comparable to their participation on the energy and atmosphere sustainability criteria.

Finally during operation and maintenance it is expected that the facility serves its function as intended, that changes are reduced or eliminated, and that call backs are eliminated. There is not a significant difference on the optimum participation of team members depending on the sustainability criteria selected, because for most sustainability criteria (with the exception of materials and resources), the participation of team members is around 75% for facility manager and 25% for a specialty consultant. On the materials and resources the participation of the facility manager is 100%. As the opinion of the facility manager and the user has been taken into consideration since the conceptualization phase, the facility is supposed to reflect all these opinions and no changes are necessary. During the operation and maintenance phase it is essential to have a program of continuous training not only for the facility management and maintenance team, but also for all final users. In addition it is very important to conduct user satisfaction surveys to determine aspects for improvement.

Conclusions

In order to create sustainable buildings, it is important to provide integrated design, construction and operation throughout the project; all stakeholders must participate in the planning and design, requiring a new process for the AEC industry. Factors that need to be considered and that can aid in successful sustainable buildings include: selection of project team members early in the process, increased collaborative and open communication, coordination among team members from the start, and the selection of design options and systems, based on their environmental and social impact through value engineering.

The integrated project delivery approach has the potential to optimize the sustainability of the project. Decision making should be incorporated early in the conceptualization and criteria design phases of the project; therefore, early contribution by all team members is required, so that everyone understands the project goals and objectives and can fully utilize their specialized capabilities to benefit the project. Each key stakeholder plays a different role within the project as it evolves, and the intention of the integrated approach is to maximize these roles, with the support of other team members.

Construction project integration should be attained in two different levels; one is the integration of project components and systems, and the other is integration of processes and the team. The first approach on the conception and understanding of the project as a holistic system, composed of interacting subsystems; therefore the optimization of that system is reached when synergies among those subsystems is attained, because the whole is more than the sum of its parts. In order to achieve systems integration, it is necessary to achieve the second level of integration. The process and team integration seeks to carry out a collaborative process integrated by the key project team members, who actively participate in the establishment of common goals and objectives at the early stages of the project on a participative decision making process. The team is formed very early in the process and is built upon a culture of trust and ethics. The responsibilities and the risks are allocated to the party which can better handle them and which has the capacity to minimize the risks. Information is exchanged between different parties through a process of open communication, making correct use of technology to improve the communication process. The different parties are working on the best interest of the project and not on the best interest of the party, because performance is measured in terms of project optimization and not local optimization.

These changes should be led to a large extent by the clients and top management, because they should select the delivery system that will be used and should set the culture of the project. However, the changes will not take place if they are not implemented by the entire supply chain. It is necessary to change the contracting and reward structure towards a structure that rewards the achievement of common goals in the best interest of the project, and not individual local optimization. These changes are not going to be possible while the team selection, contracting and reward are based on a design bid build (DBB) project delivery method. On DBB the selection criteria is based only on costs and the contract wording rewards only the individual performance and does not allow innovation. Moreover most team members come on board when major decisions have been made and most of their knowledge input has been lost. In addition to changes in delivery system, it is necessary to change the industry culture towards a culture of trust and ethics, therefore commitment should be not only from the client and the top management but also from the entire team. In order to make projects more sustainable, effective and able to meet all objectives, the selection of project delivery system is paramount, enabling a culture of trust and ethics, commitment from owners, and the entire team. Otherwise sustainability, satisfactions and savings are sacrificed.

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5

Education for Sustainable Construction

Sander van Nederveen, Reza Beheshti

From	TO
Supply-oriented work	Demand-oriented work
Capacity and effort-oriented work	Result-oriented work
Fragmented work	Integrated work
Fixed price at inception	Value versus price at the end
Risk management prior to the process	Risk management during the process
Focus on the control of costs	Focus on production of benefits
Building for a few parties	Building for all stakeholders
Settling everything at inception	Dynamic steering
Payment for promises	Payment for deliveries

Education for Sustainable Construction

Development of Knowledge and Skills for Industrialized, Integrated, Intelligent Construction

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Abstract

One of the most important prerequisites of sustainable construction is the education of construction professionals who have knowledge of innovative concepts for sustainable construction, and have the capacity and creative attitude to initiate and lead innovations for sustainable construction.
This chapter presents and discusses the way current civil engineering students at Delft University of Technology are prepared for their role as future leaders in construction innovation. First, a vision and a number of themes are discussed that are used for the development of the current curriculum. These themes are partially related to the Living Building Concept and are dealing with such themes as value-oriented building and Building Information Modelling. Next, the current curriculum is described with an emphasis on the courses that should contribute to the goal of education for sustainable construction. Finally the curriculum is evaluated against the vision and objectives on sustainable construction.

Keywords: sustainable construction, integrated design, education, value orientation, building information modelling

Introduction

Sustainable construction has become a key theme in recent years. Global warming, CO_2 emissions and expected shortage of energy and resources have become very important issues for the Building and Construction (BC) industry. Construction companies and public bodies need to deal with these issues, because of their societal responsibility, but also for making money.

Sustainable construction requires both technological and process-related innovations. An important success factor for innovations, especially for process-related innovations, is that the construction professionals can deal with innovations. Moreover, construction professionals need to be able to initiate and lead process innovations. Construction skills and training needs have changed with the introduction of new business processes, different forms of organizing production and technical innovation. In most countries adapting to changes has failed when ignoring the needs of a modernizing industry and the necessity for innovation and training. Formal training programmes proved to be inappropriate in content and method of delivery. The BC industry needs to provide the types of skill and training required to implement innovative approaches for improving the BC performance. A new generic, individually based and life-long training programme is required for the BC practitioners, trainers, researchers and policy makers, supported by the new media (Gann and Senker, 1998).

This observation has important implications for the education of construction professionals. It means that faculties and schools for construction professionals, such as faculties for architecture and civil engineering, should pay a profound of attention to basic concepts that are needed for process innovation in construction, or more specifically, for industrialized, integrated and intelligent construction. Furthermore, innovation potential and creative thinking must be stimulated, not only in the technological context, but also in the process context.

This chapter discusses the way the section Design & Construction Processes, at the Delft University of Technology, Faculty of Civil Engineering, is trying to realize this, i.e. trying to educate construction professionals who are aware of the concepts of industrialized, integrated and intelligent construction, who are innovation-minded and creative thinkers who can help construction companies and organisations with their necessary innovation processes.

Objectives

The objective that this chapter addresses is to identify how to prepare students for their future role as a construction professional who is not only a valuable designer, engineer or construction manager, but who is also able to initiate and lead future innovations in the context of industrialized, integrated and intelligent construction. In short: this chapter addresses the question how students must be educated in order to prepare them for their role as construction professionals in a sustainable society.

Background

The context of the work presented here is the Civil Engineering study, as offered by the Faculty of Civil Engineering and Geosciences (CiTG) at Delft University of Technology (2009).

The Civil Engineering study is structured as follows. In the BSc stage there is a three year study programme in which mainly basic subjects are taught, including mathematics, mechanics, design projects and general theory of construction. Furthermore, students are introduced into the main specialist fields of the faculty: Water, Construction, Transport and Earth. In the first half of the third year, students can choose a minor program in an area of their interest. Apart from this minor program, there are few possibilities for elective courses in the BSc program.

In the MSc stage, students choose a specialization track and must follow a two-year program of that specialization. Examples of MSc specializations at civil engineering are Hydraulic Engineering, Water Management, Building Engineering, Structural Engineering, and Transport & Planning. In addition, there are some inter-faculty or cross-faculty specializations, for example Construction Management and Engineering and Offshore Engineering.

In practice, this broad BSc curriculum is characterized by an emphasis on fundamentals, especially mathematics, and on “hardcore” engineering courses such as mechanics, structural dynamics, hydraulic engineering etc. The MSc stage is much more specialized and the character of this stage is highly dependent on the chosen specialization.

However, students need to learn more than hardcore engineering courses in order to become valuable engineers. Students also need to learn design skills, management skills and ICT skills. Probably more significantly, they need to develop an innovative and creative attitude towards the engineering profession. This chapter discusses how our group tries to develop these skills and attitude for our students, within the limitations of the curriculum.

Vision

The main motivation for curriculum development by our group is formed by the needs of the construction industry for adapting to inevitable changes required by transitions in the BC industry. According to our own observation, the success of construction projects usually does not depend on technical or technological factors, but on human and organizational factors. Therefore students should be educated as engineers who not only can solve difficult technical problems, but who are also able to cope with the human and organizational aspects of construction – now and in the future based on this transition of the Dutch BC industry (Table 1).

Table 1. Transition of the Dutch construction industry (also known as the PSIBouw 8-liner)

From	TO
Supply-oriented work	Demand-oriented work
Capacity and effort-oriented work	Result-oriented work
Fragmented work	Integrated work
Fixed price at inception	Value versus price at the end
Risk management prior to the process	Risk management during the process
Focus on the control of costs	Focus on production of benefits
Building for a few parties	Building for all stakeholders
Settling everything at inception	Dynamic steering
Payment for promises	Payment for deliveries

Then what are the needs of the construction industry? A lot is known about this from many studies carried out on this subject. For example, in the Netherlands a large research programme called PSIBouw is just finished, wherein a number of themes are identified in which construction companies and organisations are interested (PSIBouw, 2009). Examples of such themes are new collaboration forms, value-driven building processes, improvement of trust between participants of building projects, and exchange and sharing of building project information.

Another source of information is the experience of our MSc candidates who work at a construction company or organisation for preparing their final MSc thesis. From these students we learn that there is currently a strong interest in themes such as system engineering, value engineering, chain integration, risk management and, again, value-oriented building processes. To summarize, there is a strong interest from the construction industry in competences such as collaboration across disciplines and integration of disciplines.

However, our primary focus should not be the requirements of the current construction practice, but the requirements of the *future* construction practice. Of course there is less known of the future requirements, but we have no doubt that it is necessary to pay attention to new ideas and concepts that are not yet common in construction, but that are expected to become dominant.

Themes for Construction Innovation

Over the years, our group has identified a number of themes for the construction future. Most of these themes have been incorporated in the so-called Living Building Concept (De Ridder, 2006), an approach for innovative design and construction processes that can be seen as a holistic approach based on various concepts from design theory, systems engineering, value engineering, etc. The ‘Living Building’ concept consists of:

- A vocabulary of systems and processes together with a glossary of relevant terms.
- An extensive discourse of the role of perception in building – which for the current building paradigm unfailingly leads to great excesses in costs and time, often associated with quality problems. This is also one of the main reasons for the development of the ‘Living Building’ concept.
- A description of the interrelationship between the economic notions such as value, purpose, costs, price, revenue, budget, income, effectiveness, efficiency, productivity, etc.
- A description of actors, their mutual dealings and the subsequent effects thereof.
- A description of three different life expectancies (user’s life expectancy, economic life expectancy, technical life expectancy) and their corresponding values, as well as their whole life costs.
- A description of steering parameters and their degree of dependency on factors that are either variable or have to be considered a constant.

- A complete methodology for procurement and collaboration of all stakeholders in building, as well as a description of all relevant corresponding influence factors and the development of relevant selection criteria.
- A complete methodology for risk management, with a clear distinction between strategic, tactical and operational risk management.
- A conceptual contract matrix from which options can be chosen to enable dynamic interaction between different parties, with contrasting interests, to achieve a common goal, in order to increase benefit (the difference between value and costs).

The main themes for construction innovation that we have identified are discussed below.

Dynamic Control of Projects

Traditional construction projects rely on contracts based on the lowest price. The control of such projects is usually very static; requirements and constraints are fixed, the price is fixed, etc. These fixations become problematic when unexpected complications occur - or opportunities. In our view construction projects can greatly benefit from what we call dynamic control of projects.

Dynamic controlled projects are those in which parameters such as price and quality are not fixed. When something unexpected happens, the project participants can negotiate and decide how to proceed. For example, if a significantly better quality can be achieved with a small financial investment, then this can be agreed upon without renewal of all the contracts.

Supply-Driven Construction Processes

In traditional building projects the project specification is fully determined by the client. Clients prepare a detailed design of what they want themselves, or hire a designer to do so. The supplier starts his work with a detailed design and works from there. This means that suppliers of traditional projects must be prepared to deal with all sorts of design proposals, and with all kinds of building methods. This traditional way of working can be called a “client-driven” building process.

In a supply-driven construction process, the roles of client and supplier are quite different. In such processes, the supplier is in fact the leading participant: the supplier develops a design based on his own building system, which consists of a limited set of standard parts and connections. The client only specifies in global terms what he wants, and approves or disapproves the result developed by the supplier.

Such a process is to a large extend comparable with how the car industry works: client goes to supplier, supplier shows product catalogue, client specifies in global terms, supplier develops a proposal, client gives his approval and production and delivery processes get started (Nederveen & Gielingh, 2008).

Industrial Building Enabled by Parametric Design

This theme is closely related to the previous one. In fact, parametric design is the key enabling technology for supply-driven construction processes. A parametric design system for construction can consist of standard parts and connections of the building system, as well as design and construction knowledge associated with the parts and connections. In this way it is also possible to gain insight in the consequences of the design proposal in a very short time, in terms of production and maintenance cost, but also in terms of environment impact etc.

Furthermore, a significant advantage is the possibility of controlled industrial construction process, with potentially a much higher degree of precision, performance predictability and lower number of construction failures.

Building Information Modelling (BIM)

Building Information Modelling (BIM) is typically an enabling technology. The essence of BIM is that all building information is stored in a computer model: geometry, material, decomposition structure, functions, performance characteristics, etc. through the building life cycle (Eastman et al. 2008).

BIM is obviously an enabling technology for parametric design systems for industrialized building as described above. But also approaches such as value-based construction and dynamic control of projects can benefit from BIM. It seems fair to say that almost any innovation in construction uses information technology, and in many cases BIM technology. The specific attention of our group is on Dynamic MIB.

In a Dynamic BIM model the elements are loose (variable) in dimensions, materials, etc. and the relationships (geometries, actions/relationships) are fixed (constant). The Dynamic BIM is concurrent and consists of existing building works and alliances. It is both a top-down system with specified client-oriented systems with all elements and relationships as a bottom-up and standardised system with all specified elements and relationships.

Sustainability and Life-Cycle Approach

Sustainable construction and life-cycle thinking are approaches for construction that have been around for a number of years, but still have not been fully adopted by the construction industry.

Interest in these themes has significantly increased in recent years as a result of the growing awareness of the effects of global warming, of limits on the supply of energy and other resources, and of the impact of waste on the environment. Recent milestones in this awareness development are the publication “An Inconvenient Truth” by Al Gore (2006) and “Cradle To Cradle” by McDonough and Braungart (2002).

Furthermore, the European Commission has identified Energy Efficient Building as a key area, if not as the most important theme for construction innovation for research and development for the coming years (EeB PPP 2009).

From Vision to Curriculum

The great challenge for our group is to incorporate the vision and the themes - described above in the curriculum of the civil engineering study. This section describes how and to what extend this is done. First the BSc stage is discussed, in which Design Projects play a crucial role. Next our two MSc tracks are discussed: the Design and Construction Processes track and the Construction Management and Engineering track. These two tracks are partly overlapping, but the first track puts more emphasis on design and modelling, while the second track puts more emphasis on policy and management.

The Bachelors Stage: Design Projects

As mentioned earlier, in the Bachelor’s phase of the civil engineering study, students have mostly mandatory courses and only a few elective courses. In the mandatory program, a key role is played by the Design Project courses.

In the Design Project courses students must develop a civil engineering design (often in the area of infrastructure) in a project team setup. In the BSc phase, all students follow three design courses: one each year, with a study load of 4-6 ECTS each (112-168 study hours).

The Design Project in the first year is in essence a first introduction and experience with design for most students. Many students make a serious design drawing for the first time in their life in this course. Also for the first time, students learn to deal with design requirements and learn how to develop a solution for these requirements. Moreover, they develop basic skills in the area of teamwork, holding meetings, taking minutes, collecting information (both from the library and from the internet), holding presentations, writing professional reports, etc. Please note that very little of these skills are learned in the mainstream science and engineering courses at the faculty. Because of this range of general skills that are addressed in the first year design project, the technical elaboration of the work is usually rather limited.

The Design Projects in the second and third year build upon the first year's course, with increasing complexity and difficulty. In the second year, the emphasis is on the different design stages and on going through the design cycle several times, resulting in designs on system level, subsystem level and component level. During these design stages, students also learn to apply cost estimation and risk management methods and utilize the outcomes in the design decision process.

In the third year the complexity of the project increases mainly because the team size increases to about 20 students, which means that the students must put more effort in organizing themselves. The project teams are required to work in sub-teams that are responsible for different disciplines (transport, building, hydraulic engineering and water management). Of course this project setup means that integration of the work of the sub-teams is an essential part of the project, and interface management becomes a natural issue.

The BSc Design Project courses are very important in our view, because in these courses students must find a solution for a complex problem in a design process, in which the analytical methods they know from engineering courses fall short. Furthermore, students must work together, need conference skills, etc. Also the educational format of problem-driven project courses is an "activating" format: it stimulates students to come into action rather than sit back, remain passive and listen to professors.

With respect to the vision and innovation themes discussed earlier, one can say that many themes are introduced but not yet explored in depth. The first concept students must understand is the concept of design, including its trial-and-error nature, and its unlimited solution space. Furthermore, students must understand the complexity of construction design projects and the need for a systems approach in order to cope with this complexity. This knowledge and the associated skills form the basis of the design education of our students. In addition to that, students are introduced to themes such as value-oriented thinking, dynamic control of projects, systems engineering, life cycle thinking and sustainable building.

Only the theme of Building Information Modelling remains almost untouched. Students do use information technology, but only conventional software such as Office, SketchUp and AutoCAD. And most importantly, students regard this software merely as production tools, and they do not recognize the information management aspect of design projects, or the potential of information integration that could be achieved with BIM.

The MSc Track Design and Construction Processes

The MSc Track Design and Construction Processes (2 years) is a specialisation within the broader track of Building Engineering. The track consists of the following parts:

- General Building Engineering courses, including structural engineering, building physics building informatics and construction management (approximately 4 months)
- Specialized Design and Construction Process courses, see further below (8 months)
- Electives (4 months)
- Graduation work (8 months)

The sequence in which the courses are taken may differ, but the graduation work is normally the last work.

The most distinctive part of the Design & Construction Processes track is the part of the specialized design and construction process courses (2nd bullet). This part consists of the following courses:

- Functional Design and Methodology

- Parametric Design
- Probabilistic Design
- Knowledge and Process Modelling
- Strategic Project Management
- Systems Dynamics
- Advanced Design Systems/Dynamic BIM

All courses are 4 ECTS (112 study hours), except the last course which is 8 ECTS (224 hours). More details on the courses can be found on the University website www.bouwprocessen.citg.tudelft.nl, under Education.

The titles of the course show the emphasis of this part of the track: design processes and building modelling (BIM). The idea is that students get acquainted with different design approaches and methods, including parametric design and probabilistic design, and with building modelling approaches and methods. In addition, students learn about topics such as strategic project management and system dynamics. Finally the gained knowledge is applied in a larger course, the Advanced Design Systems course.

Compared to other MSc tracks, this track distinguishes itself by its focus on design and on building modelling. This is motivated by the vision that engineers that excel in design and design processes as well as building modelling and BIM will become very important actors in a sustainable construction industry of the future.

The MSc Track Construction Management and Engineering

The MSc Track Construction Management and Engineering (CME) is a Master Track on its own. It is offered by the three Dutch Universities of Technology (Delft, Eindhoven and Twente), and it is not formally connected to the civil engineering faculty or any other faculty.

The CME Track consists of the following parts:

- Compulsory courses (approximately 8 months)
- Elective courses (8 months)
- Graduation Work (8 months)

The main compulsory courses are courses on the following subjects:

- Collaborative Design & Engineering
- Project Management
- Process Management
- Legal & Governance Aspects
- Integration and Orientation

These five courses are all 7-8 ECTS (196-224 study hours). More details on the courses can be found on http://www.3tu.nl/nl/onderwijs/construction_management_engineering.

As can be concluded from the course titles, this track puts more emphasis on project management aspects. The track has one compulsory design course (Collaborative Design & Engineering), but also one on Legal and Governance Aspects. Furthermore, typical elective courses that fit well in this track include courses on (construction) economics. But also courses of the previously discussed Design and Construction Processes track can complement the courses of this track very well.

Compared to the Design and Construction Processes track, the emphasis in this track is more on construction project management, although design and engineering are also present in this track. In addition, this track aims at the development of innovation-minded construction managers. Although the course titles may not show it, many courses deal with innovative concepts such as value orientation, life cycle thinking, systems thinking and systems engineering and cradle-to-cradle thinking. Again, the idea behind this is that in our view the current students must be prepared for their role as innovation enablers for a sustainable construction industry.

The profile of the construction manager of the future

The lists provided in this section are based on the trend analysis made in the previous section and complemented with the results of subject-specific interviews with specialists in the field of CME and a graduate student survey conducted by the Faculty of Civil Engineering and Geosciences (CiTG) in 2005.

Regarding the general and scientific personal requirements of the construction manager of the future, he or she should have the following qualifications:

- A thorough scientific attitude. In his or her scientific attitude he or she does not restrict himself or herself to the specific boundaries of the CME domain and is able to cross these boundaries
- The ability to reflect on the complete scope of matters and issues in the domain: is able to form an opinion and contribute to discussions
- As an academic, the manager understands the potential benefits of research and is able to understand and incorporate the results of research
- Understands the importance of oral and written communication skills, in particular in English, and can make effective use of these
- Has the habit to reflect upon his or her own work and continuously uses relevant information to improve his or her competences
- Is able to operate (or lead) multi-disciplinary and multicultural teams

Regarding the domain-specific requirements of the construction manager of the future, he or she should have the following qualifications:

- Is able to work from different disciplinary viewpoints and levels, including the ability to recognize and to work with the interconnections that exist between levels
- Has a life-cycle mindset: is able to make decisions which guarantee future values and benefits
- Has a demand- and client-oriented mindset: is able to help clients to specify their needs and to translate these into products with most benefit for both client and supplier
- Understands the fundamental difference between process- and project management and is able to apply the underlying techniques and methodologies in projects
- Understands the concepts of dynamic control at strategic, tactic and operational levels in the different life-cycle stages of projects
- Is able to recognise and to control uncertain factors (i.e. risk management), with a special attention for process aspects and (not individual) safety aspects
- Understands the concepts for optimal design/composition of plans and projects, incorporating technical, financial, economical and social viewpoints
- Is able to recognize the relevant legal aspects during construction processes and is able to analyze these in the context of public and private institutional frameworks
- Understands the concepts of financial engineering including project financing and financial accounting and is able to recognize the associated risks

- Is able to make a well-considered judgement of the applicability of IT instruments at individual, project and company levels.

The list regarding general, scientific personal and domain-specific requirements was the starting point for the development of MSc CME specialization at the Delft location of the 3TU GS.

As mentioned earlier, the section Design and Construction Processes at the Faculty CiTG leads in the development process of the MSc CME programme in Delft. The mission of this section is the scientific clarification and practical promotion of the theme “process and system innovation in buildings”. This goal will be achieved by creating a link between innovation and the scientific research providing a significant contribution to both science and the society. This contribution will be realised by the “Living Building Concept” (LBC) as developed within the section. The LBC is an extensive theoretical framework of concepts wherein the value plays an equally significant role as the cost of a construction work. This approach will have widespread consequences for the relationships between stakeholders, the methods of tendering construction works, the assignment of tasks as well as the sharing of responsibilities and risks Ridder, 2005). The introduction and adoption of advanced information and communication technologies in the construction industry is seen as one of the key enablers for this change. Many of these concepts are (or will be) integrated with the obligatory and elective courses and are the research subjects of the graduation projects, which are conducted under the supervision of staff members of the involved section. In this respect, the participation of Faculty of Technology, Policy and Management (TPM) becomes of crucial importance, because of their wide experience in both education and research in several of the areas that are covered by the LBC. The Faculty of TPM aims to use internationally oriented teaching and research to make a significant contribution towards providing sustainable solutions to complex (social) problems which involves analyzing the structure and operation of technical multi-actor systems as well as the development of intervention strategies, practices, and instruments for designing and improving systems of this kind.

Based on the findings in the sections 5 and 6, the specific research profile of the section Design and Construction Processes at the faculty CiTG and the available expertise at the Delft location of the 3TU GS, a two-year MSc CME programme (divided in 8 blocks) has been developed (Table 2).

Table 2. Structure of the MSc CME programme in Delft

<table>
<tr><td>1.1</td><td>Legal and Governance Aspects</td><td>Choice 2/4:
1. Economics
2. Building Design and Construction Informatics
3. Realistic Design
4. System Dynamics</td></tr>
<tr><td>1.2</td><td>Process Management</td><td>Project Management</td></tr>
<tr><td>2.1</td><td>Collaborative Design and Engineering</td><td rowspan="2">1. Plan and project evaluation
2. Operations Research
3. Philosophy, Technology, Assessment and Ethics
4. Risk Management</td></tr>
<tr><td>2.2</td><td>Integration and Orientation</td></tr>
<tr><td>3.1</td><td>1. Dynamic Control of Projects
2. Financial Engineering</td><td>International Management/Cross Cultural Management</td></tr>
<tr><td>3.2</td><td>Preparing Graduation Project</td><td>Elective Courses (choice from list, incl. Knowledge Management and Advanced System Design)</td></tr>
<tr><td>4.1+4.2</td><td colspan="2">Graduation project (30 EC)</td></tr>
</table>

	general courses		obligatory courses		elective courses

Note that the whole CME programme has been benchmarked against similar CME programmes offered outside the Netherlands including programmes offered by the university of Loughborough and

University of Reading (United Kingdom), Universitat Stuttgart (Germany) and Purdue University (United States).

The following courses of the MSc CME specialization block contain IT related subjects:

- Building Design and Construction Informatics. This course is an introductory course of theories, methods and techniques regarding the application of information and communication technologies, to improve the quality, efficiency and effectivity of design and construction processes. The main emphasis of the course is on information modelling and product data technology for the building and construction industry. The goal of the exercises is to familiarise the students with the basic skills of building information modelling using UML (Unified Modelling Language) as well as building feature modelling using ArchiCAD.
- Knowledge Management (accompanying previous course in the list). The main emphasis of this course is on information management and knowledge technology for the building and construction industry. The goal of this course is to provide students with the fundamental knowledge and skills of IT tools in building and construction, including basic skills of process modelling using SADT techniques (IDEF0) as well as knowledge modelling using a real life case.
- System Dynamics. This course deals with dynamic non-linear feedback systems on a high level of aggregation in order to develop hypotheses and conceptual models for complex (civil engineering) systems. A computer supported gaming and simulation environment for advanced simulation of non-linear problem-solving will be offered to the students.
- Advanced System Design. In this course students (individual or as a group of two students) design, develop and implement a system for mainly a (building and civil) engineering problem. The emphasis of this exercise is on system development methods and techniques and the use of IT solutions. The goal of the exercise is to familiarise the students with practical aspects of system development, enabling them to employ IT-enabled tools whenever required for the purpose of their graduation project or during their professional work.

Results

The BSc Design Project courses described above have already been running for a number of years, with modifications almost every year. These courses generally function well. The students appreciate the courses and the lecturers share the opinion that students get a proper preparation for their role as designer/engineers.

On the other hand, the Design Project courses have their limitations. The courses are in fact umbrella courses for a wide range of skills; students can develop these skills up to a basic level, but not much further. For example, they learn a little bit about how to run and manage a project, but they do not get a thorough education in project management, including theories, methods and different approaches. The same can be said for subjects as cost management, risk management, etc. The reason for this is that the Design Projects are used as a vehicle for many skills – and recently some new skills are added to the list, namely Geo Information and Drawing.

For most aspects of design projects the training of so many skills in one course is not really a big issue for the BSc stage, as long as you do not expect too much from the students after these courses.

An exception is, in our view, the ICT aspect. In the current design projects, ICT is only seen as a tool for doing design work. There is hardly any attention for the information modelling or information management aspect of a design project. This can be seen in the MSc stage, where students apparently have no idea of ICT and BIM as key supporting tools for complex design projects.

The MSc tracks discussed in this chapter have a shorter history. The Construction Management and Engineering track started in 2007 and the first graduates left the university in 2009. In these few years, an enthusiastic community of CME students has formed (approximately 20-30 students per year). The

Design & Construction Processes Track only started in 2009 in its current form (before 2009 the track also existed, but lacked focus). Hopefully, this track will get an equally enthusiastic student community in the coming years.

Looking at the current curriculum of the two discussed MSc tracks, we can name a few subjects that deserve special attention:

- Systems thinking: many students have problems with systems thinking. They find it abstract and they do not see its value; civil engineering students prefer to solve calculations. This is a persistent issue, which will probably never disappear.
- Gaming and simulation: this is a new area that in our opinion has a lot of potential in the context of process innovation in construction. But we need to develop more expertise in gaming and simulation in order to be able to add more gaming and simulation elements to the curriculum.
- Sustainability: this is a broad theme including concepts such as Life-Cycle Thinking, Cradle-to-Cradle Thinking, Energy Efficiency, CO2 emissions, minimalization of waste etc. Many of these concepts are already discussed in our MSc tracks and also in the BSc courses, but not really in depth. While the sustainability issues are on the top priority list of policy makers (see the EU activities in this field), we can observe that still few students choose sustainability subjects for their graduation work. Also few companies and organisations stimulate graduation work on sustainability issues by offering internships.

From the above subjects, the subject of sustainability and all the associated concepts is probably the one that deserves most attention, for example when the current study programs need to be evaluated. However, regarding sustainability several barriers and limitations can be seen that make it difficult to make improvements. One limitation for civil engineering is that our faculty does not deal with indoor building spaces and therefore with heating and ventilation systems and other energy-consuming systems.

Another issue related to sustainability is that in the area of total energy and waste impact, a lot of analysis work and development of awareness remains to be done. For example, few people have insight into the energy consumption and waste impact of construction, production and transport of building materials, etc. compared to the energy consumption and waste impact of building use. As soon as the mainstream of construction companies and organisations get to know this kind of information and feel the urge to make improvements, then major steps can be taken towards a sustainable construction industry.

Conclusions

This chapter discussed the way civil engineering students at Delft University of Technology are prepared for their role as future innovation leaders for sustainable construction. The work presented is motivated by the vision that the success of construction projects is mainly dependent on human and organizational aspects of construction projects, related to design processes, building modelling and project management.

These ideas have been applied in a number of Design Project courses for the BSc stage of the civil engineering study, and in two dedicated MSc tracks: Design & Construction Processes and Construction Management & Engineering. Many important concepts for construction innovation are dealt with in these courses, such as value orientation, systems thinking, building information modelling and life cycle thinking.

However, some of these concepts are not yet sufficiently dealt with, most notably building information modelling and current sustainability issues such as energy consumption and waste impact. These subjects could significantly benefit both from new knowledge out of research projects and from knowledge out of construction practice. Hopefully, in the near future the transition can be made from research results to curriculum improvement, finally resulting in better construction engineers and managers that can take the lead in innovations towards a sustainable construction industry.

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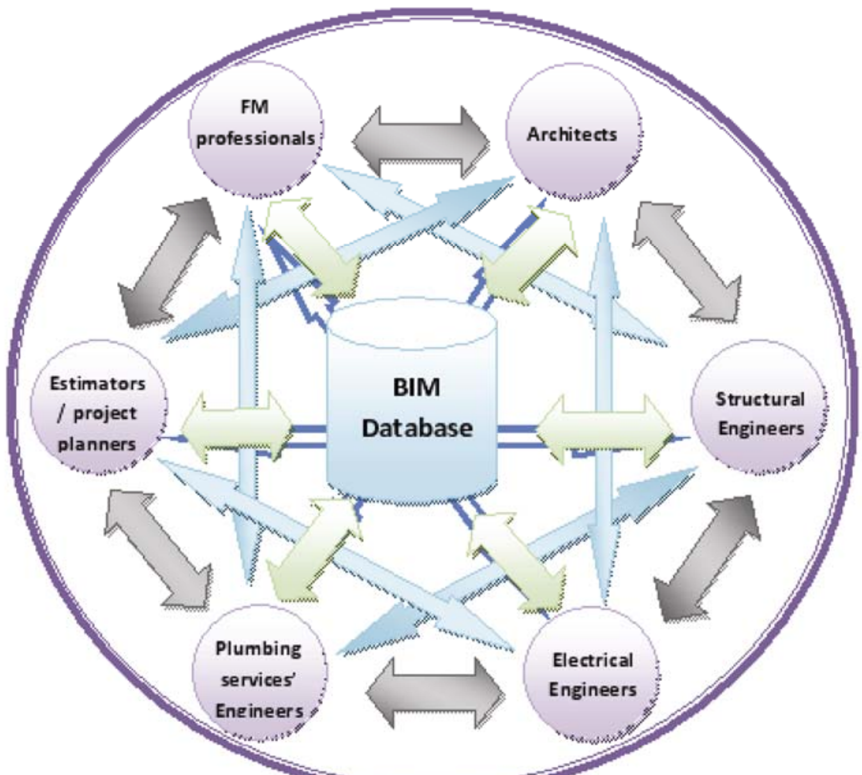
6

Modelling Outcomes of Collaboration in Building Information Modelling Through Gaming Theory Lenses

Oluwole A Olatunji, Willy D Sher, Ning Gu



Modelling Outcomes of Collaboration in Building Information Modelling Through Gaming Theory Lenses

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Abstract

Construction project performance is vulnerable to process fragmentation and weak frameworks for sustaining objectivity and value integration between stakeholders, including clients, involved in the project development processes. For centuries, conventional construction processes have endured the challenges associated with this phenomenon. Several industry reports have suggested this situation is responsive to effective communication, collaboration, thorough integration and a passion for objectivity in data sharing and information management between key players. While entity-based computer-aided design (CAD) lacks the framework to facilitate an effective result in this direction, Building Information Modelling (BIM) has shown the potential for major improvements over the limitations of manual and CAD design methods. Three Game Theory models (Prisoner's dilemma, Pareto Optima and Hawk-dove) have been proposed to mirror certain implications of players' *actions in BIM environment. In all the gaming lenses used, the study suggests that stakeholders and industry will only benefit when BIM is fully adopted. It has been established that when BIM is partially adopted, the compliant party is likely to benefit more, while the non-compliant party may not necessarily gain the same benefits. The study concluded that BIM means a lot to the industry; the industry cannot afford the consequences of failing to adopt BIM potentials and allied innovations in an era where digital technology is revolutionising other industries. Recommendations are made on areas for further research.*

Keywords: building information modelling (BIM), collaboration, game, hawk-dove, pareto optima, prisoner's dilemma

Introduction

The impacts of fragmented processes on whole-life performance of infrastructures in design, construction and facilities management industries are no longer issues of inconclusive debate. A wealth of evidence from well-known industry reports has shown how this limitation often leads to project failures, clients' dissatisfaction with professional service delivery, and variability in costs, contract periods and quality of projects. Many authors have used the respected UK's Egan (1998) and Latham's Report (1994), and the Hong Kong Housing Authority (HKHA's) Report (2000) for benchmarking public concerns over the image of the construction industry regarding project performance. Other studies (Acharya et al. 2006; Al-Momani 2000; Palaneeswaran et al. 2006; Ryd 2004) have further underpinned how significant the limitations of fragmented processes could imply on the interests of construction clients and other stakeholders.

As a potential solution for this challenge, previous studies have suggested the adoption and deployment of advanced tools of information technology (IT), which support objectivity, artificial intelligence and integration of processes. Although the implementation of integrative models of IT tools is not unknown in the construction industry, the tools being used (e.g. entity-based Computer-Aided Design (CAD)) have not been able to deliver the most satisfactory results. This is because entity-based CAD and allied applications largely support fragmented processes. Individual stakeholders design and input project data independently and without commitment to the interests of other stakeholders. Moreover, apart from the structural limitations that prevent entity-based CAD applications from triggering the needed drivers of success in integrated design systems, these applications also have major challenges with spatiality and information flow.

Several reports have identified the potential of building information modelling (BIM) in addressing both the limitations of CAD and revolutionising the entire design, construction and facilities management processes. According to (Luciani 2008), the revolution caused by BIM potentials, though new and not fully conceptualized, are truly radical and have started rebranding the structure of construction markets. However, some limitations also exist in the realization of all BIM promises. According to (Gu et al. 2008; Succar 2009), its adoption is still slow, and there is neither the definitive understanding of all disciplines regarding BIM capabilities, nor what is in it for their roles in a BIM-propelled revolution; or the comprehensive understanding of market drivers of clients' interests in a BIM market. Against these, BIM serves as a digital information repository wherein stakeholders are able to integrate, share data and values to create object-oriented designs and overcome all the limitations of entity-based CAD. Collaboration has been identified as one of the most important attributes of BIM that drive project performance (Gu et al. 2008 ; Lottaz et al. 2000). This chapter aims to review and mirror what collaboration means to the industry and its possible outcomes in virtual environments using some propositions of game theory; prisoner's dilemma, pareto optima and hawk-dove.

Objectives

The objectives of the study are as follows:

(1) To review the advantages of collaboration in integrated systems in design and construction processes.

(2) To predict the implications of collaboration in different gaming scenarios.

CAD and collaboration

The construction industry has witnessed a significant improvement in the adoption of information technology (IT) innovations in the past decades (Sarshar et al. 2002). According to (Doherty 1997; Samuelson 2002), entity-based CAD and allied applications have been a significant necessity of professional service delivery in the industry since the last century. CAD has generally been adopted as an equitable replacement for manual design systems. It has also been used as a reputable tool for research and in academic and professional training. Moreover, an unprecedented surge in sales of CAD in the last decade is a significant indication that CAD revolution in the industry is real (Langdon 2002).

The industry has witnessed tremendous improvements over manual conventions as the use of CAD becomes more popular. These improvements and merits, according to (McKinney and Fischer 1998; Winch and Deeth 1994), include improved speed, accuracy, quality, storage and transmission of design data, and manipulative features of electronic document management systems. Another advantage (Howard et al. (1998) is that CAD applications can instigate the exchange of digital information and integrated systems, which could drive success in certain aspects of design and construction processes. However, many schools of thought have argued that entity-based CAD systems also have marked limitations. Marir et al (1998) claimed that CAD systems support fragmented processes because different entity-based CAD applications do not communicate with each other. It also triggers information gaps between users as the methodology for compromising interface barriers is still a major challenge in the industry. Thus, whilst individual users enter discipline-specific data into CAD integrated systems, design and project information are still vulnerable to inadequacies, conflicts and errors.

Other industry reports, such as (Aranda et al. 2008b; Maher 2008; Succar 2009), have argued that entity-based CAD applications do lack the frameworks for facilitating simultaneous collaboration, and the integration of robust information into project databases. These CAD applications also feature primitive elements such as lines and splines instead of object-oriented (o-o) models, and other shortcomings that often become Achilles heels to the development processes and performance of construction infrastructures. Ankrah and Proverbs (2005) argued that performance of construction infrastructures depends largely on stakeholders' will and commitment to adopt best practices through thorough integration, value sharing, collaboration, effective communication and ease of manipulating designs in complex spatio-temporal dimensions.

Many of the major limitations in entity-based CAD often render designs vulnerable to inordinate errors, conflict of interest and fragmentation of information between stakeholders in design, procurement and facilities management processes. Some authors have also reported that these limitations support conventional fragmented processes, against collaboration which has been established as a vitally important component of integrated system. According to (Kalay 2001), collaboration is not limited to superficial or semi-structured co-ordination of project teams, rather it involves uniformity in the nature of data being created and transmitted in integrated system, and compliance with structured mechanisms for servicing the entire digital systems under which they operate. While investigating the drivers of effective collaboration in virtual teams, (Nikas et al. 2007; Rezgui 2007) argued that partial adoption of integrated technologies and wanton compromise of the ethos of collaboration could spur tragic outcomes on project expectations. The nature of these outcomes and the potential impact of total or partial breakdown in collaboration have not received adequate attention in existing literatures.

Moreover, (Han et al. 2007) also identified the industry's reluctance to adopt BIM, the limitations of entity-based CAD and allied applications being used; and the compatibility of these applications with integrated systems as some of the impediments to effective collaboration in virtual teams. There are three possibilities in collaboration, and they shall be used in later discussions as follows:

1. Perfect cooperation between parties to engage all the ethos of collaboration in BIM environment. This scenario will be referred to as perfect collaboration.
2. Partial cooperation between parties to engage the ethos of collaboration i.e. few component players of integrated systems may have all the requisite facilities and engage in BIM deployment while others do not have the framework to drive the system. The phenomenon shall be referred to as partial collaboration.
3. Outright lack of cooperation by stakeholders to collaborate. This scenario shall be referred to as null cooperation in the later part of this study. This concept shall be addressed as non collaboration.

Some other studies have demonstrated the potential of BIM in facilitating digital integrated systems that can overcome the limitations of entity-based CAD systems, and provide reliable platforms for facilitating enduring performance of construction projects in their entire lifecycles (Moses et al. 2008; Nakamura et al. 2006). However, BIM is an end in itself; it does not guarantee automatic results when deployed on every project until its functional drivers are activated appropriately. Meeting these requirements to service the performance of virtual environments has been a major challenge in BIM adoption. These requirements include appropriate skills (Sher et al. 2009) and compliant software applications (Tse et al. 2005) as well as the enduring spirit of collaboration (Aranda et al. 2008b). The goal of this chapter therefore is to elicit perfect collaboration as an important driver of success in the BIM environment. There are three main sections in this study: the first section reviews collaboration platforms in BIM, the second section exemplifies the applications of game theory in virtual environments, and lastly; the third section discusses possible outcomes of collaboration in specific scenarios through gaming lenses.

Collaboration platform and building information modelling

BIM means different things to different people and disciplines. Ironically, as BIM is still a young phenomenon in the industry, many of its potentials are still being conceptualized. Some of these attributes have been summarised in the literature presented in Table 1. Summarising these propositions, BIM evidently represents a dynamic platform for inter-operating digital information on construction projects, including virtual repositories for generating, sorting, sourcing, sharing, updating and extending all forms of digital data across dispersed disciplines that are participating in integrated systems. (Aranda-Mena et al. 2009) have summarized some contemporary and comparative opinions regarding BIM definitions and concepts. Arguably, BIM technologies, techniques and skills are laterally different and more productive than conventional CAD applications. Case studies reported by (Aranda-Mena et al. 2008a; Fusell et al. 2007; Olofsson et al. 2008) indicate that, apart from the adoption of software applications and integrated processes, success in BIM platforms is triggered by certain behavioural patterns in the stakeholders. Such necessary attributes include a genuine willingness and commitment of the stakeholders to co-operate, collaborate, share values and communicate effectively. As these frameworks are missing in entity-based CAD systems, and this challenge has clearly been criticised (McKinney and Fischer 1998), BIM promises a major shift in data management in conventional design, construction and facilities management systems.

Table 1. Literature chart on attributes of BIM

Major Attributes	Simple definition of attributes	(Lee et al. 2006)	(Aranda-Mena et al. 2009)	(Heesom and Mahdjoubi 2004)	(Tse et al. 2005)	(Fusell et al. 2007)	(Marshall-Ponting and Aouad 2005)	(Kalay 1998)	(Leung et al. 2008)
Inter-operability	Open and compatible exchange of digital information between all design stakeholders	✓	✓	✓	✓	✓	✓	✓	
Collaboration	Consistent willingness of all parties involved in BIM processes to share standardized information, use compatible tools and take responsibility as appropriate	✓	✓	✓	✓	✓	✓	✓	
Objected-oriented design	The use of 'real' objects to represent design variables instead of conventional entities or geometries	✓	✓	✓	✓	✓	✓		
Simultaneous Access	Not just like multi-window systems used in conventional CAD, it means interoperable access of all users to project database at the same time, even though they are separated by long distance.	✓	✓			✓			✓
Project visualization	Visualization of designs in multi-dimensional spatiality, including the use of 3D and object models	✓	✓		✓	✓	✓		✓
Auto-quantification	Automated generation of accurate quantities for procurement purposes – this is not just scaling and dimensioning, but integrated instigation of graphic and non-graphic data for procurement and construction purposes	✓		✓	✓	✓		✓	
Value-audit	Extensibility of model objects into both *soft and hard* structured value engineering and management concepts		✓		✓	✓			
Integrated systems	Combination of open systems that allow multi-disciplinary access, storage, design, engineering, estimating, simulation, planning and co-ordination	✓	✓	✓		✓	✓	✓	
nD-modelling	Multi-dimensional modelling, including architectural, engineering, procurement, construction planning and co-ordination, and other activities involved in whole life cycle management of facilities	✓	✓	✓	✓	✓	✓	✓	
Co-operation	Conscientious intent to selflessly participate in integrated systems, including surrendering, delivering, extending and protecting the integrity of digital information and systems, without wanton compromise at any stage	✓	✓	✓	✓	✓	✓		

Value integration	Recognition, understanding and unification of diversified multidisciplinary values, above trade egos and motives that trigger conflict of interest, but rather including the motivation and respect of all professionals involved in the project	✓	✓	✓	✓	✓	✓		
Effective communication	Exchange of compliant and robust digital information in manners that effectively drive the mechanisms of knowledge sharing in integrated systems	✓	✓	✓	✓	✓	✓	✓	
Virtual enterprise	Ad-hoc alliance of independent stakeholders, though geographically dispersed, to collaborate using agile, flexible, fluid, goal focused and web-based technologies to drive the ethos of integrated systems	✓	✓	✓	✓	✓	✓	✓	✓
Integrated Project planning	Extensive application of integrated design and project data for construction planning and co-ordination purposes	✓	✓	✓		✓		✓	✓
Simulation	The use of virtual characters (avatars) to replicate real life occurrences in a BIM			✓				✓	✓
Flexibility	Ease of manipulating higher dimension models to lower dimension models (nD… 5D, 4D – 2D) and vice versa without compromising the robustness, quality and accuracy of graphic and non-graphic context of the models	✓	✓	✓	✓	✓	✓	✓	

Against the limitations of CAD which often render it vulnerable to major errors and conflicts of interest between stakeholders in design, procurement and facilities management processes, collaboration has been established as an important component of an integrated system. According to (Kalay 1998; 2001), collaboration is not limited to superficial or semi-structured co-ordination of project teams; rather it involves uniformity in the nature of the data being created and transmitted in an integrated system, and compliance with structured mechanisms for servicing digital systems. While investigating the drivers of effective collaboration in virtual teams, (Nikas et al. 2007; Rezgui 2007) argued that the partial adoption of integrated technologies and a wanton compromise of the ethos of collaboration could result in poor outcomes on project expectations. Moreover (Han et al. 2007) also identified the industry's reluctance to adopt BIM, the limitations of entity-based CAD and the use of allied applications, and the compatibility of these applications with integrated systems as some of the impediments to effective collaboration in virtual teams. Arguably, there are three possibilities in collaboration, viz; perfect collaboration, partial collaboration and non collaboration. These scenarios are discussed below:

Perfect Collaboration

According to (van Leeuwen and Fridqvist 2006), there is perfect collaboration when virtual teams engage in concept modelling, which provides a flexible platform for the team to access data, even though they are dispersed and remote, and share resources in real time using corresponding applications. This implies, to achieve perfect collaboration, all parties and teams must adopt a relative approach to BIM concepts and technologies, and they must be committed to these principles for the entire life of the project. Moreover, what differentiates this system from other forms of collaboration earlier listed is that the creation and exchange of data is largely digital and reversible within the team and BIM database. Figure 1 describes the ontological relationship between team members in perfect collaboration.

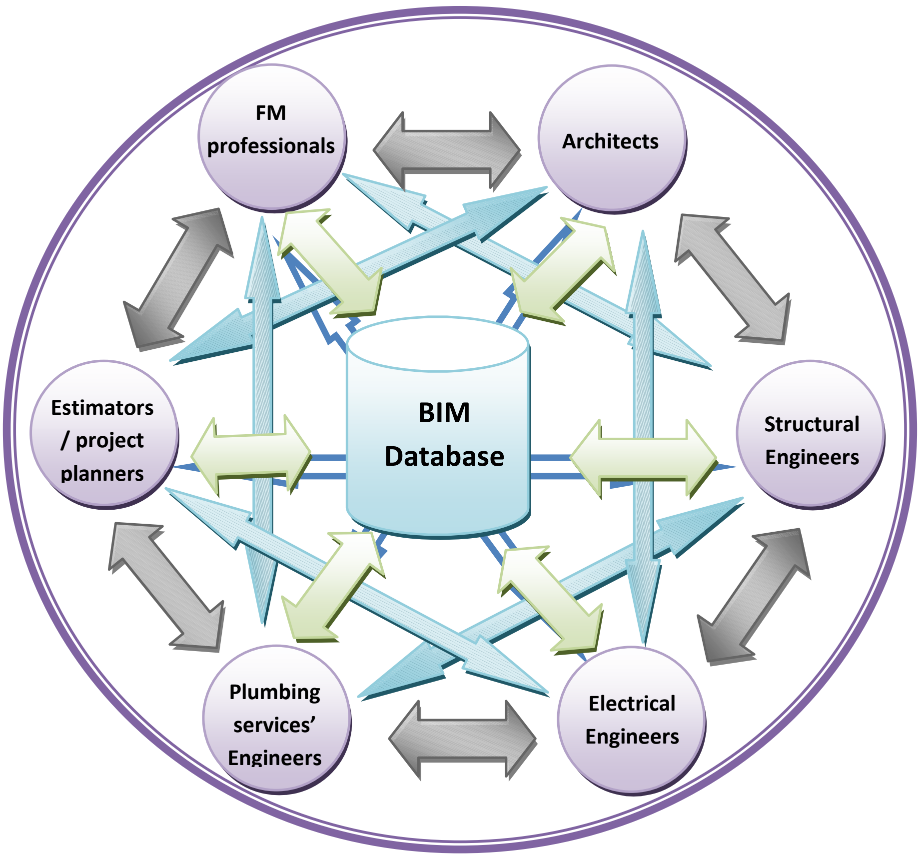

Figure 1. Ontological relationship between team members in perfect collaboration

Partial Collaboration

In contrast, partial collaboration implies that some members of the project team have the choice to adopt other methods against being compliant to BIM concepts and technologies, even though the project exemplifies contemporary design systems. This is most likely when a section of the industry adopts BIM and others who are not yet compliant take part in object-oriented CAD (o-o CAD) and allied applications. While the BIM-compliant party creates and shares digital data with other team members who are not BIM-compliant, the latter will struggle with some limitations, including organizational friction, inadequacies in technical processes and software compatibility problems (Dean and McClendon 2007; Zamanian and Pittman 1999). This phenomenon cannot but have particular implications for project development processes, and this has been exemplified in case studies that have reported on partial adoption (Aranda-Mena et al. 2008b). Figure 2 shows the information transfer process in a typical partial collaboration phenomenon.

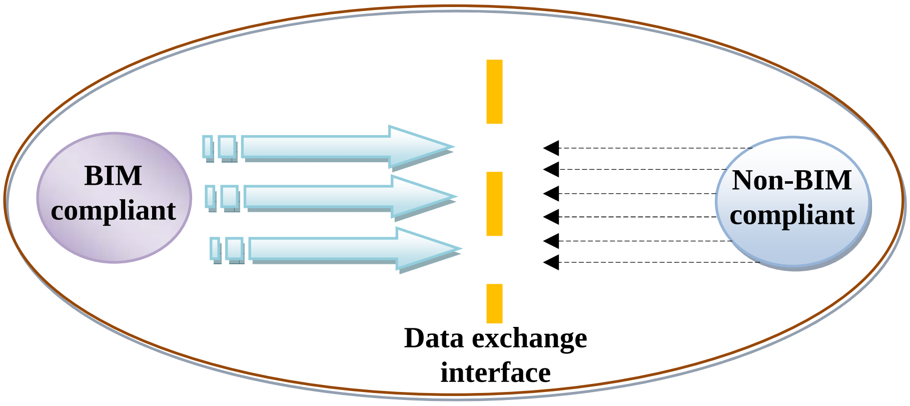

Figure 2. Typical partial collaboration phenomenon

Non Collaboration

Some authors (Baiden et al. 2003; Cheng 2003; Egbu et al. 2001; Gameson and Sher 2002) have used different case scenarios to demonstrate poor tolerance or non collaboration as a possibility in construction systems and their impacts on project delivery. Although, the authors reported the unique role of IT in promoting team spirit, it is impossible to rule out the fact that there are team players who are either yet to understand the role of IT and how to adopt what strategic tool and when, or have major challenges in adopting the ethos of team spirit that underlie integrated systems. Therefore, viewing non collaboration in technical and sociological contexts, there are two possibilities: (1) team members use entity-based CAD applications or analogue tools that have inconsequential or no relationship with integrated systems (Gross et al. 1998). (2) there are delibrate decisions by stakeholders to reject collaboration for strategic purposes (Parker and Skitmore 2005). These situations have far-reaching implications on project delivery; information flow will be marred by inconsistency, conflict, errors and delay in service delivery as team members are fragmented with technological bias against structured digital information management systems.

Depending on circumstances and contexts of use, non collaboration implies that members are more likely to take deliberate actions that defy team spirit, not just because software and other system dynamics are not compatible, but because they are commited to their actions and outputs being in constant conflict with other members of the team. According to Kolarevic et al (2000), members of a project team who engage in tools that support or dedicated to fragmented processes will have tough challenges with the ethos of collaboration in integrated systems, if not practically impossible, unless they adopt some changes that re-position the systems with which they operate. Moreover, Gruneberg and Hughes (2006) suggested that it is difficult to enforce thorough collaboration in project teams, including with clients, unless all stakehoders are committed to the dynamics of effective risk allocation that can overcome self interests. The same study underpinned the relevance of gaming in construction collaboration, in the light of team players' actions and the consequences of such actions.

Game theory and collaboration construction

Strategic applications of Gaming theory and industrial relevance

Game theory is often used to demonstrate the philosophies of social and system dynamics in team practices (Lane 1999). This has frequently been applied mainly on issues relating to conflict management (McCain 1999). The focus of Gaming mechanisms is to predict possible outcomes of behaviours when team members, also known as *actors* or *players*, choose to behave within limited options in specific collaborative scenarios. Though commonly used in behavioural sciences, game theory philosophies have been used to define construction situations, both as in life cycle processes and intrinsic forms of cooperation in collaboration scenarios (Gruneberg and Hughes 2006; Wübbenhorst 1986).

Rather than limiting the industrial application of game theory to cooperation and dispute scenarios only, (Vaaland 2004) argued that a good way to explore collaboration scenarios is to mirror its basic indices in non-dispute conventions. Therefore, as it is being popularly used in construction, it can also be used to model other scenarios where cooperation is an ultimate factor. This is not only because conflict explicates inverse relationships in cooperation, rather both concepts share identical variables (i.e. limited *IF* probability options in cooperation scenarios). Other empirical studies by (Auger et al. 1998; Sheehan and Kogiku 1981) have established the relevance of three forms or lenses of *Gaming* in construction, viz; (1) Prisoner’s Dillema (2) Pareto-Optima (3) Hawk-Dove. Some of the conditionalities that underpin the relevance *Gaming* philosophies, as established from literatures and considered for in this study, are:

(1) members actions definitely affect the team
(2) members have only two options as directions of actions – to cooperate in collaboration or not
(3) only two player-positions are feasible

A player cooperates with the ethos of integrated systems when such party complies with appropriate estabslished frameworks that drive collaboration within project team members. Signficant evidence which has already been reported in literatures (e.g. (Aranda et al. 2008a; Gu et al. 2008; Sher et al. 2009; Tse et al. 2005)) suggests that the drivers of collaboration include contemporary workable skills, technological hardware, software and humanware to service all major precepts of BIM. A player therefore defects when there is little or no resources and commitement to markedly service the tools of cooperation to maximise collaboration.

Gaming lenses

Prisoner’s Dillema

In the Prisoner’s Dillema gaming scenario, players only have limited options as possible outomes in two negative options. On the one hand, the limited options are such that both players can either cooperate or refuse cooperation to reduce immediate risks and future effects that associate with those imminent and definite risks. Moreover, the actions of each player is tailored towards maximising self interest, with or without considering the implications of such actions on the other party. When both players cooperate, they are both better off. However, when only one party cooperates and the other does not, the party that defect gains more to the detriment of the party that cooperates. When both parties refuse to cooperate, they both benefit on the basis of their individual interest, and this is relative to what they have invested into their course of action.

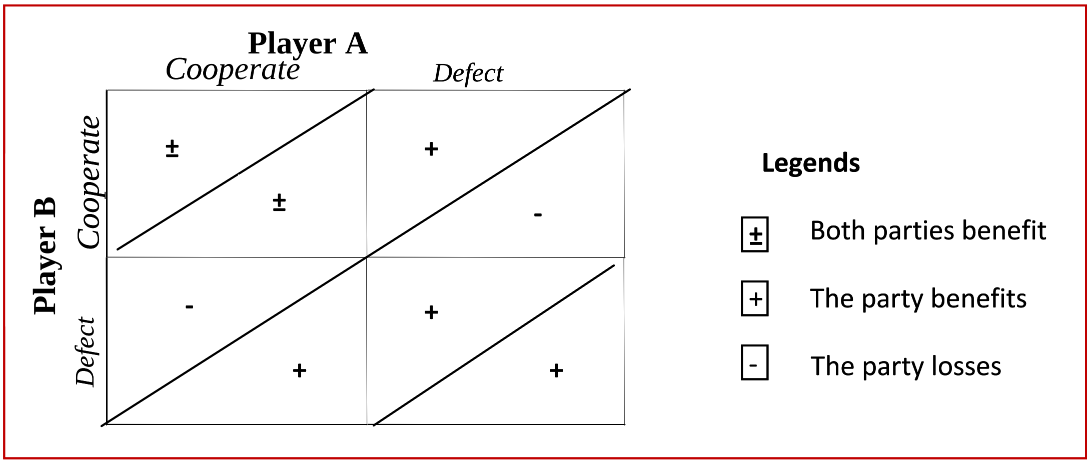

Figure 3. Gaming logic for Prisoner's Dillema model

Figure 3 illustrates prisoner's dillema logic. It typifies players at the two ends of data exchange in a typical integrated system. Players represent active data generators and users in construction project development processes. This include professional handlers of construction and facilities management processes, clients and project policy influencers – especially in project packaging. The Prisoner's Dillema model described in Figure 3 above has been used frequently in different scenarios in construction processes. (Saxby 2004) explored its aplication in construction procurement, while (Gruneberg and Hughes 2006) used it to mirror collaboration in construction consortia relationships. In theory, it is applicable when players must adopt definitive position on collaboration in the face of risks and uncertainties. The application of this in the design and BIM industries is that when all parties (intra-relationships between project development and management consultants and the capacity to extend this extrinsically to clients) cooperate to facilitate collaboration in integrated systems, all parties benefit in improved service delivery and systemic savings or benefits of BIM. However, when a party refuses to cooperate whether due to technical or economic reasons, this party benefits more in the short run than the party that is committed to the pricinples of collaboration. When both party remain committed to self interest against collaboration, both party benefit according to quality of their commitment and the focus of industry standard.

Pareto-Optima

Pareto-optima is popularly conceptualised on the result of the early works of an Italian economist and sociologist, Vilfredo Pareto (1848 - 1923). It is often used in gaming scenarios to demonstrate effective allocation of resources. (Bass and Ndekugri 2003) have exemplified this model breaking even in dispute negotiation. In practice, both parties are well-off when they cooperate maximally. It may appear as if one of the parties (the party that contributes least to the common course at first) benefits more more in the short run, however in the long run, that party will emerge as the most valuable contributor, even though the system is stable and balanced as all players benefit evenly. Moreover, there is no way a party will be better off in the common course without the other party being worse-off. This is because, on the one hand, the party that cooperates benefits more, while the party that defects is worse of. When they both defect, they are both worse-off. On the other hand, if things fall apart in the course of cooperation, the party that would have benefitted if the cooperation had worked out well will be worse off.

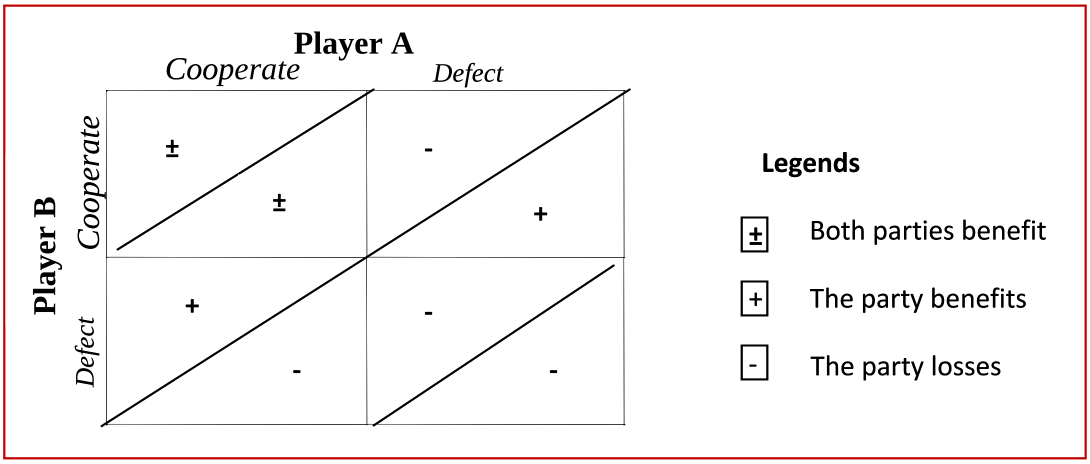

Figure 4. Gaming logic for Pareto Optima model

Figure 4 above illustrates pareto-optima logic. The implication of this model is that all parties and players will benefit from BIM when they maximally cooperate to collaborate in intergrated systems. In the short run, there is limited incentive in the industry to widen the horizon for BIM adoption and deployment due to the slow pace of adoption and undefinitve methodical understanding of BIM precepts by all stakeholders. However, even though this challenge persists, the party that remains committed to implementing BIM will benefit more when the market is fully ripe for systemic BIM deployment.

Hawk-dove

According to (Gruneberg and Hughes 2006), players in hawk-dove game model always have implicit self intentions outside team's benefits during cooperation. This is often complicated by players' latent bias towards protecting personal interests through fragmented conventions. Moreover, part of players' motives in this gaming relationship model is to share the benefits of cooperation unequally. If the cooperation relationship succeeds, both parties will be worse off. If the relationship fails, both parties benefit somewhat equally. Moreover, when the relationship fails mid-way the party that least co-operates benefits more in the long run than the party that defects; the party that contributes more to the relationship loses more than the party that refuses to collaborate.

Figure 5 illustrates hawk-dove gaming logic. Evidently, hawk dove phenomenon has been a major concern in the industry. According to (Ahmad et al. 2007), the frameworks for managing effective flow of information are still very weak. The complex nature of uncertainties in the industry could partly be a major disincentive for this. Many empirical evidence that feature in literatures (e.g. (Egbu et al. 1999)) suggest that most construction professionals and practices still struggle to understand and deploy the precepts of collaboration. While construction market is structured to favour self interest due to fragmented conventions, BIM can only drive its potential efficiency through thorough collaboration. Therefore, when parties decide to refute BIM, product performance in not guaranteed. Consequently, all parties will be worse-off. When all stakeholders decide to cooperate, collaborate and service all the ethos of BIM, they will all benefit moderately in the short run, and markedly in the long run.

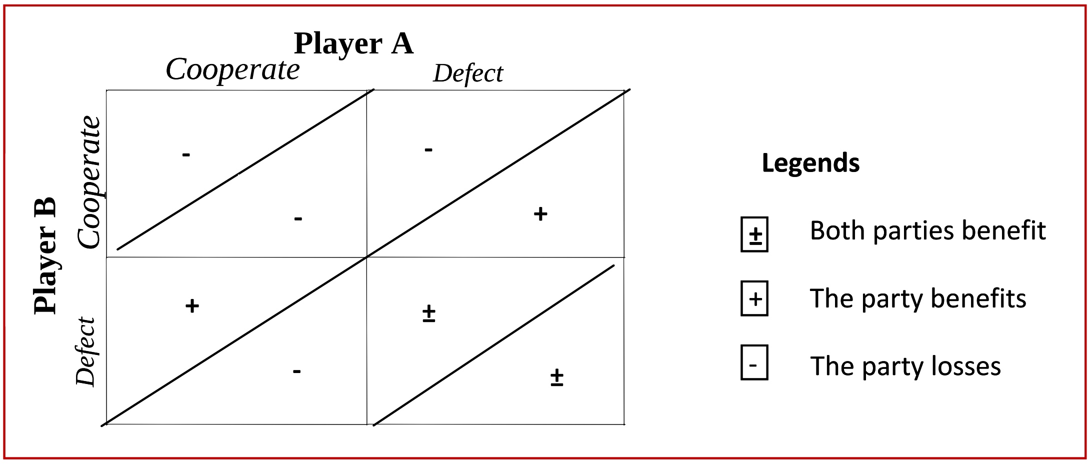

Figure 5. Gaming logic for Hawk-dove model

BIM and industrial applications of gaming

Product development systems in construction are delimited by risks. These risks are not only stochastic; the industry currently has very limited options to definitively ameliorate all forms of risks. According to (Liu et al. 2003), construction has a poor record in coping with risks, as there has never a part of construction stakeholders that has ever been vindicated in the spate of public concern on the image of the industry. The industry therefore has few options but to devise workable tools and models that facilitate process improvement and restore public confidence or to expect to endure the predictable consequences of poor product performance.

Having established the roles played by collaboration and system integration in servicing project performance through BIM, the adoption of platforms and allied innovation in this technology has been slow and unimpressive. While many adherents of BIM continue to drive market advantage through the creation and dissemination of digital data, others have either no idea of how BIM works or how best to implement it. However, in contrast to industry disincentives, there are many indications that the BIM revolution has truly begun (Ballesty et al. 2007; Fusell et al. 2007; Khemlani 2007; Luciani 2008).

The Game theory models described above can be used to predict possible outcomes under different collaboration scenarios. During perfect collaboration, all stakeholders use tools that generate and standardize digital data within BIM integrated systems. In partial collaboration, some players do have the choice to maintain their old non-BIM compliant tools while rendering modern day professional services, while in non collaboration there is no framework for generating and managing data in forms that support process de-fragmentation - a challenge that has plagued the industry for centuries.

In gaming models, each stakeholder (also referred to as player) represents a node of information transmission and feedback between his point of action in BIM and the rest of the system. Using the Prisoner’s Dilemma lenses, although players do not have conclusive powers to indemnify all life cycle variables of all forms of risks and uncertainties, there are still possibilities of outstanding benefits as much as players cooperate in collaboration. When all players adopt BIM, they are bound to be better off, with the least benefits being far more than what the best fragmented processes could offer (Aranda-Mena et al 2008a). Even when each player is motivated by customized business drivers, the economic gain triggered in BIM collaborative platforms is plausible. However, if all players in the industry do not adopt BIM integrated technologies, the party that implements it may be discouraged as there will not be sufficient motivation to drive absolute product performance. The party that refuses to cooperate benefits more in the short run than the party that defects because no extra marked commitment has been made.

The Pareto Optima model suggests that all parties in cooperation (in integrated systems) benefit evenly. However, all the potentials of BIM will only be realized when it is not used as a design tool alone, but rather as a platform where all stakeholders are equal. (Peter and Dan 1999) have argued how egotism could impact on the usual course in integrated relationships. Arguably, BIM seems to be making slow progress in recent years because many non-design professionals see it as mainly a design tool. There are also misconceptions that threaten the relevance of other professionals. Gu et al (2008) concluded that the rate of BIM adoption will only improve when other professionals discover their roles in BIM and what is in it for them. Even though designers benefit more from BIM at the moment, unless other professionals are integrated into BIM initiatives, all parties will be worse off in the long run.

The Hawk Dove gaming model typifies fragmented processes. Some wealth of evidence has shown that fragmented processes never helped product performance in the industry. This model suggests that if stakeholders continue to extol self interest at the expense of collaboration, the industry will be worse off. However, when individual parties adopt BIM, these parties will enjoy the benefits of early entrant advantage in market competition. The party that refuses to adopt BIM continues to risk the potential for competition and improvement in professional service delivery, such party also has a lot to lose in terms of survival and the ability to keep up with the pace of future developments in the industry.

Conclusions

The industry has been observed to reflect certain difficult challenges under fragmented processes. Interestingly, better alternatives have been established in BIM potentials. In BIM, stakeholders can collaborate, share data and values, communicate and integrate intelligent technologies and techniques to drive digital information management systems. This study has used three gaming models - Prisoner’s dilemma, Pareto-optima and Hawk-dove - to demonstrate the possible implications of current developments in BIM adoption and associated challenges. It had been proved from these models that the best solution is for the industry to devise proactive ways that will encourage all stakeholders to participate in BIM adoption. This is because the industry has a better chance of rebranding its image only when all parties adopt BIM. However, in all cases of partial or lack of adoption, both the industry and its stakeholders (professionals and clients) are worse off in the long run.

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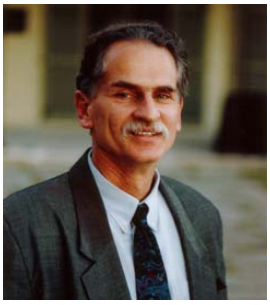

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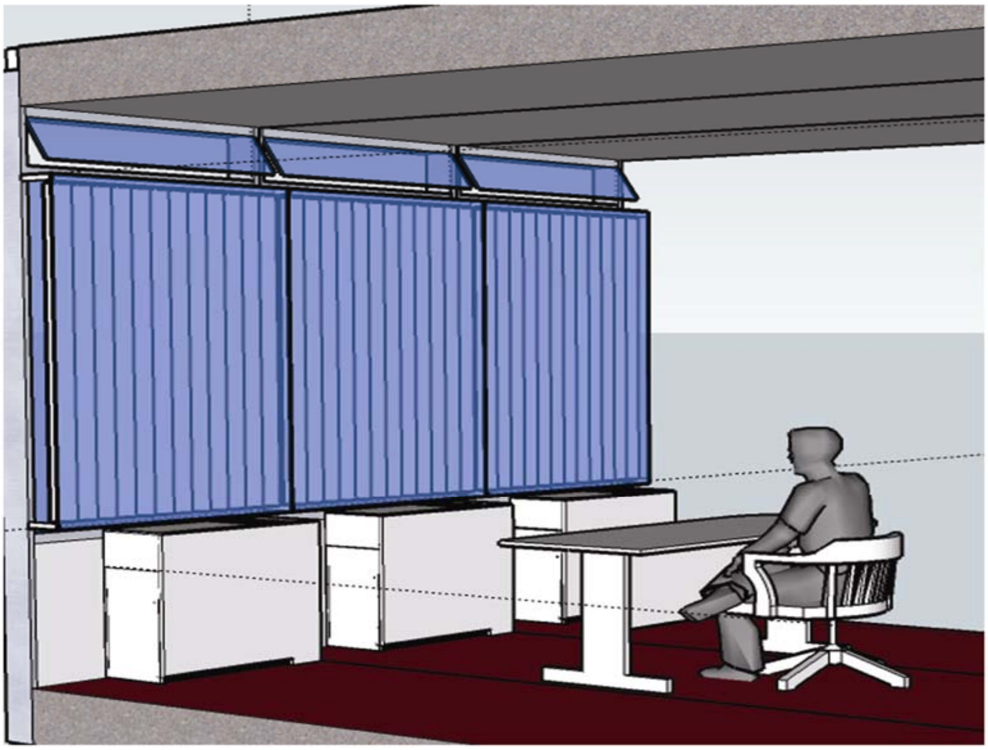
7

The Climate Adaptive Skin – Developing a New Façade Concept Using Passive Technologies

Bas Hasselaar, Wim van der Spoel, Regina Bokel, Hans Cauberg



The Climate Adaptive Skin - Developing a New Façade Concept Using Passive Technologies

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Abstract

A new generation of façades is under development that takes a different approach to both climate control and user comfort perception. The Climate Adaptive Skin is a façade concept under development at the TU Delft that aims to create a comfortable indoor office climate while consuming as little primary energy as possible. Building services are integrated into the façade itself at office-room scale, making the office adjacent to the façade independent of centralised HVAC systems and the indoor environment optimally adjustable by the user. Energy consumption is reduced to a minimum by using technologies and materials that are able to react to the changing thermal environment, such as phase change materials (PCM) and thermotropic glass. The façade concept is simulated using a custom made model in Simulink that has been validated using measurements on test units in a climate chamber. The resulting model can be used to predict the behaviour of the façade in real life situations.

Keywords: climate control, cooling, façade, phase change materials, PCM, adaptive, thermal comfort

Introduction

In most modern buildings, a comfortable indoor climate is created using energy consuming centralised building services that provide heat or cold, ventilation air and often regulate artificial lighting as well. A new façade is under development that takes a different approach to both climate control and user comfort perception.

The basic concept behind the façade is that it is able to create a comfortable indoor climate using both the indoor and outdoor climate. This means that characteristics of the indoor office space, i.e. presence of internal heat sources, a need for fresh air and daylight, and room temperatures within certain limits, are used and combined with outdoor (temperature, air and solar) influences to create a comfortable indoor climate, with the goal to minimise (primary) energy consumption.

Besides the energy demand of the façade, additional conditions are formulated, such as a limited façade thickness and a simple, ‘robust’ façade design. A robust design will minimise maintenance and reduce the likelihood of malfunction.

The limited façade thickness reduces its footprint, and leaves more useful building area to both architect and user. Also, a limited façade thickness makes it easier to attach the façade to the building, reducing potential construction difficulties. The desire to create a ‘simple’ façade that can function, i.e. create a comfortable indoor climate, autonomously to a large extent, while requiring little maintenance, has its advantages. A façade independent of warm/cold air/water needs no pipes or ducts for climate control. No ducts or pipes means that installing a façade is much easier, quicker, and that there is no need for a lowered ceiling or duct along the façade to accommodate the space with these services. In short, the whole building layout can be a lot simpler and be used more flexible if the façade can provide a comfortable indoor climate without the need for supplied air or water. By choosing technologies that are relatively low-tech, the chance of malfunction is reduced as there are fewer moving parts and electronics which can break down.

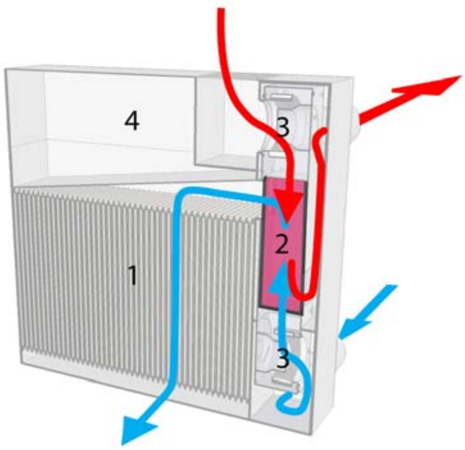
Recent insights into thermal comfort [1] indicate that thermal perceptions are affected by recent thermal experiences and expectancies. In other words, people accept higher indoor temperatures in summer when it is hot outside and lower indoor temperatures in winter when they wear a sweater because it is cold outside. This however applies mostly to naturally ventilated buildings where people can open or close a window; they tend to be less tolerant towards varying indoor temperatures if a building is fully air conditioned.

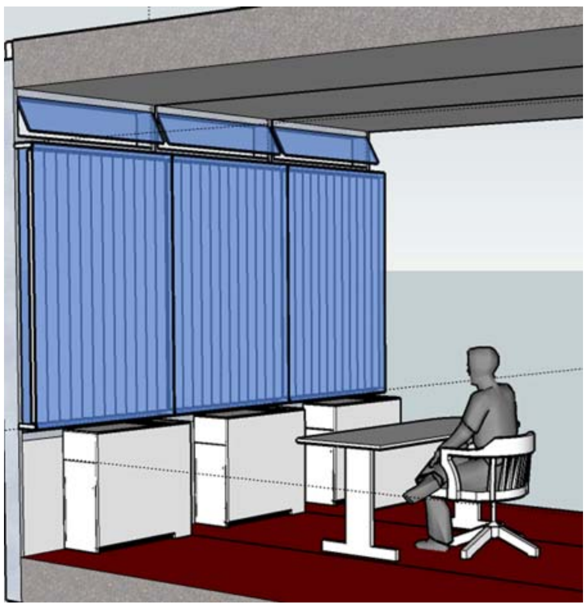
The façade featured in this paper will be one of the first to be specifically designed around the new insights into adaptive comfort perception, meaning that the strict temperature limits that are usually applied are replaced by a more lenient approach, allowing higher indoor temperatures in summer as long as people have a direct influence on the climate they are working in. Building services are integrated into the façade itself at office-room scale, making the office adjacent to the façade independent of centralised HVAC systems and the indoor environment optimally adjustable by the user. By making use of mostly passive technologies and by extracting ventilation air directly from the outside, the façade is able to provide a comfortable indoor climate at individual level without consuming considerable amounts of energy. The thus created comfort is based on standards that regard comfort in terms of a number of variables, which can be set at predefined values which are expected to provide optimal comfort for 95% of the occupants. These standards however are based on research into the comfort perception of people doing office work in a completely air-conditioned environment and who have no direct control over their local climate.

The performance of the façade concept is optimised for a mild climate, similar to the climate in The Netherlands.

The Climate Adaptive Skin (CAS)

The main characteristics of the façade are schematically shown in Fig. 1 with the full façade on the right and an enlargement of the ventilation unit at parapet level, containing most of the installations, on the left. The schematic representation of an office on the right shows three identical ventilation units of which a cross section is shown on the left. This is not necessarily the only or optimal layout; the three separate units could be replaced by one larger unit servicing the same office area.





1. PCM stack
2. Heat exchanger
3. Fans
4. Space for electronics etc

Figure 1. Schematic representation of the Climate Adaptive Skin with shading behind glass, operable windows and three ventilation units (right) and section of one ventilation unit (left)

Ventilation

A ventilation unit contains three components that play an important role in the provision of fresh and conditioned air: an air to air heat exchanger (number 2 in Fig. 1), two fans (numbers 3 in Fig. 1) and a stack of PCM (Phase Change Material) plates with a phase change temperature range of 20-22°C (number 1 in Fig. 1). Fresh air is drawn directly from outside, preheated by the heat exchanger and then forced through the PCM plates before being distributed into the indoor environment. Stale air is drawn from the indoor environment at the top end of the ventilation unit, forced through the heat exchanger where thermal energy is exchanged with the incoming outdoor air, before being discharged to the outside.

Users are given the option to manually open the window for additional ventilation, providing the psychological advantage of being able to control their immediate environment.

Light

The part of the façade above the ventilation units is almost fully transparent. This is beneficial for two reasons: 1. provision of daylight which reduces the need for additional artificial lighting, and 2. the reduction of glare caused by large luminosity differences between transparent and non-transparent parts of the facade.

To prevent potential overheating in summer, the façade should be equipped with high quality shading. In theory, any shading device can be used, as long as its performance is able to match the performance criteria set in this paper.

Heat/Cold

The acclimatisation of the indoor temperature works in a number of ways: first of all, the façade is supposed to be well insulated and air tight. This way, the façade can use indoor heat loads (people, equipment and lighting) in combination with controlled ventilation to create a comfortable indoor environment for almost 80% of the year.

The ventilation air exchanges thermal energy with the PCM plates by flowing along the surface of the plates. Since the plates have a relatively constant temperature of 20-22°C, the air flowing along the plates is either heated or cooled, depending on the outdoor temperatures.

The PCM has both a heating and cooling task, depending on the outdoor temperature. In summer, the PCM cools fresh outdoor air down to roughly 22 degrees during the day to use for ventilation and cooling, while using night ventilation to regenerate its cooling capacity during the night. In winter, the PCM heats up the incoming ventilation air during the day, while at night, when necessary, electric heating coils or Peltier elements (TEC – thermal electric cooling, can also be used for heating) regenerate the PCM’s heating capacity, using lower priced night electricity and shaving off peak daytime demand.

As such, the façade is able to function using nothing but electricity, which could be generated using photovoltaic panels at the bottom part of the façade. Even though energetically and exergetically the use of electricity for resistive heating might not be the optimal solution, it simplifies both the design and the connections of the façade to the building to a great extent.

Simulation and operation

To obtain an indication of how the façade performs, it is simulated using the Mathworks programme Simulink [2]. It should be noted that the performance of the façade is attached to an office room that is 5.4 m deep and is surrounded by other rooms, i.e. the only side that exchanges thermal energy with the outdoor climate is the façade and is simulated with the Dutch climate in mind, using the weather file for 1995, which had a very warm summer.

To see the influence of individual components on the total performance of the façade, a reference situation has been defined from which changes in the settings are assessed. Using the reference situation as a starting point, the parameters have been refined until favourable conditions were achieved. The input is listed in Table 1:

Table 1. Simulation model input of south facade

Efficiency heat exchanger [%]		70%
Bypass of heat exchanger if		Night vent. on or windows open
Temperature windows open [°C]		24°C
Temperature windows close [°C]		23°C
Influence openable windows [added to ventilation rate]		0.5 extra rate
G-value change from 0.65 (no shading) to 0.15 [°C]		23°C
Dimensions façade element:	Width of the element	1200 mm
	Floor height	3000 mm
	Parapet height	750 mm
	Glass height	2000 mm
U-value glass/frame/parapet [W/m^{2}K]		1.0/2.0/0.25 W/m^{2}K
Window frame percentage of the glass area		25%
Dimensions PCM [m] / number of layers		0.005 thick *0.45 m high / 90
Minimum ventilation flow rate day [m^3/s]		0.0108 m^3/s
Maximum ventilation flow rate day [m^3/s]		0.0216 m^3/s
Added ventilation during day 0.0054 m^3/s per °C above		22°C
Min. temp. difference indoor-outdoor night vent. [°C]		2°C
Night ventilation only if operative indoor temperature		> 22°C
Night heating only if indoor temperature		< 20°C
Conditions night heating: air temp ex. PCM below? [°C]		18°C
Internal heat load [W/m^2]		30 W/m^2
Internal heat load only on workdays from		8-18 hours

Indoor space

The nature of the climate adaptive skin allows the indoor space to be free of a lowered ceiling, meaning that the thermal mass of both the floor and the (concrete) ceiling can be used to influence the indoor temperature in the simulations. It is not designed to have a specific width, but designed to be able to condition the adjacent office space, which is a standard 5.4 m deep. As such, it can be multiplied by any number in horizontal direction; the width of a CAS element is therefore chosen to be 1.2 meter, which is more or less a standard grid size in The Netherlands.

For the indoor heat production an average of 30 W/m^2 for people, equipment and lighting is taken. The transparent part of the façade equals roughly 2 m^2 through which solar irradiation heats up the indoor climate. The U-value of the window frames is generally much higher than that of the window itself, and is therefore also included into the simulation model.

Ventilation unit

The unique element in the Climate Adaptive Skin, and one of its vital parts, is the ventilation unit. This unit contains a number of elements and is responsible for the provision and conditioning of fresh ventilation air.

Heat exchanger

Stale air from the indoor environment is used to preheat incoming ventilation air using a cross-flow heat exchanger to reduce the electricity demand for heating. In earlier simulations without either heating or a heat exchanger, it was shown that additional heating is required for a large part of the year.

The heat exchanger in the simulation model uses the difference between the indoor and outdoor temperature as a basis value and multiplies that by the efficiency (at least 70 % according to the manufacturer) of the heat exchanger. This new value for the temperature difference is added to the incoming ventilation air temperature before the air enters the PCM stack.

PCM

PCMs do not change phase (solid to fluid) at a specific temperature, but at a temperature range, e.g. between 20 and 22°C. Therefore the latent heat capacity associated with the phase change should be distributed over this temperature range.

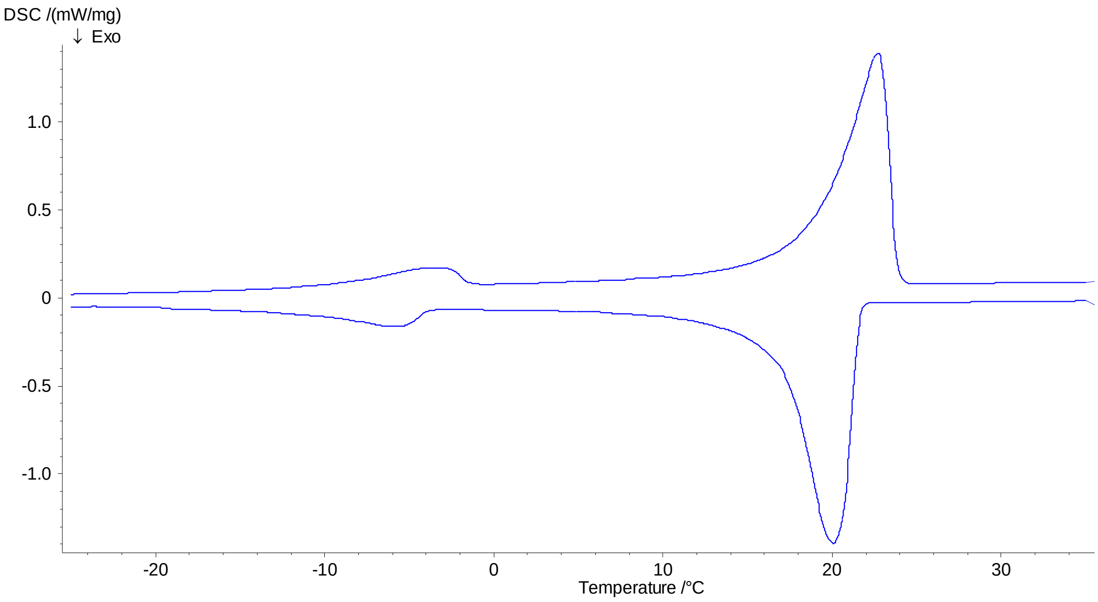


Figure 2. Depiction of the effective heat flows to and from the PCM at a certain temperature at a heating/cooling rate of 2 K/min

The graph in Figure 2 represents the effective heat flows to and from a sample of PCM as supplied by the manufacturer (Rubitherm GmbH). This PCM is also used in the CAS concept and the graph acts as the basis of the simulated heat capacity of the PCM.

To make sure that sufficient thermal energy is exchanged between the air and the PCM plates, the plates are simulated to have a thickness of 5 mm and an airflow channel of 2.5 mm width along them, effectively splitting the plates (10 mm) and the cavity between the plates (5 mm) in two to increase simulation accuracy. The height of the PCM, or the distance the air is in contact with the PCM, can be chosen, but is set to be 0.45 m in the default situation.

Night ventilation

The façade is designed for office use. This means that during normal use daytime hours are defined from 8 am to 6 pm and night time hours from 6 pm to 8 am. The performance of the façade is adjusted to these working hours, e.g. the capacity of the PCM is calculated to be enough for daytime use, to be regenerated during the night.

Night ventilation, or night flushing, is used to shed unwanted thermal energy accumulated in the PCM during the day by forcing cool outdoor air through the PCM-stack during the night. Since there is a chance that the temperature difference between phase change material and the outdoor temperature is lower during the night than during day, the ventilation rate is doubled during the night to increase the heat exchange.

Night ventilation is only beneficial if the PCM plates have absorbed so much thermal energy during the day that they have (nearly) heated up past the phase change and are unable to cool during the next day. In the simulation model this means that if the indoor temperature exceeds 22°C, the PCM has most likely accumulated enough heat to warrant night ventilation. In addition, the model requires the outdoor temperature be at least two degrees lower than the indoor temperature to prevent unnecessary energy consumption by the fans that force the airflow; a smaller difference has negligible influence on the efficiency of night cooling.

Night heating

In the Netherlands, the average temperature throughout the year is approximately 10°C, while a comfortable indoor temperature is generally required to be at least 20°C. This suggests that, especially in winter, additional heating of the PCM is necessary to enable it to stay in phase change stage and utilise its latent heat storage to condition the incoming ventilation air.

The heating of the PCM plates can be done through:

a. Electric heating foil or strips that heat up when an electric current is applied to them, or
b. through a Peltier element (Thermal electric heating).

Both are used to regenerate the PCM. The heating foil however is applied directly to the PCM plates and heats the PCM directly through conduction, while the Peltier element is connected to the fresh air supply, heating the air which in turn heats the PCM plates through convective heat transfer.

Because of the buffering capabilities of PCM, it is possible to heat the PCM during the night, using cheaper night electricity and reducing peak energy demands during the day, especially in the morning.

The PCM will be heated during the night when the indoor temperature drops below 20°C. This temperature indicates that the PCM is no longer able to heat the air to such temperatures that a comfortable indoor climate is created, and therefore requires night heating.

Of course, this is in a simulated environment, where the phase change and thermal behaviour of the PCM is uniform and constant. Testing in a controlled environment using commercially available PCM plates is necessary to validate the outcome of the simulations.

Energy consumption

Two processes consume energy in the CAS: the fans that drive the ventilation, and (potential) heating. The power consumption by the two fans would be (two fans drawing 15W for 12 hours a day, six days a week) approximately 112 kWh per year. If two efficient photovoltaic panels would be attached to the façade with a total of 1.26 m^2 of active surface, the yield in the Netherlands could be approximately 123 kWh per year [3], assuming an 80° angle placement and southern orientation of the panels. This means the total energy consumption of the fans could be offset using photovoltaic panels on the façade, leaving only energy required for additional heating.

Windows and shading

The façade is fitted with manually openable windows that enable additional natural ventilation on top of the mechanically supplied fresh air from the PCM unit.

Although the operation of the windows is user dependent, the influence of the additional ventilation is studied in the simulation model. Windows are assumed to be opened when the indoor temperature exceeds 24°C and closed when the outdoor temperature drops below 23°C. This only applies when the indoor temperature is at least the same as, or higher than, the outdoor temperature. The influence of open windows is simulated as a (conservatively estimated) increase in the ventilation rate of 0.5 per hour.

The U-value of the façade is supposed to be equal to the best insulating glass used in the design, taking the large amount of glass of the façade into account. This U-value is supposed to be 1.0

W/m^{2}K. To prevent overheating from excessive solar irradiation, shading is utilised which changes the g-value from 0.65 to 0.15 once a threshold temperature of 23°C is reached.

Simulation results

Using the model, the influence of each of the parameters was examined by simulating values both higher and lower than those in a self-created reference situation. As such, the influence of each parameter could be determined by studying various output graphs and comparing the energy demand.

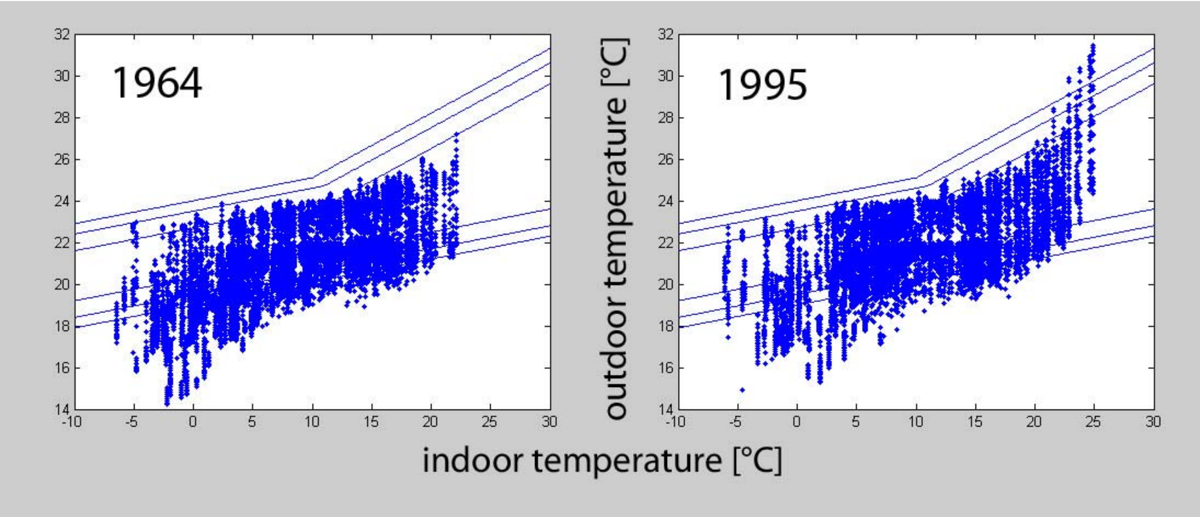
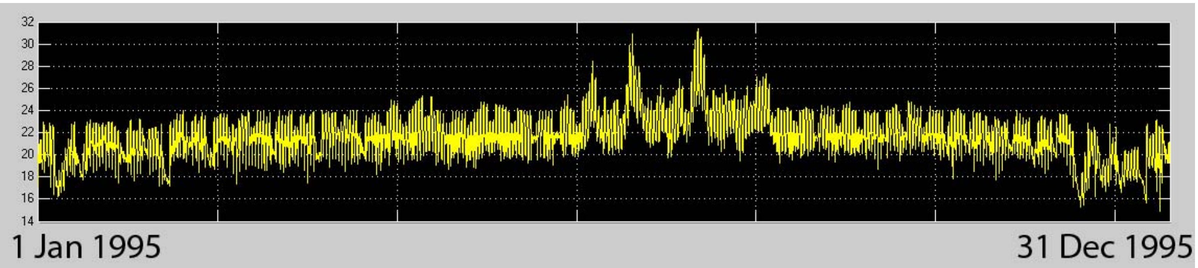


Figure 3. Representation of hourly indoor temperatures within comfort limits



.Figure 4. Simulated indoor temperature from Jan 1st to Dec 31st 1995

Figure 3 displays two graphs created by the simulation model showing the extent to which people feel comfortable during a year. Six lines or limits can be distinguished, split into two sets of three lines. The top limit indicates the maximum temperature at which 65 % of the people still find the indoor climate comfortable, the second limit indicates the maximum temperature that 80 % of the people still find comfortable, while the third limit indicates a 90 % satisfaction rate. The lower three lines/limits indicate the same percentages, but this time for the minimum temperatures. It should be noted that the dots in the graph represent every hour of the day, including night times when no people are present.

The model indicates that for more than 80% of the year the Climate Adaptive Skin (CAS) is able to create a comfortable indoor temperature without consuming any energy, except for the electricity demand of the fans. Depending on what year is simulated, overheating in summer can occur. In 1964, which is often used as the ‘standard’ reference year, overheating practically does not take place. In 1995, which had a very warm summer and which is sometimes used as the ‘extreme’ reference year, overheating in summer can occur in the height of summer (see Figure 4), with indoor temperatures reaching 30°C on a few occasions. The reason for overheating is that during the night, temperatures are not below 20°C, so that the PCM cannot shed unwanted heat during the night, and cannot store cooling energy in the PCM for use during the day.

In winter, the indoor temperatures are uncomfortably low in the simulations. This can clearly be seen in Figure 3 where the lower comfort limit is exceeded for a significant part of the year. This originated from the fact that no proper heating is yet implemented in the simulation model. The heating present in the model consumes a total of 4.6 kWh per m^2 floor area per year, which is roughly equivalent to a constant heat source of 0.5 W. Better insulation will decrease the heating demand, but further research is necessary to address this problem.

Test results

To assess the validity of the simulation model, two ventilation units have been tested in a climate chamber (Figure 5). The ventilation units contain PCM plates, a heat exchanger and two fans (one for fresh air, one for stale air) that provide the ventilation in the CAS concept.

Figure 5. Test ventilation units in the climate chamber

Figure 6 represents a 3.5 day test, during which the daytime temperatures climbed to approximately 30°C, while at night the temperatures dropped to about 15°C, with a constant ventilation rate of 28.8 m^3/h, equivalent to a ventilation rate of 3, or complete refresh of the indoor air of 3 times per hour in the simulation model. The phase change in the PCM plates can be seen in a plateau in the exit temperature (the dotted line in Figure 6) after the quick drop in outdoor temperature.

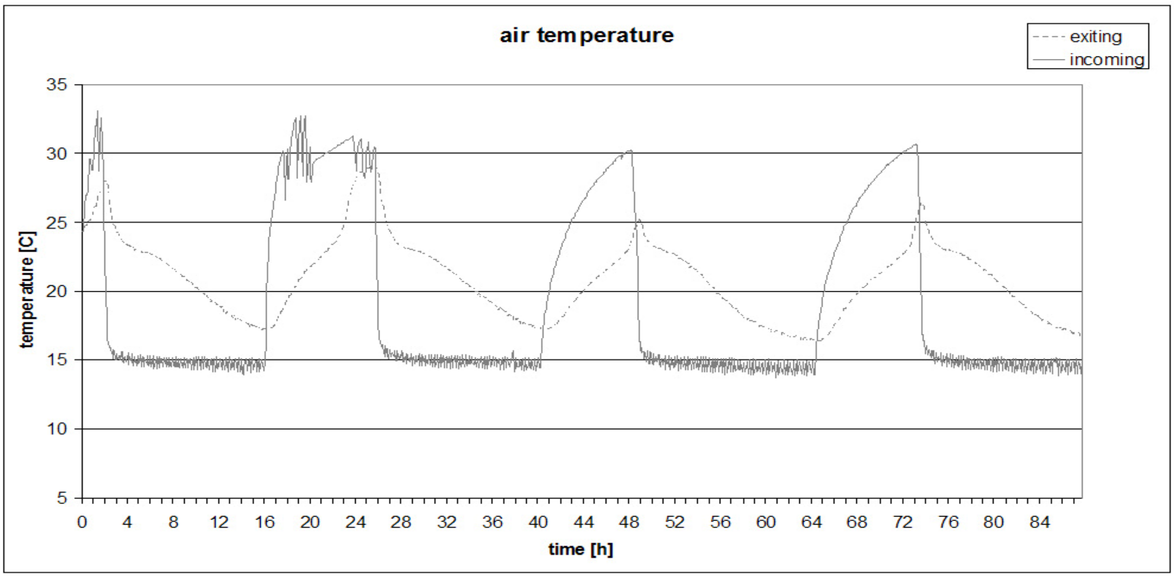


Figure 6. Measured incoming and exiting air temperatures in ventilation unit in 3.5 day cycle

By comparing the test data with simulation data, the following results are obtained (Figure 7). As can be seen, the results are quite similar, but not identical. Especially in the two last cycles the measured data display a peak indicating that the PCM has reached a full liquid state, whereas the simulation model does not show this behaviour. This is most likely due to a slight difference in thermal behaviour between the simulated PCM and the actual material. The simulation model matches the graph in Fig. 2 closely, but it is very well possible that the graph does not display an accurate characteristic of the PCM in use. It is expected the graph of the PCM used in the test setup has a slightly different curve than the curve that is used as the basis for latent energy in the simulation model.

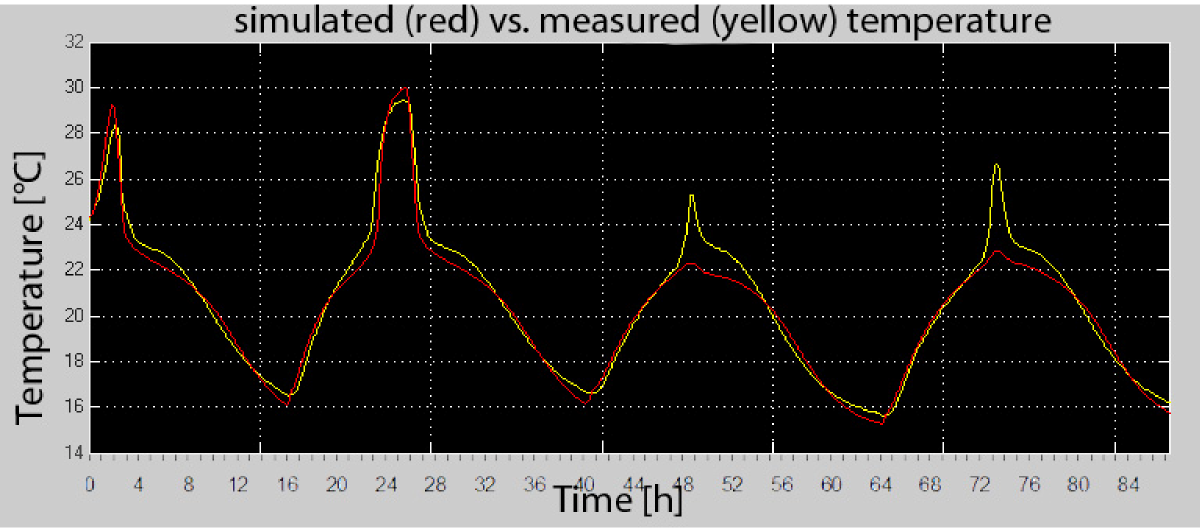


Figure 7. Simulated (red) and measured (yellow) exiting air temperatures in the ventilation unit

Conclusions

Research has been carried out in search of a façade concept that is able to condition an office space autonomously using mostly passive technologies. To validate the concept, a simulation model is developed which in turn is validated using two test units and a climate chamber.

The simulation model suggests that it is possible to create a comfortable indoor environment throughout the year using the Climate Adaptive Skin concept, as long as extra heating is provided. The heating can be provided in different ways, e.g. through heating of the PCM plates to stay within the concept of autonomous operation, or alternatively e.g. through floor heating. Application of the concept, including the ventilation unit, means that no centralised climate control is needed for cooling or ventilation.

If photovoltaic panels are fitted to the façade to power the fans that drive the ventilation, the facade would in theory be able to ventilate and cool the adjacent office autonomously and energy neutrally over the year, with the fans for ventilation being the only moving parts.

Tests performed on ventilation units that are similar to those simulated display results that are close to what can be expected based on the simulations; the tests indicate that the ventilation unit is able to condition ventilation air as intended.

With the validated simulation model the behaviour of the Climate Adaptive Skin in real life situations can be predicted. Building and testing a full-scale fully functional prototype is the next step before market introduction.

Acknowledgements

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Author's Biography

Bas Hasselaar, MSc (1979) studied Building Technology at the Faculty of Architecture at Delft University of Technology, The Netherlands. In 2002 he interrupted his study in Delft to study the Masters course ‘Sustainable Development’ at the Faculty of the Built Environment at the University of New South Wales in Sydney, Australia at which he graduated with High Distinction. In 2003, he returned to the Delft University of Technology to graduate with Honourable Mention. In 2004-2005 he conducted research into the possibilities of decentralised sanitation in an urban context, after which he started his PhD research into Climate Adaptive Skins.

Johannes J.M. Cauberg (1944) studied Building Physics at the faculty of Applied Sciences at Delft University of Technology (The Netherlands). From 1968 till 1975 he worked as a consultant at Huygen Consulting Engineers. In 1975 he became CEO of this firm changing its name into Cauberg-Huygen Consulting Engineers BV, a consultancy in the fields of building physics, climate and environmental engineering. In 1999 he was inaugurated as full professor in Building Physics and Building Services at Delft University of Technology. Since 2009 he is an emeritus professor.

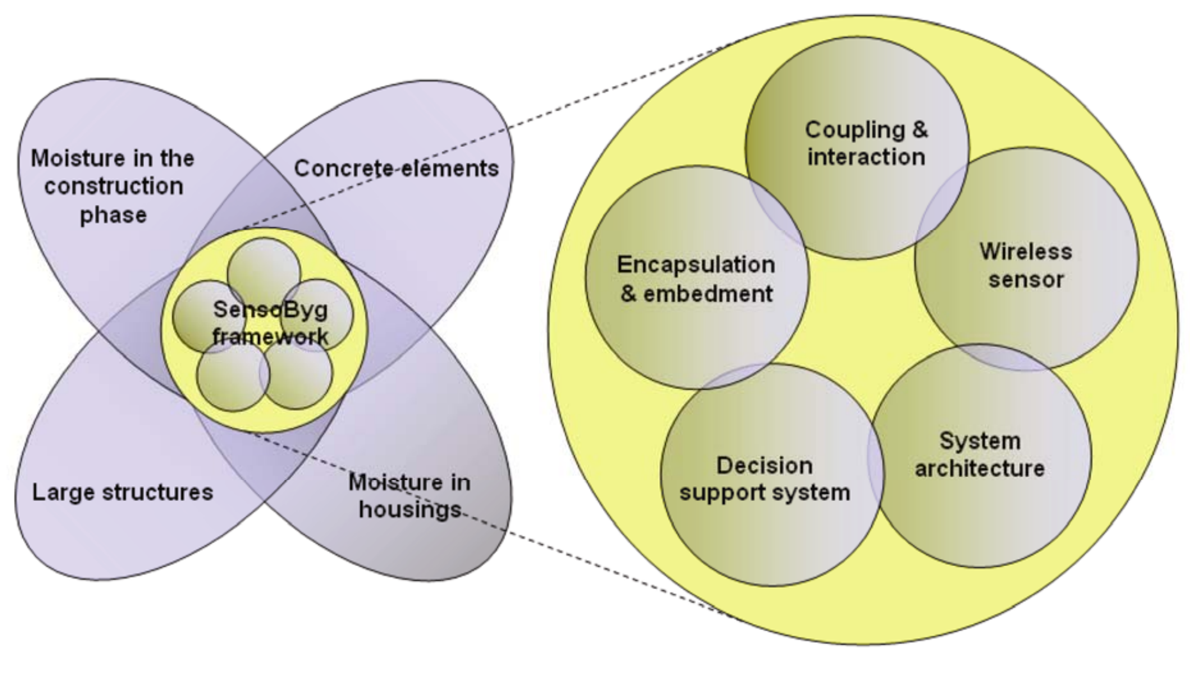
Regina Bokel is researcher and university lecturer in building physics & climate design with focus on energy modelling and ventilation in the built environment.

Wim van der Spoel is researcher and university lecturer in building physics & climate design with focus on passive cooling, low-energy and dynamical systems modelling of energy processes in the built environment.

8

Use of Wireless Sensors in the Building Industry, SensoByg

Claus V Nielsen, Henrik E Sorensen



Use of wireless sensors in the building industry, SensoByg

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Abstract

The use of sensors for monitoring material properties and structural health in buildings and civil structures yields obvious technical and economical advantages for building owners and for society. Repair and maintenance of buildings and structures are typically performed only on the basis of a visual inspection, sometimes combined with a more thorough technical survey, where a few properties related to durability and strength are measured. Such tests are often destructive and furthermore, disturb the inhabitants of the building or bridge traffic.

Due to recent developments in wireless technology a good basis has been formed for further development of sensor technology for monitoring structures and buildings. Wireless sensor systems are expected to drop in price which makes them interesting for the construction industry.

A Danish R&D consortium titled "SensoByg" addresses the use of wireless sensors for surveying buildings and structures. It is a four year project comprising 18 partners from industry and academia. The scope is to develop and demonstrate the advantages of using monitoring systems based on embedded, wireless sensor technology and intelligent support systems for decision-making.

Focus is placed on wireless monitoring of moisture and temperature as such sensor units are readily available on the market.

Applications addressed in the paper include the following: (i) management, operation and maintenance of civil structures, (ii) moisture related damage to buildings and houses including implications for indoor climate and (iii) drying out of newly cast concrete. Examples of these applications are given in the paper.

Keywords: wireless, moisture, relative humidity, durability, maintenance, sensors, condition monitoring, concrete, bridges

Introduction

The paper describes a Danish R&D project "SensoByg" on wireless surveying of structures and buildings. Focus of the project is placed on the systems handling the sensor data, providing decision making tools for building owners, building operators and contractors. Technical details regarding installation of sensors for various applications are investigated. Most of the project is based on full scale demonstrations made in close collaboration with the industrial partners of SensoByg. Fig. 1 shows the main applications to be investigated within SensoByg. These are large (civil) structures, moisture related damage in housing, moisture and temperature in concrete production (both cast-in-place and precast elements). These applications are described further in the following sections.

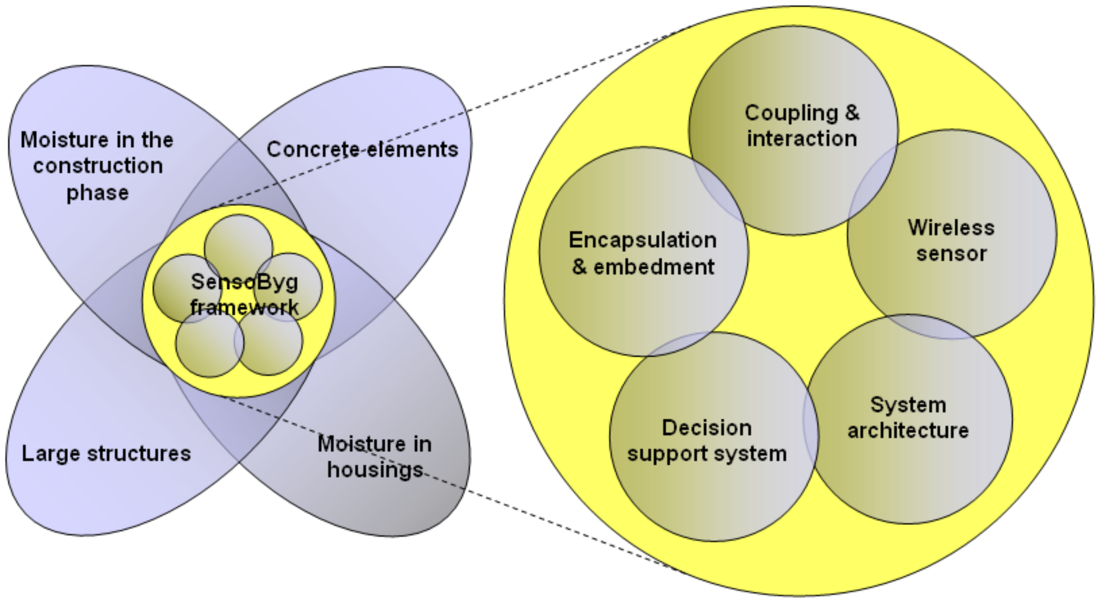

Figure 1. SensoByg organisation and subdivision into the four main applications

It is expected that sensor prices will drop significantly as the technology develops and thereby pave the way for a more extensive use in the construction industry. SensoByg is a step in that direction.

Objectives

The main purpose for the SensoByg project is to develop robust, reliable systems for monitoring buildings, civil structures and building materials by means of wireless embedded sensor technology. This paper will describe some of the important tasks being carried out during the project and give preliminary conclusions. It is outside the scope of the project to develop the next generation of sensor technology, e.g. passive sensors based on SAW technology. Hence, the demonstration of possibilities is based on existing sensor technology. The outcome of SensoByg is expected to be the possibility to create intelligent building materials and intelligent buildings and structures which again would contribute to better sustainability in the construction industry.

SensoByg is organised in 5 technical focus areas and 4 demonstration projects (Fig. 1). Two of the focus areas are wireless sensors and coupling/interaction where the sensors, to be applied in the project, are developed. The focus area encapsulation investigates the possibilities to cast-in and to embed wireless sensors in fresh concrete. It is crucial that the sensor is protected against alkaline water and concrete slurry. The technical focus areas are linking together the individual applications or demonstration projects.

The two last focus areas (decision support and system architecture) are developing a generic concept for wireless sensor networks and the end-user tools.

Background

In 2007 the Danish Ministry of Science, Technology and Innovation granted a R&D project to the construction industry in Denmark. The project is titled SensoByg and its full name is "Sensor based surveillance in construction". SensoByg started in March 2007 and it is running for almost 4 years until end of 2010. It has a 3 M€ budget. The Ministry supports half the budget and the industrial partners are obliged to deliver the other half in terms of working hours and consumables. The SensoByg group of partners encompasses:

- Danish Technological Institute (DTI) is acting as overall project manager for the 12 industrial partners and 6 R&D performers.

- The R&D performers of SensoByg are: Aalborg University (building physics), Technical University of Denmark (wireless signals, antenna technology and radio wave technology), Alexandra Institute (software architecture for sensor networks), Lund technical University (moisture in building materials), Aarhus University (software systems and computer science) and DTI (sensor technology, concrete technology).
- Four building owners (or representatives) including the Danish Road Directorate and the Fehmarn organisation responsible for the future Denmark - Germany fixed link.
- Three concrete manufacturers (working with precast as well as ready mixed).
- One software developer, one consulting engineer and two companies working with sensors for the construction and building industry.

The range of participants should ensure that all aspects of sensor applications in buildings as well as in civil structures are taken into account.

The use of monitoring systems to survey structures is not new. However, such systems are often rather complicated and expensive to establish, which means that only very large structures are normally surveyed. Furthermore, wiring and installation of monitoring instruments is rather troublesome. Therefore, wireless applications are expected to become an advantage in future buildings and structures. The reference list shows examples of recent investigations on the subject.

Sensor technology

Two different sensors are developed for the applications (Figs. 2 and 3). In both cases the sensor is a commercial off-the-shelf unit measuring temperature and relative humidity. This sensor unit is suitable for a range of monitoring tasks as it is described in the next sections. The sensor transmits its data with a radio frequency of 433 MHz and the signal is received by a reader box which again stores it until it is transmitted via GSM to a host server. Here the data can be accessed by the end-user applications. The sensor design is made with the aid of FEM simulations in order to obtain optimum balance between power consumption and wireless performance. Another important issue is the size of the sensor and it is recognised that the sensors developed for demonstration purposes (Figs. 2 and 3) may not be suitable for all applications due to their size. However, SensoByg has chosen to prioritise performance over size.

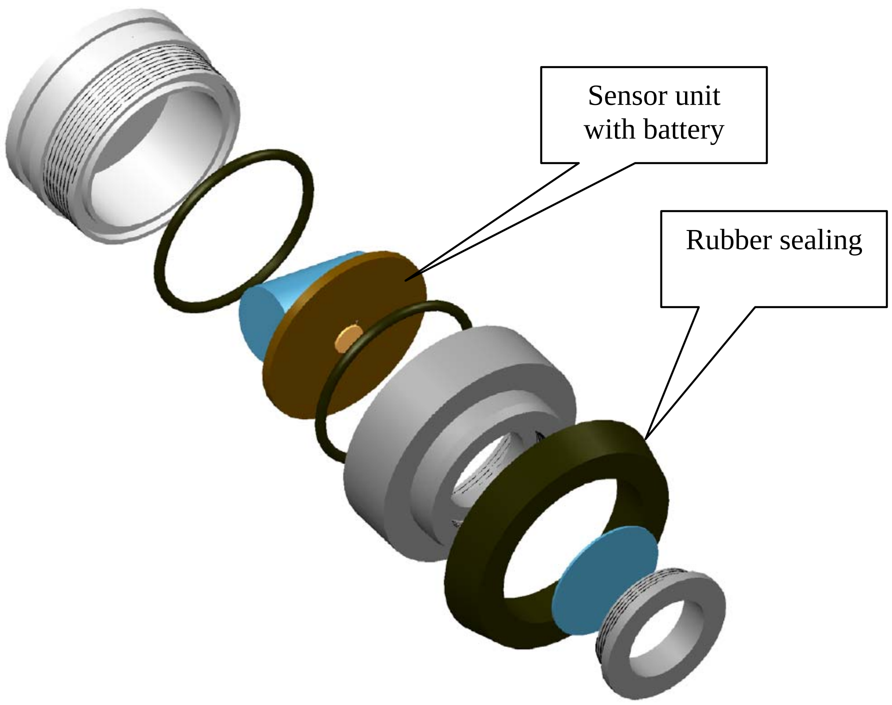

Figure 2. Cylindrical wireless sensor unit. Diameter 35 mm. Design by DTI

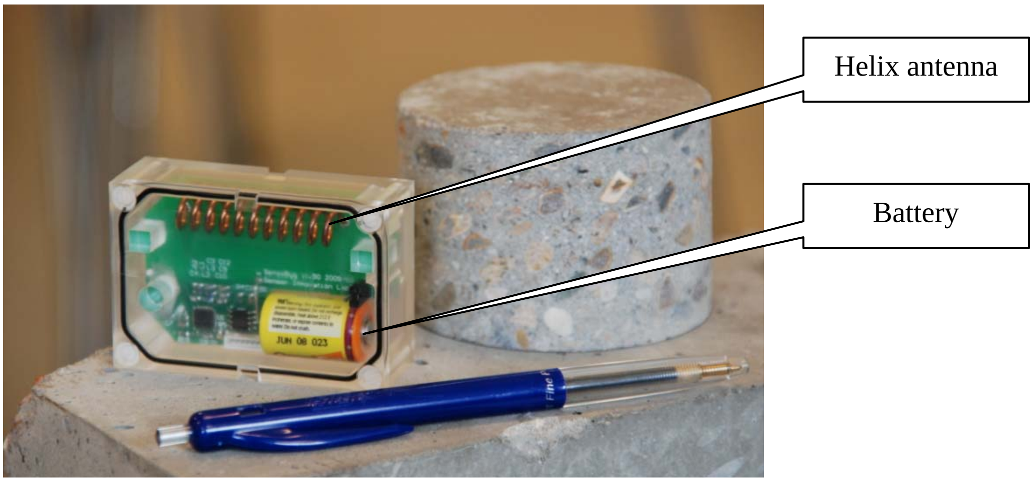

Figure 3. Rectangular wireless sensor unit with helix antenna. Design by DTI

The sensor that is meant for cast-in applications (Fig. 3) is protected in a transparent plastic casing with dimensions approx. 2x4x6 cm. In order to avoid water or cement paste to enter the sensor unit an appropriate membrane material is used to block water molecules but allowing water vapour to enter the sensor unit. The performance of the sensors is demonstrated in the full-scale applications and so far they have survived castings in self-compacting concrete and dry mix concrete (roller compacted).

Applications in civil structures

Large structures such as civil structures (e.g. bridges and tunnels) are often designed with 100+ years of service life. They are often placed in aggressive environments (frost, thaw, de-icing, seawater, etc.). Sensors may be useful to monitor the critical areas for strength and durability both during construction (short term quality assurance) and over long term considerations of maintenance issues. Since civil structures are often important infrastructures, causing large problems in case of failure and during repairs, it is important to be able to monitor the state of the structures with as little disturbance as possible. Embedded wireless sensors are expected to provide better decisions for repair need and improved prioritising assistance to consulting engineers and building owners.

During the summer of 2007 a preliminary application was installed in connection with a highway bridge repair project under the auspices of the Danish Road Directorate (Fig. 4). The repair was typical for Danish concrete bridges where the waterproof membrane under the asphalt pavement becomes defective after 20-40 years of service life. Then water gets access to the reinforced concrete bridge deck from above, bringing harmful chlorides to the concrete and increasing the risk of corrosion. After removal of asphalt and the old damaged concrete the bridge deck is recast, followed by new waterproofing membrane and pavement. The whole operation is carried out in two phases in order to minimize traffic disturbance.

A total of 5 wireless moisture sensors corresponding to the one shown in Fig. 3 have been installed in small box outs directly under the membrane. Each sensor is equipped with extra batteries in order to ensure up to 30 years battery life (Fig. 4 and 5). The five sensors are installed along the bridge deck gutter line over a length of 30 m. Their purpose is to monitor whether the membrane starts to leak and indicate the time of rehabilitation. It is recognized that the sensors are probably not going to last 30 years but they will give valuable information on the practical aspects of installation and embedment techniques. It is also demonstrated how the sensor survive heat impact from hot bitumen during application of membrane and hot asphalt.

Sensor signals are transmitted every hour to a reader, which is placed at the bridge. The reader box is equipped with a solar panel in order to provide sufficient energy to receive and store the sensor signals and subsequently transmitting the signals to an internet server by means of a GSM modem. In that way the system is fully independent of the public electricity supply.

Figure 4. Left: Preparing repaired bridge deck for new waterproof membrane. Right: Sensor (black box) with extra battery package (grey box)

Figure 5. Box out in bridge deck where the sensor and battery box are installed and a protection lid is added on top. Right: Ready for applying the waterproofing membrane

Results from the first few weeks of operation are depicted in Fig. 6. A sampling frequency of one per hour may not be suitable for real applications since the data amounts get huge and the battery is used every time a signal is sent to the reader box. However, in the preliminary tests we were eager to obtain proper data rather than optimizing battery life. Furthermore, the data signals from the sensor farthest away from the reader box are not always picked up due to the signal conditions on the site in general and on the signal distance of 30 m in particular. Thus, it is nice to have a rather high sampling rate so that the data are sufficient for evaluation. In real applications a sampling frequency of once every week may be sufficient.

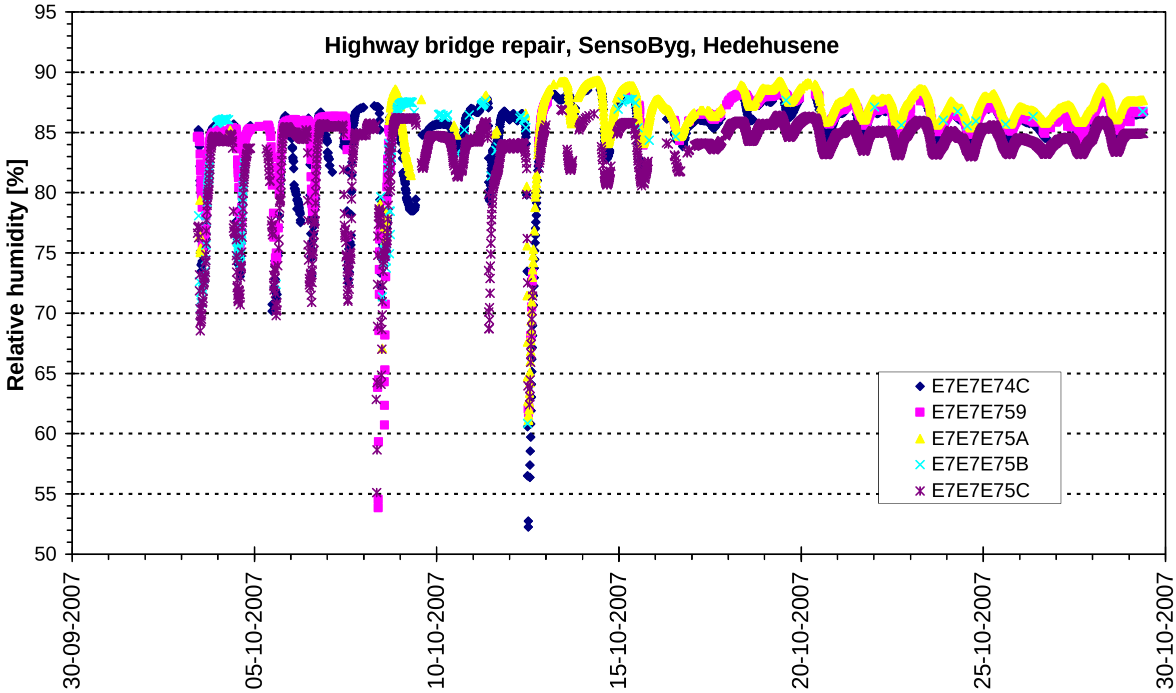

Figure 6. Diagram of relative humidity measured in the five sensors located right under the waterproofing membrane

It is expected that in case of a leaking membrane the relative humidity in one of the sensors will increase abruptly, being an indication of water penetrating the asphalt. Such registrations will constitute a valuable decision support together with visual on site control. Monitoring will decrease the need for destructive tests on the asphalt and concrete in order to provide information on the condition of a waterproofing membrane. This philosophy is easily converted to other critical areas of civil structures such as prestressing tendons and drainage systems.

Experiences with the highway bridge application clearly show that battery life issues are crucial since damages in such structures are often not expected until after a couple of decades. Therefore, new energy harvesting technologies are foreseen to influence the condition monitoring of civil structures. Furthermore, since the largest potential is lying within refurbishment and renovation works on existing structures, suitable post-installation techniques are to be developed.

Moisture in buildings and indoor climate

Indoor climate in buildings and houses is becoming more and more important as the requirements for buildings energy performance and air tightness are becoming stricter. Better energy performance means more insulation less window area and controlled ventilation systems. Therefore, it is important that indoor air quality is not impaired for health reasons. Wireless technologies are becoming more common in modern buildings. For instance in terms of fire alarms, electricity consumption readings, remote control of heating/cooling, etc.

SensoByg will install wireless sensors in buildings in order to monitor the operation and maintenance phase. The following subjects are included in a full scale monitoring of two flats in Copenhagen:

- Monitoring structural elements such as wooden roof structure or a basement where visual access is difficult to obtain. This would reduce the risk of rot and save expensive repair works.
- Monitoring building elements in close contact with water such as bathrooms, sewage installations and the climate shield. Leaking water is the cause of damage in buildings and a built-in monitoring system would help minimise damage

- Monitoring indoor air temperature and relative humidity. A combination of temperature and relative humidity is used to evaluate whether there is a risk of fungi growth on the inner surfaces of the building.
- Monitoring energy consumption for room heating. The building owner may use these data to alter the behaviour of the inhabitants so that energy is saved.

Most of the above mentioned items are strongly correlated with measuring relative humidity and moisture. The moisture level in construction materials or in the indoor air is an excellent indicator for damage and unhealthy indoor climate. Another common denominator for these items is that moisture related damage generally develops slowly over time. Hence, it is difficult to detect unless you are recording data over time, which is impossible with conventional methods.

Figure 7. Installation of wireless sensor in lightweight concrete wall next to water installation

Therefore, the wireless RH sensors are ideal for such applications where continuous monitoring is needed. First of all it is important to determine the most suitable location of sensors in order to catch the most critical damage (Fig. 7). Secondly, the decision making needs tools so that the risk of damage or unhealthy indoor climate is assessed in a scientifically sound manner. Both these aspects are dealt with by experts in building materials and indoor climate.

Applications in concrete production

In connection with concrete castings there may be a need to monitor the concrete temperature in a structure for a number of reasons:

- Firstly, it may be used to evaluate the maturity and strength of a concrete pour in order to decide time of formwork stripping and/or prestressing. The use of temperature registrations combined with age is converted into maturity, which again is related to the strength development and degree of hydration of concrete (Nielsen 2007). These principles are applicable to cast-in-place structures and precast concrete products.
- Secondly, the temperature difference between the core of a casting and the surface should not exceed a certain limit due to the risk of early-age thermal cracking. This is especially a concern of massive cast-in-place structures where the heat of hydration escapes slowly. On-line monitoring of critical cross-sections could help eliminate the risk of early-age cracking and improve the durability of the structure.
- Thirdly, temperature monitoring on the building site and on the formwork and reinforcement could be suitable to control active measures such as embedded cooling pipes or heating wires or it may help to warn against freezing conditions prior to casting.

Generally it is a difficult task to establish a conventional temperature monitoring system by means of thermo couples due to the need for wiring and data loggers. Often the temperature readings are not gathered and investigated until weeks after the casting took place. This means that these readings cannot be used for real time decision making. Wireless temperature sensors would make on-line assessment of the temperature conditions possible in a real time environment and the building site engineers could use it to make actual decisions. For precast concrete products the elements are moved around from the casting facility to temporary storage, to the building site and finally to its final position in a building. Hence, precast concrete is often subject to various curing conditions and the need for continuous monitoring may be helpful for certain products.

Moisture monitoring in concrete. Another important aspect of concrete production is the moisture content. During hydration the cement reacts chemically with the mixing water but even after complete hydration there is still say 110 litres of water per m^3 in the concrete pore system (Grasley et al. 2006). If the concrete is applied into a slab on grade and the floor material is a moisture sensitive material, e.g. wood or glued plastic flooring the relative humidity in the concrete should not exceed say 85 %-RH. Otherwise the glue looses its adherence and the basis for growth of fungi is there, increasing the risk of poor and unhealthy indoor climate.

For conventional concrete for houses this means, that there is an excess amount of water of approximately 30 litres/m^3, that needs drying out before flooring is applied. During the cold season concrete drying is a very slow and lengthy process, requiring a lot of energy for heating and ventilation. Drying out of concrete will often require 2-3 months with controlled drying climate, i.e. moderate temperatures and fairly dry air.

It is a big challenge to plan this process into a tight construction schedule. Furthermore, a building site is always subject to rain and other sources of water during construction that may hinder the drying out process further (Figure 8).

Figure 8. Ponds of rain water on a concrete slab delay the drying out of the concrete

In Denmark the floor contractor is obliged to document that the moisture, level in terms of relative humidity in the concrete pores, is below the threshold value before the flooring is applied. Conventional measuring of relative humidity in a floor slab is often destructive and time consuming as described below:

- A RH sensor is placed in a drilled hole so that the relative humidity is registered in half thickness of the slab. The sensor should be left in the hole for at least a day in order to obtain moisture equilibrium. Then the operator has to return the next day to take a reading. At a building site it is not safe to leave expensive and delicate equipment such as a RH sensor in place for several hours. Also the readings may be sensitive to temperature variations.

- Alternatively a sample of concrete is taken from the slab in half thickness depth. This sample is then sealed in plastic bags and taken to a laboratory where it is brought in temperature equilibrium and then in contact with a RH sensor.

Both methods are destructive and they need special equipment such as hammer drill. It is not normal to take more than a single sample from even a large concrete floor and the variation in moisture content is not considered. Another restriction on moisture measuring is the presence of cast-in heating pipes, which makes destructive sampling difficult. Furthermore, the methods require skilled persons to condition and handle the sample. This person is never the same as the one who is running the building site. A number of capacitive surface probes exist, being able to assess the moisture level in an easy manner. However, these methods are not suitable for determining the moisture content below a depth of a few mm.

Wireless RH sensors (similar to those in Figures 2 and 3) are placed in a certain area of newly cast concrete makes the contractor able to monitor the drying process continuously and make decisions on when to bring in extra heating, ventilation or air driers to the building site. He would also be able to plan his work better and to control the interfaces between the different labor groups on the site. At the end of the day the floor quality would be better and the need for expensive repair work is reduced or avoided. SensoByg is demonstrating these applications on full scale building sites and furthermore, a forecast tool is developed so that the contractor may use the RH readings to predict the drying process based on certain assumptions.

It is obvious that the installation of such embedded sensors should be carried out with high precision. Otherwise the measurements become subject to large variations and therefore useless. Another important aspect is the disturbance of the moisture profile by the sensor unit itself. Finite element calculations have been carried out on one-dimensional drying of a concrete slab (Nilsson & Fredlund 2009), showing that the orientation of the sensor unit has significant impact on the moisture profile. If the sensor unit is “blocking” the natural direction of moisture transport the error in RH readings will be more than ±10 % from the theoretical value for an undisturbed moisture profile. These results are based on a characteristic sensor size of around 50 mm.

Results

Results from the SensoByg project are in the making and therefore, not ready for presentation here. A series of important issues have been identified for the successful applications of wireless sensors in the construction industry:

- The development of proper methods for installation of sensors in newly cast concrete is important. The environment on a building site is harsh and aggressive for delicate electronic devices. This should be addressed when installation methods are chosen.
- Fixing sensor units so that the correct location of the measurements is ensured.
- The sensor casing should be robust enough to resist the impact of falling concrete as well as impacts from the casting equipment and vibrators. At the same time it should allow water vapor to enter the sensor unit but keep fluid water and cement slurry from entering the casing.
- Both concrete, reinforcement and water influences the wireless signal strength and imposes strict demands on the sensor design. The balance between sufficient battery life and signal performance is crucial.
- Methods for post-installation are also needed for various building elements such as concrete bridges and tunnels, lightweight stud walls, bathroom walls and wooden floors. It is recognised that post-installation in existing structures is probably where the largest potential lies.
- Precision, stability and accuracy of sensor units should be verified. In many cases the sensor is hidden inside structural elements and no possibility of recalibration and maintenance exists.

All the above mentioned issues are being demonstrated and investigated through a combination of full scale applications and laboratory tests.

Another important outcome is the interface towards the end-user. It should be both versatile and simple to use. The different applications involve different types of end-users. For the management of civil structures the end-user is often highly skilled experts with experience from complicated structures and complicated links between structure, material and durability. For houses and indoor climate the end-user is often a person with some technical building background who is responsible for many housing units at the same time. For moisture and temperature of new concrete the end-user is contractors who are responsible for the processes on the building site. All of these applications are being developed under the auspices of SensoByg.

Conclusions

Wireless sensor systems are being investigated in a Danish R&D project. Different applications are being demonstrated in full scale. The following applications are expected to become very beneficial to implement wireless monitoring:

- Control of indoor climate in residential buildings. The risk of poor indoor climate is linked to the relative humidity of the indoor air combined with temperature. By monitoring over time and using practical experiences of growth of fungi the indoor climate is assessed and used as an indicator of indoor air quality.
- Management of civil structures subject to aggressive environmental exposures. Operation and maintenance surveillance. Critical parts such as edge beams and waterproofing membranes have large potential for wireless monitoring in order to evaluate the need for repairs and refurbishment. The monitoring data will be part of the decision making process when prioritising between different structures. This could lead to better sustainability of our infrastructure due to a higher utilisation of the materials and exploitation of their full service life potential.
- Control of moisture and drying out of newly cast concrete. Especially concrete floors to be covered with moisture sensitive flooring material are important to monitor in order to avoid moisture damage due to erroneous execution. Conventional moisture control is a lengthy process and the use of cast-in sensors would make this process much more operational in practice. Moisture related damage on new buildings is responsible for large costs, which are likely to be reduced significantly if monitoring is used on a larger scale than at present.

A subject being considered is quality control of large concrete castings. Sensors being able to monitor and detect honeycombs, entrapped air and segregating concrete during casting could mean a large quality improvement of concrete structures in general. However, it was decided early on to omit this subject from the project since the available sensor technology is not advanced enough for this purpose.

The project has identified several technical challenges, especially concerning installation and design of sensors to be used in the harsh environment of newly cast concrete. It is recognised that further development is needed before the right sensor design is available commercially. The key words for sensor design are price, size and service life. However, it is anticipated that suitable sensors are going to be available in due time and that the project is helping applications like the ones stated above to become realised in a not to far future.

Acknowledgements

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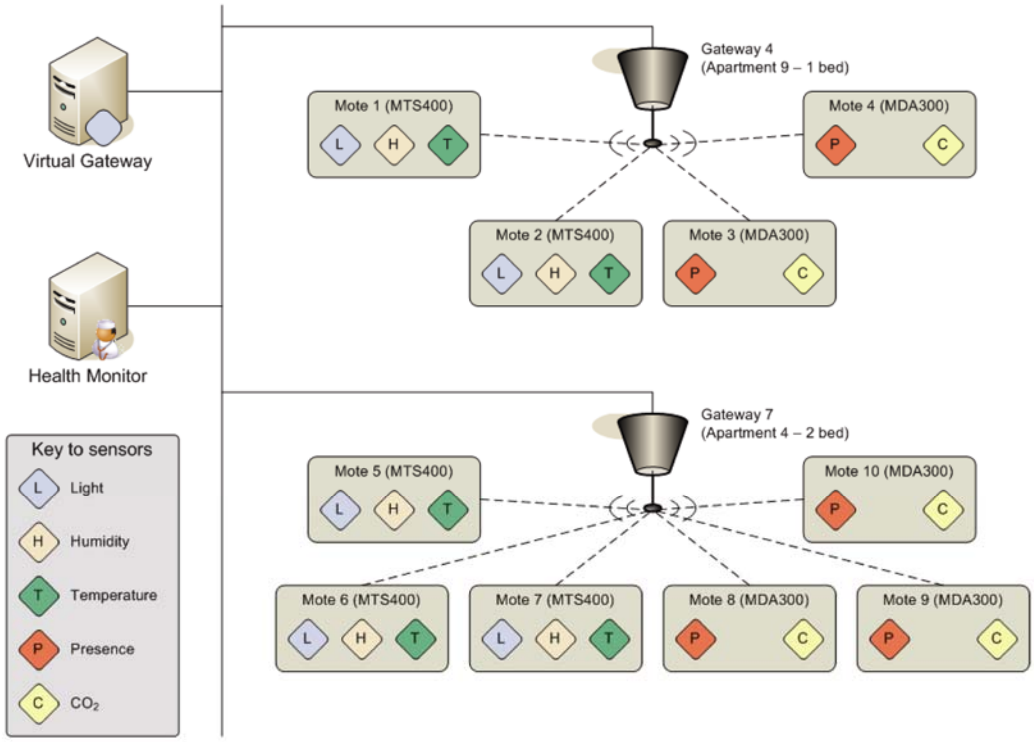
9

A Health Monitoring Application for Wireless Sensor Networks

Abolghasem (Hamid) Asgari, Mark Irons



A Health Monitoring Application for Wireless Sensor Networks

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Abstract

Operational health monitoring of Wireless Sensor Networks (WSN) is becoming an essential part of these networks. A WSN health monitoring application is distinct from the sensor data visualisation as each is aimed at different audiences i.e., the WSN health monitor is intended to aid those who set-up and maintain the network, while the sensor data visualisation is aimed at building/facilities managers or the building occupants for comfort monitoring and awareness. Health monitoring should provide an indication of sensor node failures, resource exhaustion, poor connectivity, and other abnormalities. There are several problems that may result in the WSN gateway not receiving sensor data, for example, low battery voltage or poor connectivity to the gateway. It is very time consuming to resolve such problems if there is no means of monitoring the operation of the WSN. This necessitates the development of an easy to understand, visual method of monitoring the health of the WSN in real-time. We have developed an application that is capable of monitoring the operational health of a deployed WSN and displaying the results through a browser-based user interface. The sensor nodes collect environmental data and periodically send the updates, which are stored by the virtual gateway in a database. The WSN health monitoring tool is implemented as an enterprise Java application that exposes a REST interface through which the virtual gateway can provide required sensor information.

Keywords: wireless sensor networks, service oriented architecture, network health monitoring, security, REST-based SOA

Introduction

The emergence of Wireless Sensor Networks (WSN) has brought significant benefits as far as building/environmental monitoring is concerned, since they are more cost-efficient (because of the lack of wired installations) compared to their wired counterparts, while additionally they allow for flexible positioning of the sensor devices. Any WSN architecture should be designed to allow its straightforward integration to the general networking infrastructure where any other application can utilize the data gathered by WSN. The common approach to achieve this is the Service Oriented Architectures (SOA) open framework where all architectural elements are decoupled and considered as service providers and consumers. Service discovery and access to the services is performed in a dynamic manner, ensuring a generic and extensible design. Web Services constitute the most significant technological enabler of SOAs due to the interoperability they offer and that they can easily support integration of existing systems. In I3CON project, we have designed, developed, implemented, and deployed a WSN architectural framework to be used by other applications over an SOA infrastructure [1], [2], [3], [4].

The functionality of the WSN architecture is decomposed in two complementing aspects, namely:

- WSN services exposed to applications (service consumers) by means of enterprise middleware.

- WSN tasking to enable configuring sensor nodes for data collection by means of the tasking middleware.

The WSN architecture assumes the role of service provider as far as data collection and information management is concerned. This justifies the need for a WSN service interface to be defined and exposed to the SOA infrastructure, in order to hide the complexity and heterogeneity of the underlying WSNs.

The WSN architecture is implemented over two sensor platforms, i.e. the sensor node and the gateway, while at a higher layer of abstraction a Server entity (i.e. Virtual Gateway) is responsible for managing the WSN nodes. A gateway essentially is a network-bridging device, which connects each WSN zone to the Intranet/enterprise network. The Virtual Gateway is made aware of various WSN zones available in the enterprise building and their respective zone gateways by accessing a topology map. When applications/services require interaction with the WSN architecture as a whole, this occurs through the relevant WSN service interface that interacts with the Virtual Gateway. The Virtual Gateway is equipped with an enterprise middleware layer, which is responsible for communicating with the WSN service interface of the SOA. We used a web services model that constitutes a means for various software platforms to interoperate, without any prerequisite regarding platform and framework homogeneity being necessary. A WSN environment is essentially a collection of resources (i.e. sensors) that continuously monitor their environment (i.e. get measurements). We have therefore defined a REST-based (*REpresentational State Transfer*) style SOA to enable integration of the WSN with enterprise services [5], [6], [7].

By exploiting the aforementioned architecture, an external application has been developed to monitor the operational health of WSN, identify possible operational problems in the network, and display these to administrators via a web-based user interface. The application also enables the structure of the WSN to be browsed through the user interface. The application is regarded as a consumer of WSN data and a service provider to the external clients (managers or occupants) in the SOA paradigm. The application assumes that the WSN is comprised of one or more wired gateways, with each gateway servicing a number of wireless motes in a zone. A mote may contain several sensors, each sampling a different quantity, e.g. light, temperature, humidity, presence, CO_2, etc. Associated with each sensor is a collection of measurements, each with a time-stamp and a value.

The remainder of this paper is structured as follows. Section 2 briefly describes the WSN generic security issues and implementation of an access control service. Section 3 provides a brief overview of related work and then describes the design and configuration of WSN health monitoring application. Section 4 provides the instructions for the operation of the application. Section 5 discusses the interface of the application to the virtual gateway for accessing to the required data. A brief summary is given in Section 6.

WSN Security and Access Control Service

Before explaining the WSN health monitoring application that we have developed, here, we briefly discuss the WSN security as an important and related aspect to the health of WSN. Given the vulnerabilities of WSNs, security is a highly desirable and necessary function, depending on the context and the physical environment in which a sensor network may operate [13].

Since WSNs use wireless communications, they are vulnerable to attacks, which are rather simpler to launch when compared to the wired environment [14]. Many wired networks benefit from their inherent physical security properties. However, wireless communications are difficult to protect; they are by nature a broadcast medium, in which adversaries can easily eavesdrop on, intercept, inject, and alter transmitted data. In addition, adversaries are not restricted to using sensor network hardware. They can interact with the network from a distance by using radio transceivers and powerful workstations. Sensor networks are vulnerable to resource consumption attacks. Adversaries can repeatedly send packets to waste the network bandwidth and drain the nodes' batteries. Since sensor networks are often physically deployed in less secure environments, an adversary can steal nodes, recover their cryptographic material, and possibly pose as one or more authorized nodes of the network.

Security should satisfy a number of basic requirements, i.e. availability, data access control, integrity, message confidentiality and control the access to task the sensor and retrieve the data in the presence of adversaries [15]. Service and network *availability* is of great concern because energy is a limited resource in sensor nodes that is consumed for processing and communications. Equipped with richer resources, the adversaries can launch serious attacks such as resource consumption attacks and node compromise attacks. *Link layer access control* implies that the link layer protocol should prevent unauthorized parties from participating in the network. Legitimate nodes should be able to detect messages from unauthorized nodes and reject them. Closely related to message authenticity is message integrity. *Data integrity* guarantees that data should arrive unaltered to their destination. If an adversary modifies a message from an authorized sender while the message is in transit, the receiver should be able to detect this tampering. *Confidentiality* means keeping information secret from unauthorized parties. It is typically achieved with encryption preventing the recovery of whole/partial message by adversaries. Data encryption guarantees that sensitive data are not revealed to third parties, intruders, etc. Data is encrypted for coping with attacks that target sensitive information relayed and processed by the WSN. *Access control service* is to provide a secure access to WSN infrastructure for sensor tasking and data retrieval.

As far as I3CON project is concerned, data encryption, data integrity and access control have been selected as the most prominent security functions. The first two can be provided as middleware services, i.e., they do not affect existing interfaces and are transparent to the communication between sensor nodes. Both of these security functions have been designed and implemented by Intracom (an I3CON project partner) in their testbed environment and reported in [3]. The following section describes the access control service development and implementation carried out by TRT (UK).

WSN Access Control Service

The overall requirement is to create a general access control mechanism that provides secure access to data. There is an implementation requirement for a modern access control architecture that can support efficient, effective and secure modern working practices. Concepts such as secure communication of sensitive information, roles and separation of duties are important. Access control requirements generally cover *Authentication*, *Authorisation* and *Accounting* (AAA). AAA is a way to control: who is allowed access to data, what services they are allowed to use once they have access, and recording what they have done. An AAA framework defines how control of access to information and services (data and applications) is performed. Authentication is the process of checking that a requestor is who (or what) he/she claims to be. Authorisation is the process of giving a requestor permission to access an application or access some data. Accounting (Auditing) is the process that all actions are recorded with an auditing process and usage of resources can be accounted for with an accounting facility.

As previously described, the I3CON solution defines a REST web services API to provide clients with a mechanism to task (i.e. conFigure) and query the WSN. Sensor tasking and querying are distinct operations that clients must only be allowed to perform if they have been granted the necessary rights to do so. This requires the I3CON REST web service to enforce a level of access control that can authenticate clients and ensure that they have authority to make a particular request. An I3CON WSN access control mechanism has been implemented that provides authentication of REST clients and restricts access to specific resources based on a combination of URL patterns and roles assigned to the client. The implementation is based on the Spring Framework's security project [16], which provides comprehensive application-layer security services to Java based applications.

Spring Security provides support for authentication (i.e. the process of establishing that a client is who they say they are), and for authorisation (i.e. the process of establishing that a client is allowed to perform an operation). A wide range of authentication mechanisms is supported, including HTTP BASIC authentication [17], OpenID [18] and HTTP X.509 [19]. The I3CON solution uses HTTP

Digest authentication [17], which ensures that client passwords are not sent in clear text. It should be noted that Spring Security does not provide transport-layer security, however it can be used in conjunction with an appropriate transport layer security mechanism (e.g. HTTPS) to provide a secure data channel in addition to authentication and authorisation. The Spring Security authorisation mechanism can be used to control access to class methods, object instances, and HTTP resources (identified via a URL pattern).

Two client roles have been defined for the I3CON REST API. Clients who are granted the role ROLE_WSN_QUERY are permitted to query WSN data. Clients who are granted the role ROLE_WSN_TASK are allowed to perform tasking operations on the WSN network. Clients who are granted both roles are allowed to perform WSN query and tasking operations. Spring Security can be configured to obtain client details from a variety of sources, for example an in-memory map, or a relational database. The access control mechanism required for the I3CON prototype is relatively simple, and is expected to support a small number of clients. For this reason the client details (i.e. username, password, and assigned roles) are stored in an in-memory map that is configured during application start-up from an XML configuration file. This provides the flexibility necessary to configure and change users after the system has been deployed.

WSN Health Monitoring Application

Related work

A number of related works are briefly discussed below. MOTE-VIEW is a client-tier application developed by Crossbow designed to perform as a sensor network monitoring and management tool [8]. NanoMon [9] is software developed for WSN monitoring which is also capable of visualising the history of received sensed data as well as network topology. In [10] a middleware service is proposed for monitoring of sensor networks by using sensor agent nodes equipped with error/failure information forwarding capability. An execution and monitoring framework for sensor network services and applications, called ISEE is proposed in [11]. One of the ISEE modules provides a consistent graphical representation of any sensor network. A work on using heterogeneous collaborative groupware to monitor WSNs is presented in [12]. Our work focuses on providing network health monitoring services that complies and utilises the REST-based web services SOA style.

Design and Configuration of WSN Health Monitoring Application

The Health Monitoring application uses data that is stored in the data base and provided by the Virtual Gateway to identify several types of possible operational problems in the WSN, as listed below:

- The battery level of a mote is below a configurable threshold.
- The time-stamp of the most recent measurement from a sensor is older than a configurable number of milliseconds.
- No measurements have been received from a sensor.

The Health Monitoring application is implemented as a Java web application that runs inside a standard servlet container, e.g. Apache Tomcat. The application can be configured to automatically analyse the health of the WSN at regular intervals, and it is also possible to manually initiate a check of the WSN through the user interface. The application is configured via a properties file located at i3con-manager/WEB-INF/application.properties. The configurable properties are shown below:

- **bimResource** – the location of the XML resource that describes the topology and structure of the deployed WSN, e.g. file:i3con_margaritas_deployment_01.xml. This file is the same format as used by the virtual gateway. The structure of deployed WSN is shown in Figure 1.
- **moteLowBatteryWarningLevel** – the battery level in volts below which a mote battery is considered too low.
- **sensorMeasurementTooOldWarningInterval** – the age in milliseconds above which the most recent measurement from a sensor is considered too old.

- **autoRefresh** – true if the Health Monitoring application should automatically check the health of the WSN at regular intervals, otherwise false.
- **autoRefreshInterval** – if *autoRefresh* is true this is the period in milliseconds at which the health of the WSN will be checked.

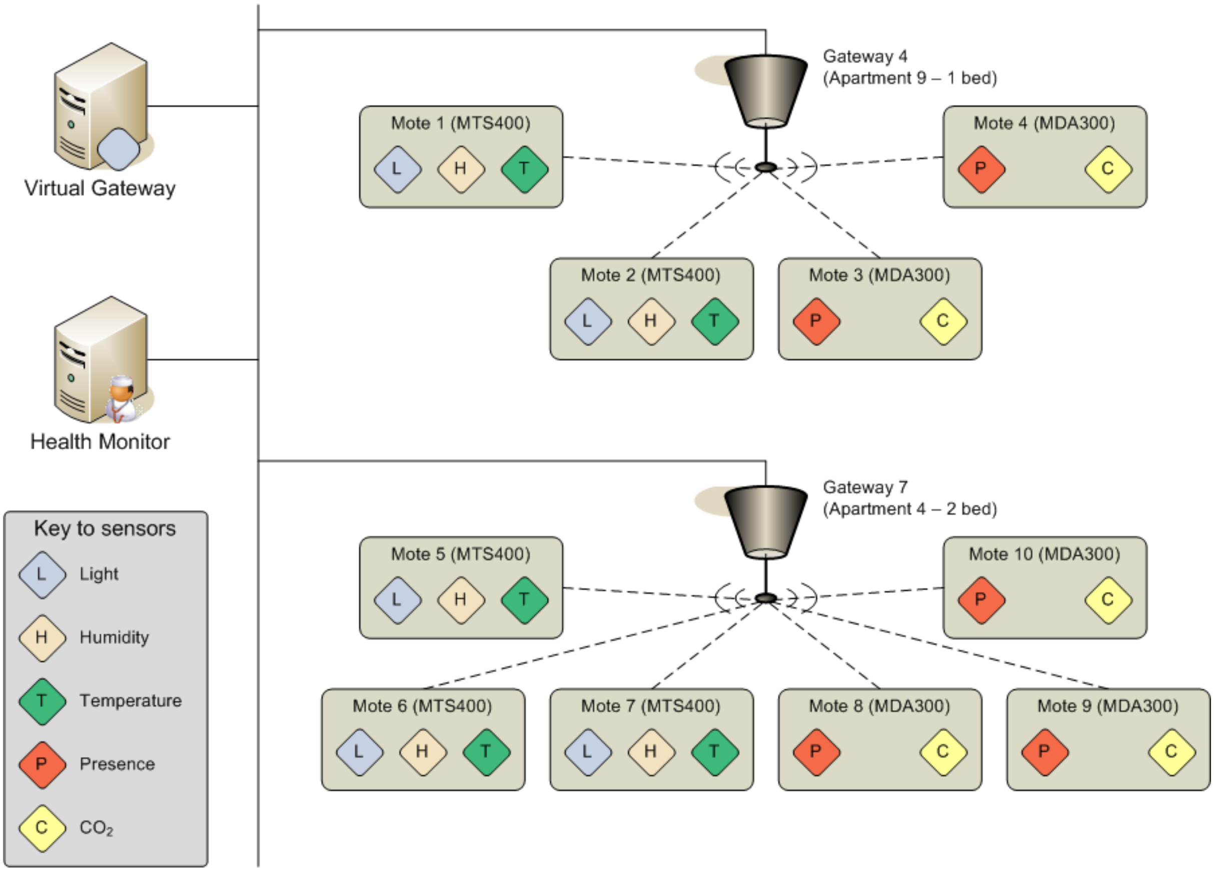

Figure 1. I3CON WSN Topology

Operation of WSN Health Monitoring Application

To use the Health Monitoring application, the user must point a web browser at the following URL:

http://<host>:<port>/i3con-manager/

The application requires a user name and password to login. These can be configured by editing the configuration file located at i3con-manager/WEB-INF/applicationContext-security.xml. Following successful login the user is presented with the default home page, as shown in Figure 2.

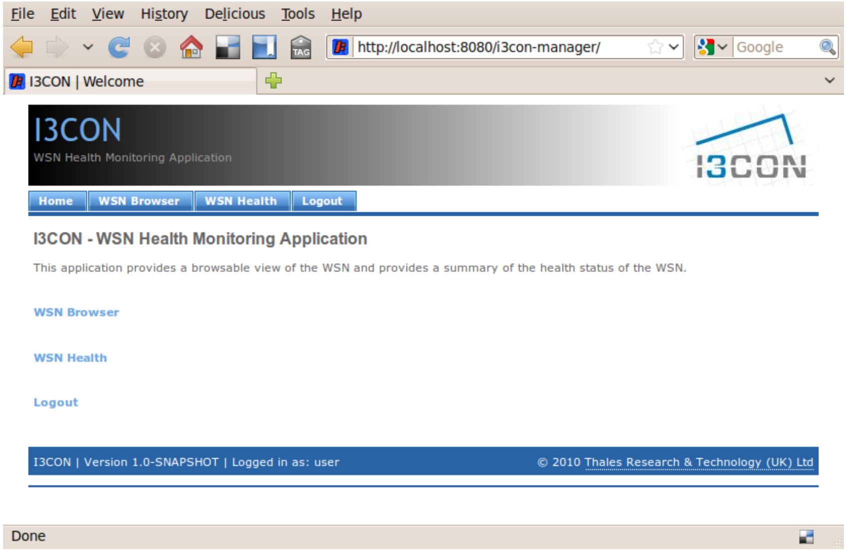

Figure 2. I3CON Network Health Monitoring - default home page

WSN Browser Display

The user must select the *WSN Browser* from the menu to browse the network. Clicking on a gateway will display all the motes attached to the gateway. Clicking on a mote will display all the sensors on the mote and clicking on a sensor will display the measurements from that sensor. An example is shown in Figure 3.

Figure 3. I3CON Network Health Monitoring - browser display

The application adheres to a REST-style URL hierarchy for browsing the WSN, so for example to view details of the temperature sensor on mote 1, gateway 4 the URL is:

http://<host>:<port>/i3con-manager/REST/gateways/4/motes/1/sensors/Temperature.html

This convention enables URLs to be entered manually in order to directly view details of a particular part of the WSN. The application also exposes the same data in an XML format, which is accessed by removing the *.html* extension from the end of the URL. Some examples are shown in Figure 4.

To get details of a gateway	
request	http://<host>:<port>/i3con-manager/REST/gateways/4/
response	<gateway> <id>4</id> <description>Apartment 9 (1-bed)</description> <ipAddress>192.168.1.73</ipAddress> </gateway>
To get details of a mote	
request	http://<host>:<port>/i3con-manager/REST/gateways/4/motes/1/
response	<mote> <id>1</id> <batteryLevel>0.0</batteryLevel> <description>MTS400</description> </mote>
To get details of a sensor	
request	http://<host>:<port>/i3con-manager/REST/gateways/4/motes/1/sensors/Temperature
response	<sensor> <id>9550741e-e028-440b-961a-922437a10e10</id> <measurementQuantity>Temperature</measurementQuantity> </sensor>

Figure 4. Examples of how to get information about WSN nodes

WSN Health Display

To view possible problems in the WSN that could affect the operation of WSN monitoring for building management purposes, the user must select the *WSN Health* option from the menu. If the application is actively busy checking the health of the WSN, a page will be displayed to indicate that the application is busy. The display will automatically be refreshed to display the results when they become available. If the application is not actively checking the health of the WSN the results of the last check will be displayed immediately. An example is shown in Figure 5.

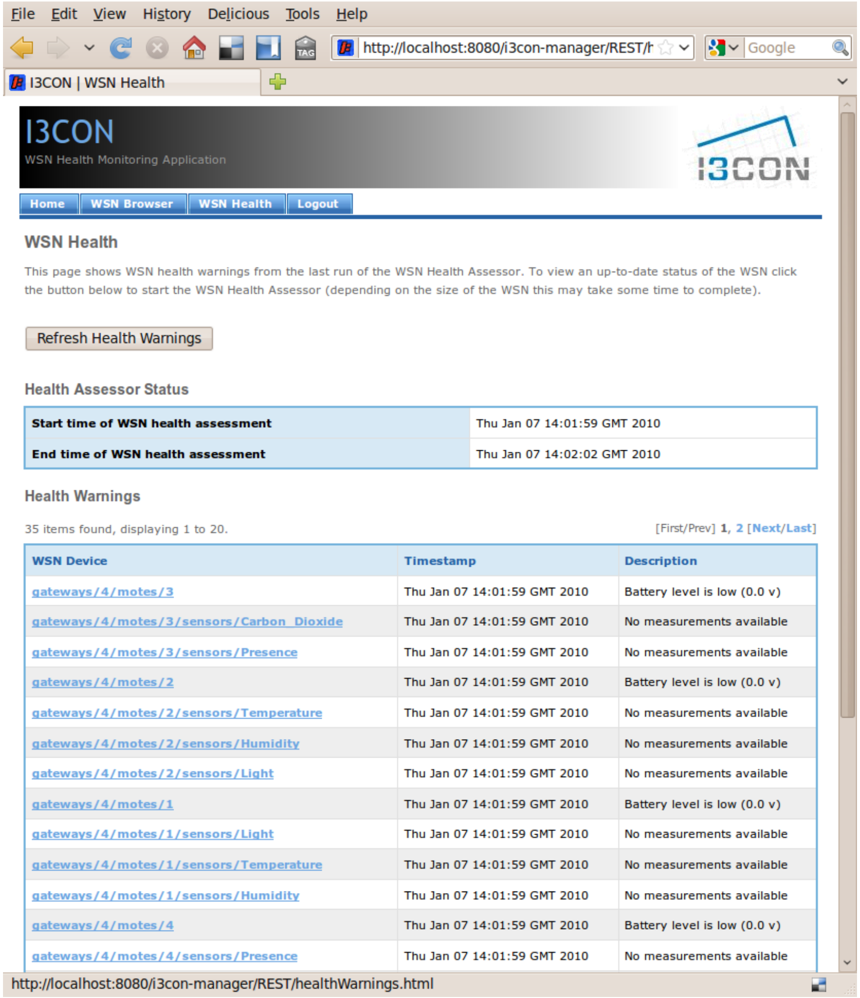

Figure 5. I3CON Network Health Monitoring - health display

The start time and end time of the health assessment are displayed together with a list of health warnings that were identified. Clicking on an entry in the table will display the details for the WSN device that is the source of the problem. Clicking the Refresh Health Warnings button will cause a new health assessment of the WSN to be started immediately.

Health Monitoring Application Interface to Virtual Gateway

The WSN Health Monitoring application relies on data provided by the Virtual Gateway in order to provide accurate information about the state of the WSN. The Health Monitoring application implements a REST style interface that the Virtual Gateway uses to provide sensor measurements and mote battery status updates.

To update the battery level of a mote, the Virtual Gateway should perform a HTTP PUT to the following URL:

http://<host>:<port>/i3con-manager/REST/
gateways/<gateway_id>/motes/<mote_id>/batteryLevel/

The data associated with the PUT request must be an XML document specifying the battery level in the following format:

<batteryLevel>1.55</batteryLevel>

If the PUT request is successful the application will return a response with status code 200 (OK) and a body containing an XML document describing the mote, including the updated battery level.

To provide information about a new sensor measurement the Virtual Gateway should perform a HTTP POST to the following URL:

```
http://<host>:<port>/i3con-manager/REST/
        gateways/<gateway_id>/motes/<mote_id>/sensors/
                <sensor_measurement_quantity>/measurements/
```

The data associated with the POST request must be an XML document containing details of the measurement in the following format:

```
<measurement>
  <timestamp>2010-01-05T09:30:00.000+00:00</timestamp>
  <value>100.0</value>
</measurement>
```

If the POST request is successful the application will return a response with status code 200 (OK) and a body containing an XML document describing the measurement, including an ID assigned by the application. It should be noted that the virtual gateway passes data to the health monitor via the REST interface as it is received from the motes.

Summary

In I3CON project, we have designed an architectural framework for WSN for monitoring of enterprise buildings. We further have developed a REST-based style SOA to enable integration of the WSN architecture with other enterprise services. In this paper, we briefly discussed the issues related to WSN security and described the implementation of an access control service mechanism. We have also described the implementation of an application for WSN operational health monitoring based on the above architectural frameworks. The application has been deployed and is in use in TRT (UK) WSN testbed and in Margaritas building in Madrid. There is also a plan to deploy WSN infrastructure in a building in Seville, Spain. The captured WSN environmental data will be used by a number of applications including the health monitoring.

Acknowledgements

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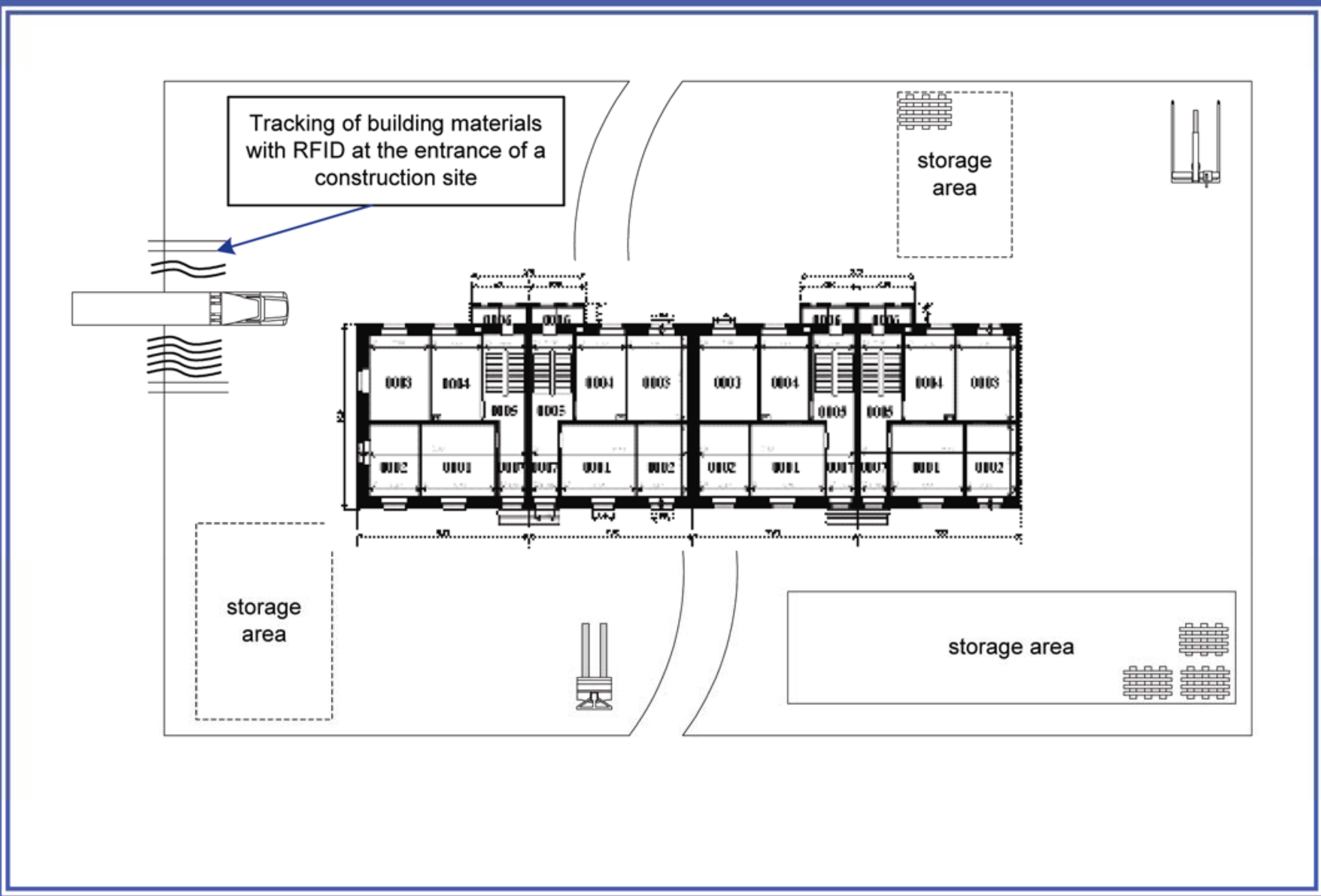
10

The Contribution of RFID to Life Cycle Management in Construction

Frank Schultmann, Nicole Gollenbeck-Sunke



The Contribution of RFID to Life Cycle Management in Construction

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Abstract

Radio Frequency Identification (RFID) technology has attracted increasing attention of researchers as well as practitioners in recent years. However it can be observed that main parts of the construction industry still lack the application of innovative technologies, such as the application of automated identification systems. Potential areas of application of RFID in construction are revealed and a future prospective for the adoption of this technology in sustainable construction management throughout the whole life cycle of a building is developed. Thereby, the relevancy of RFID can be seen especially in industrialised construction, where RFID technology could be applied for the efficient production of building components and parts and tracking them from production to installation. Further potentials of RFID in construction encompass issues like the automation and optimisation of facility management processes and monitoring of operating resources during occupation and operation of buildings as well as environmentally sound deconstruction planning based on information gathered with RFID.

Keywords: radio frequency identification, construction industry, facility management, site management, product identification

Introduction

Automated identification of objects enables the simplification and optimisation of processes in a variety of applications. Examples of identification techniques are Bar Code and the Radio Frequency Identification Technology (RFID). RFID is an Auto-Identification technology that allows the unique identification of objects up to a distance of several feet. It has already been established in rather simple applications like theft-secure in department stores for several decades. In comparison to other Bar Code systems, the advantages of RFID are, for instance, higher reading ranges, the non-necessity of line-of-sight between the reading device and the transponder onto which the data information is stored, and the possibility to store new data onto the transponder independent of on the employed technique.

However, applications and research mainly focus on the implementation of RFID in off-site production where it has already been proven to be successful. This comprises, for instance, the automotive sector and the electrical and electronics industry in various fields, such as anti-theft systems, tracking of products throughout the supply chain, and auto-identification of goods (RFID central, 2007; Srivastava, 2004; Wing, 2006).

Generally, production processes in construction are more complex than in ordinary make-to-stock or manufacture-to-order production environments. Characterised by its design-to-order production, the final assembly of the building takes place on-site and it remains there till the end of its life time. In contrast to the complexity, it can be observed that the construction industry still lacks the application of innovation and high end technologies, such as automated identification systems, although the amount of materials and components as well as information arising during the life time of a building and the different phases of its life cycle are significantly higher than in traditional manufacturing processes. Thereby, the application of such innovative technologies could significantly increase the sustainability of life cycle management in construction, not just with respect to economic means (e.g. more efficient processes), but also with respect to ecological (e.g. waste management in construction) and social aspects (e.g. worker safety on site).

Objectives

This paper reveals potential areas of application of RFID in construction. Additionally RFID applications are embedded in the life cycle of a building and its contribution to sustainability. Thereby, special focus can be drawn to the application of RFID in industrialized construction where it can be applied for the production of building components and parts and tracking them from production to installation. Hence, a future prospective for the adoption of this technology in sustainable construction management throughout the life cycle of a building is developed. It is not intended, however, to give a complete overview of all possible applications in construction as done, for instance, by Wing (2006) and Jaselskis and El-Misalami (2003) as well as in König et al. (2009). Instead, the prospective encompasses issues like material management or safety on site, the automation and optimisation of facility management processes and monitoring of operating resources during occupation and operation of buildings, as well as environmentally sound deconstruction planning based on information gathered with RFID.

RFID - Technology

"Radio Frequency Identification" is a technique for the identification of objects with radio waves. Basically, a RFID system consists of three components: the transponder, the reader, and antenna.

The transponder contains an integrated circuit (IC, i.e. chip) for the data storage and an antenna for sending and receiving data. It is directly tagged to the object and also referred to as "tag". In general, there are two types of transponders. While active transponders contain a battery for internal power supply, passive transponders gain energy from the reader's electromagnetic field (Sweeney, 2005; Jilovec, 2004). Usually, passive transponders are cheaper while active transponders have a higher memory capacity and higher reading ranges. Transponders or tags come along as, for instance, smart cards, coins or labels. The reader communicates and reads the information from the tag. Additionally, the reader can send new data to the tag. Data is usually further transferred to a backend system, like a standardised software application such as an Enterprise Resource Planning (ERP) system. Attached to the reader is the antenna, this sends signals from the reader waiting for the reply of the transponder. For simplification, the device of the reader and antenna will be considered as "reading device" or "reader". The reading range of a RFID system depends on the frequency of the electromagnetic waves. The higher the frequency, the higher the possible reading ranges. These ranges vary from some millimeters up to several metres. The bandwidth of the frequencies RFID systems use are subdivided into Low Frequencies (LF), High Frequencies (HF), Ultra High Frequencies (UHF) and Microwaves. Thereby the frequencies of 135 kHz, 13.56 MHz, 868/915 MHz, 2.45 GHz and 5.8 GHz are most commonly used depending on the application.[1] Generally, low-frequency tags are used for reading distances less than 25 cm, for instance, access control or work-in-progress inventory. In contrast, high-frequency tags are used for reading distances of a few metres (smart cards). Ultrahigh-frequency tags are used, for instance, when high-speed reading is essential and the reading distances are up to several metres, e.g. for toll payment (Srivastava, 2004).

RFID has already been proven to be successful for various applications in recent years. A well-known application is the installation of theft-secure devices, e.g. in supermarkets and department stores, recognizable by the antennas installed at the cash or exit of the stores. Therefore, transponders are tagged to the product and activate a signal at the exit of the store when moving into the reception area of a reading device, unless the RFID tag has been deactivated or removed and kept for further reuse

1 A detailed survey of different RFID applications is given by Schoblick and Schoblick (2005), Finkenzeller (2003), and Schneider (2004).

after successful payment for the product. For this application a simple 1-bit transponder distinguishes between two states which are necessary for the theft-secure: localization of the tag within or outside reading range.

In contrast to conventional Auto-ID Systems (e.g. Bar Code), RFID bears the following advantages (Jaselskis et al., 1995):

- Less contact, non line-of-sight identification of objects over long distances,
- Bulk or mass identification,
- Insensitivity of the transponders against moisture, dirt and abrasion,
- Possibility to store larger amounts of data directly at the item, and
- Possibility to write new data onto the chip of the transponder.

Future Prospective on the Application of RFID in Construction

While other industries shift towards the application of RFID to facilitate logistical and organizational processes, the construction industry is still lagging behind. However, Auto-ID systems and especially RFID offer enormous potential for the construction industry during all phases of the life cycle[2]. There is potential for, among others (König, 2009):

- Improvement of internal and external production as well as logistic processes: improvement of communication and collaboration while simultaneously decreasing communication effort, simplified assignment of construction materials, components and equipment to projects, traceable material flow even during occupation of building, improved information exchange between suppliers and contractors, direct assignment of products to projects, information stored on product.
- Increase in construction quality: unique identification and traceability of construction materials and components, tagging of deconstruction and recovery data to the product or component.
- Improvement of jobsite security and healthcare: emergency alerts or machine switch offs in emergency zones, check of completeness of safety working clothing, coupling of operation permission for machines independent of permissions stored on RFID-tags in ID cards for construction workers.

Hence, RFID can help increase service and performance levels of the construction industry. Therefore, different information occurring in the various stages of its life cycle need to be gathered in order to facilitate optimizing construction processes. Considering a building, objects for auto identification comprise all project resources except resources like know how and monetary flows. These resources are:

- Labour,
- Materials and components, and
- Equipment.

Thereby, the data occurring over the life cycle of a building (see Fig. 1) for these resources are for instance:

- Labour: Personal data, such as name, date of birth, information on working status, and skills.
- Materials and components: Master, producer and organizational data, such as the identity of the material or component in terms of a unique ID, characteristics of material, measures (master data), name of the manufacturer, date and place of manufacturing (manufacturer data), or date of delivery, maintenance intervals, maintenance, time and type of repair (organizational data).

[2] A similar listing than the one introduced in the following can be found, for instance, in (Jaselskis and El-Misalami, 2003; Schneider, 2004).

- Equipment: Master, producer and organizational data in terms of a unique ID, operation limitations, name of manufacturer, date of delivery, ownership, or required skills.

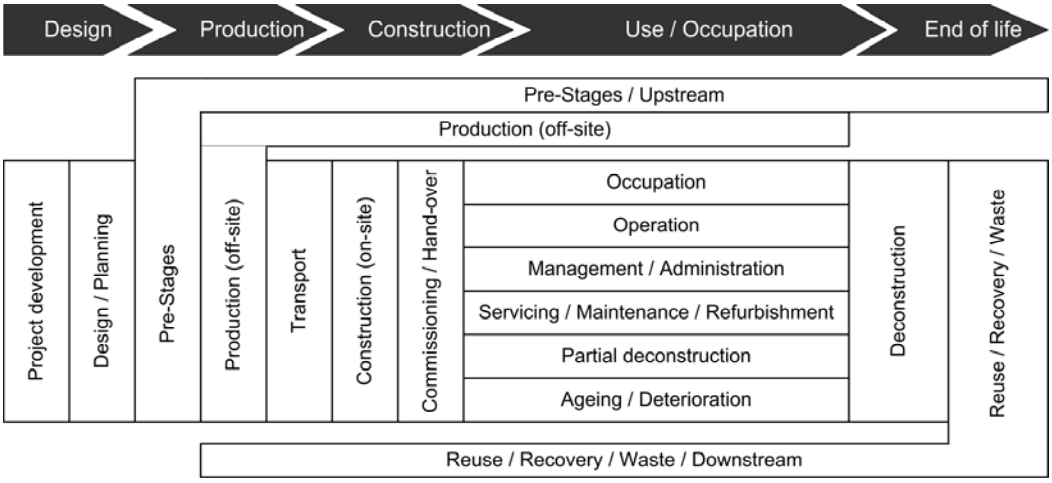

Figure 1. Extended model of the building life cycle (Lützkendorf and Lorenz, 2006)

Production

Similar to other industries like the automotive sector an efficient management of the Supply Chain (SC) presents enormous potential in cost reduction, the avoidance of out-of-stock situations and wrong deliveries as well as an increase in logistical processes. The construction industry could benefit from improved standardisation of incoming goods inspection as well as the tracking and tracing of construction materials and components (Simchi-Levi et al., 2003). Additionally, RFID enhances the information flow among offices and sites in a construction supply chain environment and, hence, improves not only work efficiency on the construction site, but also provides a dynamic operation control and management for the whole project (Wang et al., 2007). Hence, the application of RFID in the production process of buildings, in particular on the construction site, increases the economic sustainability of construction processes and helps to reduce costs for material identification and project control.

Material Identification and Quality Control. In comparison to barcodes RFID enables the identification of materials like discrete solids, liquids, gaseous and metals as well as other components. Currently, product identification marking mainly made directly on the product or packaging by a worker with pen or chalk, as print on the side of the material or on a material layer, as engraving or laser marking, or as label with or without barcode (König, 2009). For easy identification, however, an RFID tag can be attached to each of the components. For expandable items, usually, package labeling is used. Pallet-level tagging can lead to even more efficient identification of products and reduce misdirected shipments and enables a more efficient consignment verification (Jaselskis et al., 1995; Jaselskis and El-Misalami, 2003; Yagi et al., 2005; Srivastava, 2004; König, 2009). Fig. 2 illustrates the identification of building materials supported by a RFID system at the goods receipt on a construction site. Furthermore, information about building materials, e. g. the name of the supplier, the delivery date, the amount delivered as well as the method of delivery can be stored on the RFID tag and enables the supplier as well as the consumer to trace materials and components, even if delivered as freight consisting of different materials and components, in order to save time collecting necessary information (Matsuda, 2005). Thereby, manual recording of inspection results of material tests by paper-based documents can be replaced by RFID. An RFID quality management system can serve as a platform for gathering, filtering, managing, monitoring and sharing quality data, as it was already shown for concrete specimen quality testing in Taiwan (Wang 2008).

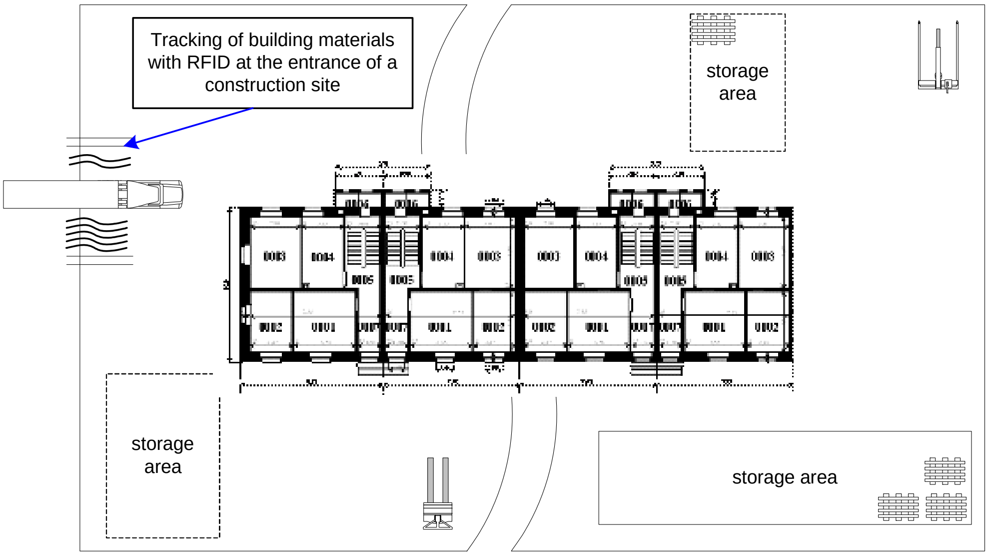

Figure 2. RFID system for object identification at the goods receipt

For instance, a RFID trial was conducted by Fluor Construction in cooperation with Shaw industries, a supplier of metal pipes, in September 2003. The aim was to determine whether RFID could help automate and speed up the identification of building materials. It was shown that pipes with a length up to 40 feet loaded on a truck could be identified from a distance of 10 feet using a frequency of 915 MHz. In this 100 percent accurate readings had been recorded (Collins, 2004). The application of RFID could, hence, reduce lack of information on receipt of ordered material and components (Jaselskis et al., 1995).

Tracking and Tracing of Construction Materials and Project Progress. Despite the control of the delivery process, warehouse management and stock keeping is eased since a great part of the materials are usually stored temporarily on the construction site. As site congestion is usually high and part of the storage space is also assigned randomly, RFID could support the identification of these objects on the building site. Having lost track of certain components and materials RFID supports the construction worker finding certain building materials and components even over longer distances without line-of-sight. This could be realized with a simple handheld reader or via GPS from a certain place inside or outside the construction site, e.g. Song et al. (2006) or Ergen et al. (2007) who develop a prototype model for the location of precast concrete components with minimal worker input in the storage yard of a manufacturing plant. Additionally, with the material tracking function it is possible to monitor project progress by comparing the planned project progress with the current progress in project schedule. If drawing and plans are available digitally, parts lists can be compared with components already built in (König, 2009).

Furthermore, RFID can be applied in automated materials management. Using RFID tags materials data as they arrive at the site can be recorded and their movement around the site is detected and recommendations on materials purchasing orders or warnings on low material stock can be made (Navon and Berkovich, 2006).

Construction

Access Control and On-Site Safety. Mainly in office buildings and premises automatic identification and *access control* systems have been successfully implemented. Similar to the systems used in, for instance, skiing resorts, RFID could be applied at the entrance of a construction site to automatically activate the gate opening mechanism if a person or car moves into the reception area of the systems reading device after reconciling the personalized data stored on the transponder. This could be implemented as a smart card technology, i.e. information is stored on a plastic card (like access to parking lots) the construction worker owns and access is granted if the data stored on the smart card is verified with the data stored in the backend system. These smart cards can either work without or with direct contact to the reader.

Thereby, it is not just ensured, that only authorized personnel enters and operates on the construction site, but also that health and safety on-site can be more easily enacted and monitored. For instance, emergency evacuation of a construction site with a registration of persons who have already left the emergency area. After being registered when entering the construction site, it would be immediately traceable which worker has already been evacuated. Similar to access control, the construction worker would have a smart card with personal data stored. The smart card could store also information about skills, qualifications and authorizations of the worker. For example, data about skills and permissions for the use of equipment and machines. A RFID reader installed in a machine and vehicle like an excavator, or a crane reconciles the skills of the worker and the skills which are prerequisite for using the machine (Littlefield, 2003). The engine only starts when the reconciliation has been successful. This ensures that only workers being aware of the handling of the equipment and with the right qualifications operate it and know how to comply with safety regulations during operation to reduce endangering himself and other workers. Besides ensuring access permissions, on-site safety of construction workers with respect to fatal accidents, such as fall accidents, on the site can also be reduced by installing a safety monitoring system consisting of a mobile sensing device for detecting the worker's position, transmitter sets and repeaters for sending the detected information to a receiver, and software for interpreting this information and given related feedback (Lee et al., 2009). Referring to the social dimension of sustainability, health and safety on-site could be significantly improved by applying RFID for access and permission control.

Anti-Theft Systems and Tool Tracking. As RFID has already been applied in anti-theft systems for several decades it is also predestined to prevent loss and theft within the construction industry and on construction sites. Tools often go missing or are not returned on time, and, hence, are unavailable for other workers causing production delays and additional expenses (Littlefield, 2003; Swedberg, 2009). Both the loss and theft of materials and high end equipment is a major problem in the construction industry, as shown in a case study by the ECC (2009). US construction industry’s total costs caused by job-site theft accounted from $300 million to $1 billion in 2004 (Informationweek, 2004). For simple anti-theft applications a 1-bit transponder is sufficient. When a tagged tool is moved into the reception area of a reading device at the entrance or exit of a construction site, similar to the application in department stores, an alarm is activated. Apart from the application of 1-bit transponders for tool tracking they could also be used to store additional data like the date and the place (i.e. construction site A or B) of the last utilization. Using transponders with higher memory capacity the anti-theft system could also be expanded to an advanced tool tracking system to serve the following functions (e.g. Jaselskis et al., 1995; Goodrum et al., 2006; Goedert et al. 2009):

- Survey of the procurement/leasing and maintenance or modification history of the equipment,
- Billing to specific construction projects,
- Information about the utilization of the tool, e.g. of the construction worker who used the tool, and, as already mentioned,
- Theft-secure.

Information on the maintenance history of the equipment while it is in maintenance and repair would significantly reduce paperwork occurring for warranties and maintenance logs (Jaselskis et al., 1995; Jaselskis and El-Misalami, 2003).

Regarding tool tracking, companies like the Robert Bosch Tool Corp. have begun to sell tools with embedded RFID tags. Bosch is tagging a total of 66 different tools like circular and reciprocator saws and hammer drills (Informationweek, 2005). Data in these transponders are the tool’s model number, order information and a unique serial number. The system for the tool identification works on a frequency of 915 MHz. The database of a backend-system contains “purchase and service history, billing rates to specific construction projects, and information on who has used the tool”. The

Electronic Product Code (EPC) on the tag allows "an asset-tracking with a photograph, specifications, and description of the tool".[3]

The Pilatus Flachdach AG has implemented the, Liberty™ - "Asset Management System" to prevent loss of equipment and to reduce times for searching. Therefore weather resistant small tags are attached to all equipment and their movement on the construction site is monitored. This also includes the implementation of access permissions for authorised workers carrying a personal tag only (see also access control and on-site safety). The system registers all information in a common database and automatically informs responsible instances via E-Mail, Telephone or Pager about persons collecting and delivering the equipment, about the removal of a tag from equipment, technical problems, or in case of low battery (ECC, 2009).

WinWare Inc. and Jobsite Resources - two companies specialising in RFID solutions - develop the CribMaster RFID Mobile Tool Facility (MTF), which consists of a 53-foot trailer loaded with tools and fitted with RFID portals in the doorway. Contractors pass these doorways as they enter and leave with the tools. In the software, each tool is linked with a particular employee using the RFID tags on the employee's badges as well as those on the tools. Construction-site managers can now track tools which are in use and determine who is using them at any particular time, have information about the availability of tools and the need for replacement or replenishment (Swedberg, 2009).

Use and Occupation

RFID applications during the use and occupation of a building or constructed object refer to the automation and optimisation of facility management processes, indoor navigation in cases of emergency and on the monitoring of operating resources during occupation and operation of buildings.

Servicing and Maintenance. During use and occupation of a building quality management, maintenance and restoration operations take place. Hence the identification of components and construction materials which have to be replaced, renovated, or maintained can be supported by RFID.

For example a RFID system has been developed to reduce the maintenance effort of a sewer system (see also Schreiner Logidata, 2005a). The system works on 13.56 MHz transponders and stores information about the documented status of maintenance as well as manufacturer's data. The RFID-tag is cast into the concrete of the pipes during the fabrication process. The operator of the sewer system continuously receives information, e.g. of the next necessary maintenance of the pipe or its manufacturer. The date can be read out by remote-controlled, navigable robots provided with a RFID reading device attached. The robot placed into the pipe system identifies all transponders embedded into the concrete by moving through the system. In comparison to a camera equipped robot or even manual device, this procedure is less time consuming and more easy to handle. This is especially relevant as sewer systems last over longer periods of time. Moreover, a combined identification with camera and RFID could enable engineers to relate the pipe information to the status quo of the damage and necessary maintenance effort.

Generally, such a maintenance application is also applicable to other products of high value, for instance, heaters or other electrical or electronic equipment in a building. Read out data, most likely to be gathered with a Personal Digital Assistant (PDA) are predestined for a subsequent processing in a backend system.

Additionally, experimental results with a web-based RFID building maintenance system have shown, that a combination of a data management module for the collection of building usage and maintenance data, a statistical module to graphically display the collected data, and a scheduling module for

3 More information about the tool tracking and theft system are available on Boschtools online (2005). Another provider of RFID tool tracking solutions is ToolWatch SE (2007).

arranging maintenance activities to ensure that building functions perform normally can improve facility and equipment maintenance efficiency (Ko, 2009).

Indoor Emergency Navigation. Indoor emergency navigation based on building information modeling (BIM) can help in case of fire or other incidents during the occupation of a building. High relevancy exists, especially for complex public buildings like airports (Rüppel and Stübbe, 2008). Thereby, the same could be applied to emergency navigation on a construction site. Safety of occupants of buildings could be significantly improved by better orientation of people and rescue troupes within the building as well easier access to life saving facilities.

Operation. In recent years, the “house of the future” had been discussed also in terms of RFID technology which could support the automation of applications within households and during the occupancy of houses. One application of RFID is a refrigerator developed by the German company Liebherr. Liebherr’s refrigerator detects products beyond the date of expiry and automatically creates a shopping list (see Metro, 2009). The information is shown on a screen integrated into the door. Additionally, the RFID system could inform about products “out-of-stock” or products that have been declared as important by the owner before. As several companies in the consumer goods industry like Germanys Metro AG or the US Company Wal Mart in association with manufacturers of consumer goods and producers of RFID systems, are planning to tag each single product. Apart from information about the price and the date of expiry other information stored on the transponder could be, for instance, ingredients, calories or nutritional values as well as manufacturers and delivery dates. Another application of RFID is the automated setting of ovens. Therefore, a RFID antenna is installed in an oven to recognise products with tags. The reading device initiates related oven settings from the cooking instruction at the tag. However, this is still to be scrutinised in terms of the adoption of food with tags by the consumers. A further application, although closely related to the manufacturing industry, is the application of RFID for washing machines. Clothes are signed with tags to either support logistics in the fashion industry or to monitor working cloth of, for instance, construction workers. Washing-instructions stored on the tag are used to set the optimal washing machine program in order not to damage cloth. For further information on RFID applications in household appliances see also (RFID Journal, 2003).

Deconstruction and Recycling

At the end of the life time of a building usually, after several reuse and renovation cycles, deconstruction of a building takes place. With respect to environmentally friendly and sound behaviour, the aim of deconstruction should be to allow a systematic selective deconstruction of buildings which helps to separate different kinds of building materials and their reutilization or recycling (Schultmann and Rentz, 2002; Schultmann, 2005). Compared to other industrial products the deconstruction and recovery of buildings or building materials is quite complex. In several other industries the so called extended producer responsibility (EPR) with the objective to return spent products or components to their original producers is already implemented. Apart from components which are routinely replaced or maintained it is far less likely to return building materials to their manufacturer. The main reason is the usually long lifetime of a building ranging from 50 to 150 years, in comparison to other industrial products.

Before deconstruction takes place information has to be gathered on the composition of the building, i.e. on materials and components to be deconstructed. This includes data about the manufacturer, built in date as well as on contamination with hazardous substances. However, information on the composition of buildings either gets lost during the lifetime of the building or is not updated during renovation processes. Hence, information available for deconstruction planning is inaccurate and incomplete and costly surveys on the composition of the building and materials to be dealt with (e.g. asbestos or other contaminated material) have to be commissioned, before, on the one hand, selective deconstruction plans can be set up, and, on the other hand, cost estimates and bids can be made. Concluding, a retention of information over the whole life of the building would significantly add to the ecologic as well as to the economic dimension of sustainability by enabling a more precise cost estimation of deconstruction projects and succeeding recycling processes and by preventing unexpected incidents during the dismantling of the building.

However, data about the composition of buildings might usually be difficult to obtain as, in general, multiple modifications or renovations during the building's lifetime take place and responsibilities for information gathering and holding are not always clear. If RFID is already used for renovation processes and new materials or components are tagged with RFID transponders identification would become realistic. The data could be read by a reading device (e. g. by a handheld PDA) from the individual object. Furthermore, if data, e.g. information about the date of construction, the last date of maintenance, reparations etc., are permanently updated, their condition is directly available during the deconstruction and recovery planning phase. This is especially attractive for possible reuse of components. Additionally, by the direct availability of information about the product the data usually cannot get lost during the long time lag between construction and deconstruction. Thereby, responsibility would only have to be assigned with respect to guarantee that all necessary components are tagged with the right information, which, in most of the cases, would be the related construction firm. Data collection however, can be done by anyone with the right equipment to read the RFID tags. However, due to technological progress it still has to be shown whether a technology up to date right now will last a period of 50 to 100 years, i.e. the life time of a building, to be read out.

Limitations and Benefits of RFID in Sustainable Construction

An empirical investigation including 70 RFID experts has revealed critical success factors for the implementation of RFID (BSI, 2004). Around 50 % of the experts mention interferences caused by metal or liquids and the missing standardization of frequencies and sending power present as very high or high limitations to the application of RFID. This is followed by missing standardization in the area of product identification and reservations against data protection (Jaselskis and El-Misalami, 2003). Only a small number really think that information security as well as transponder and reader costs could hamper the application of RFID (BSI, 2004).

Currently, the costs both for RFID reading devices and transponders are quite high because of their variable character (each object has to be tagged with its own transponder). The prices for transponders range from € 5 cents to several Euro for a passive transponders and from 5 € to 50 € or more for active transponders depending on the volume and fabrication (RFID Journal, 2009). While the limitations caused by missing standards (mainly in the area of frequencies and transmitting powers) and data security can be seen as a challenge in general, and data protection is mainly a topic in the consumer goods industry, the interferences caused by metal and other environmental influences like moisture, liquids or dirt are a major concern within the construction industry. RFID systems especially developed for construction by RFID manufacturer (Schreiner Logidata, 2005b) are the so-called, (rfid)-onMetal-Label "and guarantees a reliable identification without an exertion of the electromagnetic field. The "(rfid)-onMetal-Label" can be tagged directly to metallic surfaces. The example shows that RFID companies can respond to environmental requirements within certain industries. More and more systems and components especially developed to withstand environmental conditions have been developed recently. The further development of special components appropriate for the construction industry will be a question of how far there will be an adoption of RFID within the industry in the future. Here the construction industry could benefit from the developments within industries with similar conditions like, for instance, the automotive sector (Collins, 2005).

However, construction professionals have become aware of the need for wide spread application of RFID in the construction industry to improve the sustainability of construction processes in terms of economy, ecology as well as social means (Robl, 2008). As addressed in the sections before, economic benefits result, among others, from improved material identification and the decrease in faulty or wrong deliveries, improved project progress monitoring through reduced control effort, fewer problems with loss of tools and theft on site as well as decreased data collection effort during maintenance of buildings or during deconstruction planning. Ecological benefits arise from the retention of life cycle information about the materials and components of a building, which is a prerequisite for the efficient deconstruction and recycling of valuable materials at the end of the life time of the building. Finally, social benefits occur for improved health and safety on site by access control to the site as well as operating permissions for construction equipment as well as by the application of emergency navigation systems, or simply by improving the comfort of living with household appliances like the “intelligent” refrigerator.

Nevertheless, applications like addressed in this paper are not yet widely used in the construction industry. This is partly due the technical problems mentioned but also due to a lack of information among construction enterprises. Especially small and medium-sized construction enterprises lack the know how as well as the financial resources for investments in the RFID technology. Hence, studies and information on financial benefits from the implementation of different RFID applications in construction are still lacking.

Conclusions

In this paper several applications for RFID in construction were highlighted. This – by no means complete – overview shows that RFID could unveil its benefits even under the harsh environmental influences in construction throughout the life-cycle of a construction project and product. Some of the discussed applications have already been tested in pilot studies or are implemented in individual projects, and IT solutions have been developed. However, the construction industry is still lagging behind extensively applying and adapting technologies already successfully implemented in other sectors. A positive sign towards the application of RFID in construction is the development of RFID technologies which work under conditions typical for construction, for instance metal interferences or other environmental influences. This development shows that RFID in this sector is going to be an increasingly important topic both from an economical, ecological as well as social point of view. For instance, advances can be achieved in on-site safety, currently still depending on caution and responsibility of the individual construction worker. Enhanced information sharing on life-cycle-related data of material and equipment can significantly decrease maintenance effort and material and tool tracking can increase productivity on site.

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11

Industrialised, Integrated and Intelligent Construction Project Logistics

Glenn Hawkins

Industrialised, integrated and intelligent construction project logistics

Glenn Hawkins – BSRIA

Abstract

This paper illustrates how construction is an assembly or layering process in which safe, high quality, productive, socially-responsible and environmentally-sensitive work can only be carried out if certain key pre-requisites are in place for each construction task. It describes how construction project logistics, although not adding value itself, plays a fundamental role in ensuring that projects are successfully delivered to clients, whilst minimising social and environmental impact external to the site.

It is hoped that this paper will help construction project teams develop a clearer understanding of how crucial logistics are in the creation of the modern built environment and as a result place greater emphasis on ensuring that their approach to project logistics is correctly designed, planned and implemented.

Keywords: logistics, construction, performance improvement, built environment

Introduction

Closely examine a successfully delivered, modern UK building such as an educational academy, hospital, museum, sports stadium or manufacturing facility and you stare upon engineering excellence and the organisational brilliance of the global market place.

These buildings may be configured from superstructures composed of aggregate, cement and steel reinforcement sourced from different parts of the European Union, facades composed of larch grown in Siberia and cut to profile in Scotland, coated aluminium curtain wall systems fabricated in a German facility from assorted sub-elements produced elsewhere, marble flooring quarried in the South of Italy but processed in the North, complex electronic components assembled in Japan by self-guided robots, and furniture, fittings and equipment sourced from every corner of the globe.

This collection of parts implies astonishing journeys over land, sea and air of raw materials, sub assemblies and finished parts in the pursuit of meeting a client's requirements. The aggregation of these parts into finished buildings implies incredible feats of organisation, planning and control by the project teams involved in the design and construction of these facilities.

Stand in front of the latest, successfully completed 50-storey office development in the centre of any major city. Look at the river that flows directly behind it and the railway lines and roads that seem to totally enclose the site of this new landmark. Ask yourself "How did the team that produced this unique building bring together so many different parts and then assemble them in such demanding conditions, without bringing the city to a standstill?'

The answer is because logistics informed the work of the design, construction, procurement and cost professionals involved in the project.

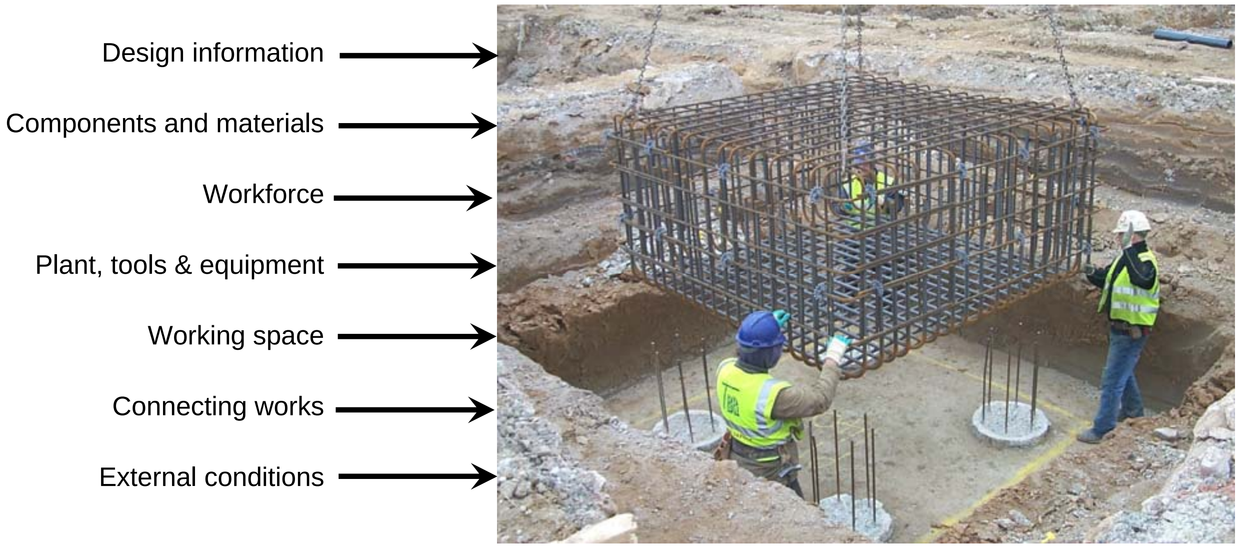
This paper examines the nature of construction and the crucial role that logistics plays in successful project delivery. It proposes how integrated, industrialised and intelligent logistics can help meet the diverse and increasingly demanding performance requirements imposed on the project teams that are creating the modern built environment.

What is construction?

Construction is the transformational work that creates value for a client by joining together the elements of a building or structure in a particular sequence. It is primarily an assembly or a layering process, whether it is in the creation of a building, or a project such as a road or railway. Traditional construction is characterised by site production, where production is carried out at the final location of the product to be constructed.

Any major construction project involves an incredibly diverse range of construction tasks from piling and substructure work to superstructure erection, building envelope installation, creation of the internal architecture and installation of the mechanical and electrical services that bring a facility to life.

However, all construction tasks require the same seven pre-requisites in order for high quality work to be delivered in a safe and productive manner. These seven pre-conditions are illustrated below. The installation of a prefabricated steel reinforcement cage for a concrete pile cap has been employed to provide an example of a construction assembly task.



Of course, the specific details of each of the seven input flows will change in accordance with the type of assembly task being undertaken. The specific requirements for the creation of reinforced concrete pile caps will be different from the installation of windows into a façade, but the seven generic inputs will be exactly the same.

Whilst this set of seven common pre-requisites presents a simple checklist for project teams to employ during the management of construction works, it also illustrates a key problem that the construction industry needs to address in order to improve project performance.

The problem is that traditional, site-based construction consists of assembly tasks that involve a high number of input flows. If any one of the seven input flows is missing or incomplete, this creates a constraint to the safe, effective and efficient execution of a particular assembly task, which may then affect the execution of another assembly task, and so on.

Designing, planning and controlling the production process on a construction site is therefore an extremely difficult task, and consequently the time, cost, quality, safety and environmental performance on many construction projects can be highly variable.

In response to the need to increase predictability of project delivery and improve project performance, construction professionals are becoming increasingly aware of the role that correctly executed logistics plays in delivering successful project outcomes for clients and for the companies involved in project delivery.

What is construction project logistics?

There are many different definitions of logistics. Each provides a different emphasis on the relationship of strategy, tactics, production and movement. This is illustrated by the definition examples shown below.

> *'All the operations needed to deliver goods or services, except making the goods or delivering the services' (Michael Baudin)*
>
> *'Logistics plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point of origin to the point of use'* (The Council of Logistics Management)
>
> *"The detailed coordination of a large and complex operation"* (Oxford English Dictionary)
>
> *'The management of materials flow through an organisation from raw materials t finished goods* (Collins English Dictionary)
>
> *' The science of planning and carrying out the movement and maintenance of forces. In its most comprehensive sense, the aspects of military operations that deal with:*
> *A. Design, development, acquisition, storage, transport, distribution, maintenance, evacuation and disposition of materiel*[1]
>
> *B. Transport of personnel*
>
> *C. Acquisition and furnishing of services*
>
> *D. Medical and health services support*
>
> (NATO)

Logistics does not add value itself. However, logistics enables value-creating work to flow by creating a production process and work environment in which construction assembly tasks can be undertaken efficiently, effectively, safely and with minimal environmental and social impact.

For example, a construction client does not receive the cranes, hoists, scaffold structures, mobile working platforms, loading gantries, material handling equipment, delivery pit lanes and temporary road configurations that enable construction assembly tasks to be performed. Nor does it receive the detailed effort that a project team puts in to design the site production environment and plan the dynamic sequence of logical construction tasks that take place within this work environment. However, an operationally-ready building, delivered to the client's time and cost requirements, would not be safely produced without this detailed logistical effort by the construction project team.

In the context of construction projects, it is evident that logistics is about delivering the right products to the right place at the right time, faster and at lower cost. However, it is important to understand that construction project logistics involves much more than this.

[1] In this context, materiel includes materials, tools, plant, equipment, vehicles, ammunition and fuel

Logistics plays a vital role in supporting assembly works on a construction site by co-ordinating and controlling the complex interaction between constantly changing work areas, a large and varied workforce, a vast number of vehicles, plant and equipment and a huge quantity of diverse materials.

In addition, correctly delivered construction logistics enables a project team to meet its social obligations external to the site boundary, such as ensuring public safety, maintaining the operation of local transport systems, meeting the needs of neighbouring businesses and minimising disruption to local residents. It achieves this by integrating a construction site into its immediate environment in a manner that is sympathetic to life outside that of the project team.

Furthermore, logistics plays a crucial role in reducing the environmental impact of the construction project process by helping to minimise non-renewable resource consumption, the generation of pollutants, carbon dioxide emissions, noise pollution, road congestion, construction waste production and visual intrusion. It achieves this by helping to ensure that the supply of materials to site is controlled by actual construction progress, appropriate material handling equipment is employed and that the transport of materials, plant and equipment is efficient and effective.

Consequently, logistics has evolved from an operational activity into a strategic necessity for construction project teams.

Demands being placed on construction project teams

The creation of the built environment presents immense technical, organisational and behavioural challenges to project teams.

These teams need to safely deliver projects on time and within budget to the required standard, whilst often maintaining a client’s primary operational function, such as the provision of education, healthcare or transport, the execution of financial transactions, or the manufacture of goods.

These teams are increasingly required to deliver shorter construction programmes, so that clients can start using their new or refurbished facilities at the earliest opportunity. These same clients are often applying economic pressure to their construction teams by demanding cost reductions.

Construction project teams also need to maintain a view that extends beyond the site boundary and ensure that social and environmental impact demands are met. Thereby ensuring that the creation of the built environment meets the needs of the present population, without compromising the ability of future generations to meet their own needs.

A correctly delivered logistics strategy, either in a project-specific context, an estate-wide context or across multiple projects can help project teams successfully meet these demands.

Shortcomings in how construction project teams execute logistics

Extensive research undertaken by BSRIA has shown that many construction project teams fail to manage logistics effectively. This creates working environments in which production rates are highly variable, worker health and safety is compromised, consistent build quality is difficult to maintain and the generation of material waste is higher than it should be. Typical characteristics found in these production environments are illustrated below.

Construction progress does not control the supply of materials to site. This means that work areas are often overrun with materials waiting to be installed, and materials arrive on site in incorrect quantities or in the wrong order.

A carpenter attempting to work in an area occupied by precast stairs, safety barriers and other assorted materials.

The areas in which construction work is taking place is not precisely coordinated with distribution routes and storage zones. This introduces constraints to installation work and the movement of people, equipment and materials around a site.

A scaffolder erecting a safety barrier in amongst a variety of stored components. This area of the site was one of the principal thoroughfares on the project.

Delivery vehicles do not arrive on site within an agreed delivery timeslot. This causes conflict between vehicles at the point of delivery and inefficiency in unloading because the appropriate means of unloading and handling deliveries are not correctly prepared.

In site locations with limited delivery space, some deliveries have to be aborted or vehicles have to circulate the area around the site whilst awaiting an opportunity to unload.

Electrical components being unloaded by hand from a location on a major road and placed in the delivery pit lane. The pit lane is occupied by another lorry that is still full of components.

When a delivery of construction components arrives on site, the appropriate material handling equipment or quantity of correctly skilled manpower is not available to efficiently and safely unload it.

Lift system components being carried into a building by hand. Other materials are blocking the site entrance and this team did not have the correct material handling equipment.

The horizontal and vertical distribution of materials through a building is not properly planned. This causes delays when there is conflict with other materials, equipment and installation workers. It also increases component damage, and introduces unsafe working practices, when delivered loads have to be taken apart and transported by hand.

A delivery of ventilation components that will not fit in the site hoist. This load had to be broken down into its individual parts and carried piece-by-piece up stairs to level 5 of the building.

Materials and equipment arrive on site without having a designated storage area near to the point of use. This means that goods are often handled several times and workers are often undertaken installation work in areas occupied by other trades materials.

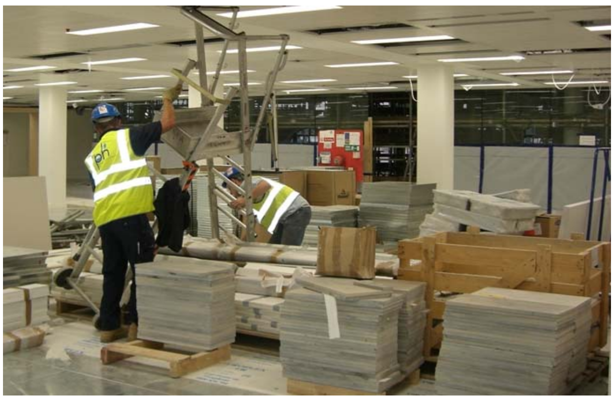
A worker attempting to assemble a fan coil unit in a work area that is occupied by the materials and equipment of several different disciplines.

Work areas are not production-focused. Poorly organised work areas, often without the use of appropriate workbenches and storage systems, mean that productivity levels are frequently low and worker health and safety is compromised.

A worker attempting to assemble a fan coil unit in a work area that is occupied by the materials and equipment of several different disciplines.

Reverse logistics is not well-managed. The withdrawal of surplus materials, plant and equipment, and items such as pallets, cable drums is not given the level of attention that it deserves. In addition, many goods are supplied to construction sites without using reusable stillages and storage containers.

This causes congestion on site which causes delays to installation work and compromises worker health and safety.



Commissioning engineers trying to work in amongst surplus materials from several different trades.

Six logistics examples that help meet the demand being placed on construction project teams

We have established that the purpose of construction project logistics is to maximise the freedom of action of the teams involved in assembly work on site. This freedom of action means that installation teams can focus on value-creating work, because constraints that cause construction productivity, build quality, worker health, site safety and material waste issues and have been identified and controlled.

Historically, construction project teams have competed against each other by providing the most value for the least cost. However, modern project teams need to provide the most value for lowest cost, in the least time and with the minimum of social and environmental impact. This can only be achieved through correctly delivered construction project logistics.

Correctly delivered logistics will ensure that the production process is correctly designed, the production infrastructure on site and external to the site is properly planned, procured and established, and actual construction progress informs the supply of resources to the workface. This will include an assessment of what is logistically possible within the constraints of the production environment that is the construction site, and within the constraints of the geographical location in which the construction site is situated. This will help ensure that the working space, materials, plant, tools, equipment and workforce required for each assembly task are correctly delivered.

This means that logistics must be conducted as an integral part of, and not parallel to, all other strategic and operational activities. As part of the integration of logistics with activities such as design, planning, procurement and commercial management, the aim should be to ensure that the following six integrated logistics principles are adopted by the whole project team.

Foresight

Logistic foresight is the ability to predict and manage critical logistics constraints to the construction project team's freedom of action. Construction professionals at all levels need to analyse the sequence of future assembly activities and forecast the requirement for

- Personnel
- Materials
- Plant, tools and equipment
- Working space
- Access (in and out of specific working environment and the overall site)
- Construction support services such as canteen, welfare, storage and security

Visibility

Situational awareness of construction tasks is the first key element of logistics visibility because it defines the real-time logistics mission and establishes priorities. A project team needs a clear, shared understanding of each task, and also maintain a view that encompasses all the tasks being undertaken on site.

In addition, the project team needs to have clear visibility of the seven pre-requisites required for each assembly task – information, materials, workforce, plant and equipment, working space, connecting works and external conditions. This visibility informs the project team about its ability to meet the demands of the tasks.

Co-operation

Assembly works require a co-operative approach to logistics from strategic preparation to execution on site. A pre-requisite for co-operation is the development of a shared understanding of what needs to take place, how and when it needs to take place, together with the timely, accurate exchange of relevant information.

Co-operation should also extend to shared use of plant, equipment, support services, space on site, off-site production facilities or consolidation centres remote from the site.

Efficiency

Logistics efficiency involves achieving the maximum level of support for assembly works for the least logistical effort and the best use of finite logistical resources. This requires a clear, shared understanding of how logistics supports the build process and precise definition of roles and responsibilities for logistics activities within the project team.

Simplicity

Logistics arrangements on a construction project should be simple, both in concept and execution. A project team will derive simplicity from the following approach:

- Robust and commonly understood project procedures
- Common logistics processes amongst all organisations involved in construction works
- Precise control of construction site works
- Clear channels of communication on the project

Agility

Logistics agility provides the construction project team with the ability to respond to constantly evolving working environments and unexpected events, and adjust rapidly. Logistics agility is promoted by:

- Resourceful and knowledgeable logistics personnel
- The provision of appropriate plant, equipment and resources
- A project team's ability to adapt the logistics infrastructure and systems as operational circumstances change
- Optimum use of resources

A project team needs to strike a balance between structures, equipment, systems that meet the requirements of simplicity and the need for functional agility.

Logistics as an enabler of improved construction project performance

The I3CON research project aims to enable the transformation towards the European Construction industry using industrial production techniques, integrated processes and intelligent systems to deliver ultra high performance buildings. An industrialised, integrated and intelligent approach to logistics will help project teams apply the 6 key logistics principles to construction site works. This will in turn help these teams meet the increasingly demanding time, cost, quality, health and safety, social and environmental demands being placed on the organisations that create the built environment
Industrialised, integrated and intelligent construction project logistics will help project teams to achieve this by:

- Developing new construction methodologies that reduce the time and resources required on site
- Transferring activities from the site to upstream stages of the supply process, which will help avoid the inferior production conditions of a site and increase concurrent production
- Allowing project teams to computer-model things such as the site production environment, building sequences, crane utilisation, site logistics infrastructures and external traffic flows. This helps optimise build programme durations, construction costs and resource use on site
- Improving the visibility of planning and control information across the project participants, hence improving the quality and speed of decision making
- Improving the robustness of logistics processes, making them less variable and more accurate
- Creating novel ways of distribution from A to B, both on site and external to the site
- Streamlining the supply of materials to site, reducing costs, inventory, lead time and environmental and social impact

- Increasing the reliability of material flow to points of assembly on site

The following images from BSRIA study projects show construction sites where the logistics strategy employed by the project teams has helped create safer and more productive work environments. These production-focused work areas are a result of a more industrialised, integrated and intelligent approach to logistics than that adopted by the projects teams whose work environments were illustrated earlier in this paper.

The measurement of flowrates in ceiling pipework. The whole floor of this major office development is free from obstruction, which means that these workers can easily move between different openings in the ceiling.

An external view of a manufacturing plant being constructed. The logistics infrastructure has been well planned, storage is well organised and good provision has been made for the movement of vehicles and site personnel.

A 10 tonne, prefabricated stone cladding panel being lifted into position by a mobile crane. 640 of these panels were used and the installation time was 32 times quicker than hand-set stone panels.

An internal street area of an office campus development. Work areas are clearly segregated from distribution routes and storage areas. Good access is provided for plant and equipment and the correct type of mobile working platforms are being used for high level works.

The use of specialist handling equipment to improve the speed and safety with which materials are moved around a large industrial construction project.

A delivery lorry from a consolidation centre that has been used to supply materials to the site of an office development. The lorry contains materials which have been called into site from by several different trades.

It is evident that these three concepts of intelligence, integration and industrialization overlap, and are interdependent, in such a way that they cannot be implemented by any construction project team in isolation.

Industrialization can be seen as a means for eliminating, or at least drastically reducing on-site activities in construction. Often, the driving force behind an industrialised approach to production is an overwhelming need for something in greater quantities, cheaper prices, better quality and reduced delivery times that current practices allow.

This need drives innovation towards standardisation. However, once standardised products become the norm, a shift in expectations occurs. Customers start to expect bespoke products without increasing cost or wait times. The solution to this demand is a logistical innovation called mass customisation. Mass customisation requires modular architecture, standardised components and sophisticated information systems support, and these can only be delivered by the construction industry through integrated ways of working and the application of information and communication technologies.

Computer modelling technology that extends beyond three dimensions is available to all construction project teams. Computer models enable project teams not only to design the product that the client ultimately receives, but also to design the production environment and logistics infrastructure, analyse traffic flows in cities, prototype the assembly process and attach a wide range of technical, commercial and operational information to each object in the model. This offers immense opportunities not only to better plan and control traditional ways of constructing the built environment, but develop entirely new methods of construction that embrace the opportunities offered by off-site manufacture.

Of course, this approach is as much as an organisational and behavioural endeavour as it is a technical endeavour. However, in relation to construction project logistics, computer modelling offers enormous potential value for strategic design and planning of construction works and the day-to-day preparation and control of each construction task and its associated seven pre-requisites. There are also other key technologies that the construction industry can employ in order to help improve the way in which it executes projects.

Economic growth and development are driven by what innovation theorists call general purpose technologies. A general purpose technology transforms economies, industries and societies. The wheel and the printing press were general purpose technologies, as was the railway of the 19th century. The railway did not just get passengers from A to B faster than horses (and help address the environmental and social problem of manure in major cities). It consolidated nations and national markets, created new cities and enabled people en masse to leave their hometowns, therefore massively increasing the gene pool.

Ubiquitous information and computing technologies (ICT) such as the Internet, the personal computer and mobile computing devices are general purpose technologies that are equally as transformative. Furthermore, these technologies are converging with each other and with other pervasive technologies such as satellite navigation and automatic identification. This allows objects and people to be connected at all times, and identified in terms of time, place and thing and offers enormous potential for improvement of construction project performance.

This real-time visibility and availability of information everywhere will allow project teams to capture demand signals from the workface and make more informed decisions. It will also enable teams to capture and analyse the digital trails of assets, which will allow them to fine tune procurement scheduling, transportation, site distribution, storage and installation processes.

For example, the Galileo satellite system, a joint venture between the European Commission and the European Space Agency, will employ a network of 30 satellites and associated ground infrastructure to pinpoint location within one metre. This will enable construction project teams to locate objects or people to a particular zone of a specific floor of a building under construction.

Within this tracking environment, intelligent physical assets, embedded with Radio Frequency Identification (RFID) tags will be able to wirelessly communicate what they are, where they are, where they have been and their operational status, free from the constraints of distance and time. A construction site that employs RFID sensing technologies will be able to read tags on materials, plant and equipment as they arrive or leave site and automatically direct goods handlers to the point of use or the storage location. This information can then automatically update the project's building information model and be linked to inventory management and automatic payment systems for the different companies involved in a project, for example.

Conclusions

Organisations involved in the creation of the built environment face increasingly demanding requirements for time, cost, quality, safety, social and environmental performance on their projects.

In order to more consistently meet this diverse range of demands, construction project teams need to develop a clearer understanding of how crucial logistics is in successful project delivery, and make sure their approach to construction project logistics is correctly designed, planned and implemented.

Project teams create value for a client by joining together the elements of a building or structure in a particular sequence, and each one of these construction assembly tasks requires seven key pre-requisites to be in place – design information, components and materials, workforce, plant, tools and equipment, working space, connecting works and external conditions. If one of these seven inputs is absent or incomplete, then a constraint is introduced to the team's ability to undertake an assembly task efficiently, effectively, safely and with minimal environmental and social impact.

Logistics does not add value itself. However, intelligent, integrated and industrialised logistics enables value-creating work to flow by creating a production process and work environment in which construction assembly tasks can be undertaken efficiently, effectively, safely and with minimal environmental and social impact.

The challenge for construction project teams is to develop a better strategic and operational approach to logistics by exploiting the enormous potential of general purpose technologies, adopting a more industrialised approach to construction by transferring activities from site to the upstream stages of the supply process, and using integrated ways of working that mean all parties have a common, shared understanding of what needs to take place, how it needs to take place, when it needs to take place and who needs to do it.

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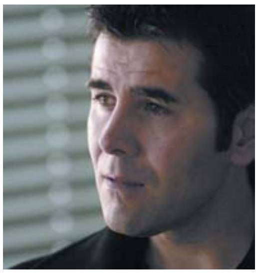

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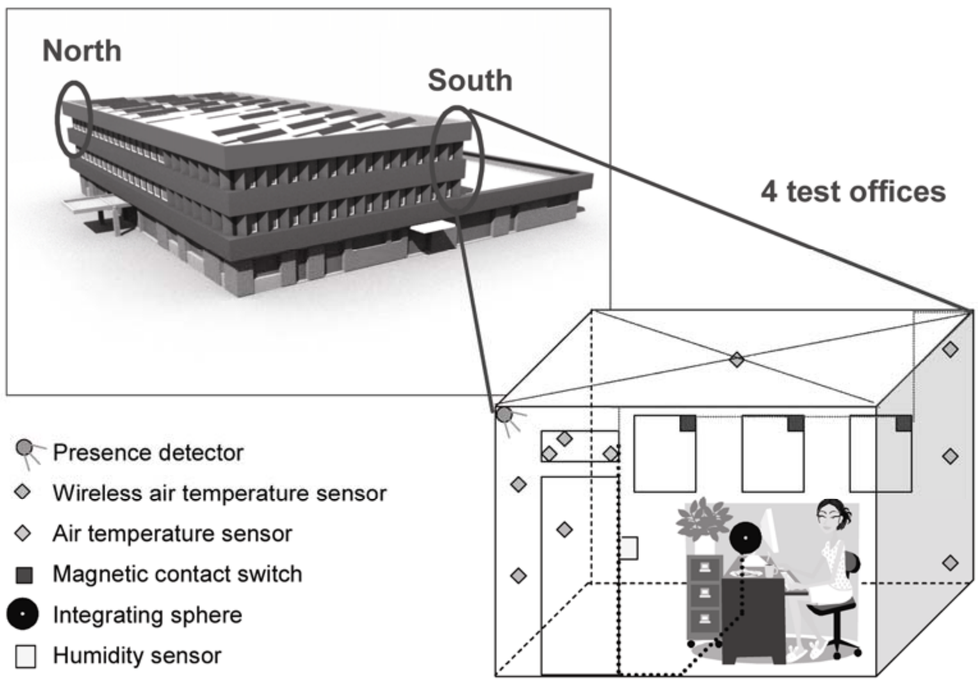
Energy and Comfort Performance Evaluation After Renovation of an Office Building

Renzi Virginie and Burgun Françoise



Energy and comfort performance evaluation after renovation of an office building

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Abstract

The construction sector has been highlighted as a key potential area for reducing global energy consumption and thus for acting on climate change. As they represent a huge part of the built environment, refurbishment of existing buildings is an important issue to consider. However efficient processes of renovation need to be well defined in order to be generalized. Although energy is an important consideration, health and comfort should not be sacrificed for low energy strategies, and the renovation must be as global as possible. For the success of the operation, occupants must be included from the very beginning of the process. This paper is about the refurbishment of an office building from the 70's, used as a real case study. The complete monitoring of the building both for energy and comfort, allow a better understanding of mechanisms and barriers, technological but also psychosocial. Measurements are compared with the perception of the occupants and we try to evaluate human interactions' impacts on the building behaviour.

Keywords: refurbishment, monitoring, energy efficiency, comfort, offices

Introduction

In Europe over 40% (42,5% in France) of our energy consumption is used in buildings, more than in transport or industry, and the sector represents a high potential of evolution and innovation in terms of energy savings. If much progress has been made in the construction of new buildings, there is still a lot to do for renovation, which corresponds to the largest part of building stock. Renovation is a big issue, as it has a huge cost-effective potential for energy saving. If energy is the main focus with the current issue of climate change, an efficient refurbishment program must also include improvement of indoor comfort for the well-being of occupants and their satisfaction.

A methodology developed by INES (National Institute of Solar Energy) in Chambery (France) focuses on reducing consumption of primary energy and decreasing greenhouse gas emissions in the built environment, while increasing users comfort. For this purpose, it aims to make the building renovation process more efficient by developing generic guidelines and tools. To achieve that objective, the work is first based on case studies.

Case Study Presentation

The building (Fig. 1) houses the ALLP head office (Association Lyonnaise de Logistique Post-hospitalière – Lyon post-hospital logistics association). The building is located in Lyon, France, in a continental climate area, and was built in 1974. About 70 people currently work in the three storey building. The total floor area is 2850m².

Figure 1. ALLP building before and during retrofit

The building has a concrete structure and energy performance was poor due to an old and low-grade internal insulation, single glazed windows and many cold bridges. Existing solar protection was original. There was no mechanical ventilation, thus fresh air came only by infiltration and hand-opening windows. Adequate air change is necessary to reach good working conditions and cannot be guaranteed in these conditions. A complete diagnostic of the building and the systems was done by an engineering office in 2005 [1]; it showed a heating consumption of about 140kWh/m². The other problem underlined by the building owner was summer overheating and discomfort. For instance a temperature of 34°C was measured in June 2005 in an office on the first floor oriented toward the South. These working conditions were not acceptable for the employees and productivity decreased by almost 20%. This situation accounts for the intent of the ALLP managers to equip the building with an air conditioning system, but the energy audit showed the need to produce a complete refurbishment program.

Just before the retrofit operation, we organised a survey led by an independent organism [2]. Questionnaires to the occupants and local measurements confirmed the overall discomfort. This kind of study needs to be more systematic when a refurbishment operation is considered, like the one existing for household, the EPIQR methodology (Energy Performance Indoor Environmental Quality Retrofit) [3], whose goals are: optimisation of energy consumption, improved indoor environmental quality and cost-effectiveness.

During the conception phase, ALLP was modelled with the dynamic simulation software TRNSYS and the building was split into eight thermal zones. The ground floor comprises two zones (entry rooms, lobby and workshops); the first and second floors are identically zoned in three parts: one office zone mainly oriented South, one office zone mainly oriented North and a common zone where comfort is not essential (staircase, etc). The two office zones on first and second floors are critical because they comprise most of the people working in the building, inducing a rather high population density and also high internal gains. The dynamic simulation was used to develop sensitivity studies on technical parameters. The building was considered from a macro-scale (envelope) to a micro-scale (regulation of the energy systems) and significant energy savings were identified at each level. The analysis was coupled with an economical approach, keeping in mind that the project had to be a demonstration case and thus reproducible. The main focus for this first case study was energy saving, and the simulation results prove that a reduction by a factor of 2 on primary energy consumption and by a factor of 4 on CO_2 emissions can easily be achieved.

Thanks to the preliminary studies and with the work of the architect, fluid engineering office, INES and the ALLP managers, the building renovation was planned. First enhancements were passive solutions including improvement of the envelope (low-emissivity double glazing filled with Argon, external insulation), new effective external solar protection (Fig. 2) and night ventilation. However simulations demonstrated that during summer, comfortable conditions would not be reached. The need of a cooling system guided the choice towards a heat pump. The system was chosen reversible even if a highly efficient new gas boiler of 350 kW had been set up in 2004, and so an air-water heat pump of 100kW was installed (Fig. 2). Distribution is done by a fan coil unit in every room. An attempt was also made to improve the efficiency of office lighting (control of artificial lighting in response to occupancy and amount of daylight). 90 m² of photovoltaic panels were installed on the roof. The 10 kW grid connected system should produce about 11 MWh per year.

Figure 2. Details of the renovation: heat pump located on the roof and new solar shading device

Monitoring

Refurbishment was achieved by mid 2007 and the building was fully equipped with sensors. The monitoring allows the gathering of the necessary feedback on energy consumption and comfort in the offices. The tele-supervision of the building is done by a Building Management System (BMS) that integrates an internet protocol. The remote access permits to automate, control and monitor the building with a lot of freedom in data acquisition. All the results allow feedback at two levels. The first one is focused on the behavior of the building and is based on energy meters and ambient temperature probes, as well as exterior weather sensors. The second one applies to the scale of an office room in which wireless sensors record the temperature, humidity, luminosity, occupancy, opening of window (Fig. 3). The aim of the first level of monitoring is to detect failure, evaluate the performance of the renovation and compare measurements of energy consumption with predicted values. A longer observation period is also necessary to evaluate the software model accuracy. The second level of monitoring illustrates the working conditions in critical office rooms, and thus the occupants' level of comfort. It also gives an idea of the evaluation of the airflow distribution on comfort. Measurements help to identify potential problems associated with the control of heating, cooling, ventilation and air conditioning (HVAC) regulation.

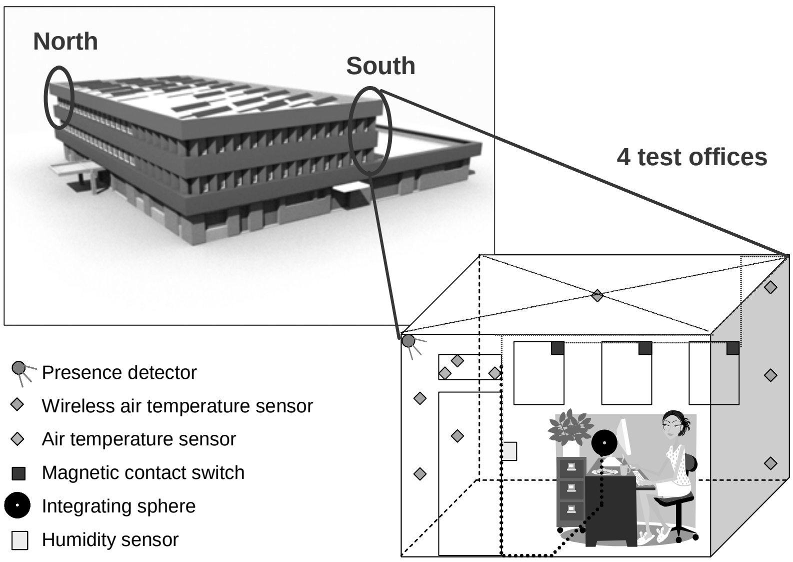

Figure 3. Local monitoring of 4 test offices

The web platform allows access to the data from any internet-connected computer. The interface was made as user-friendly as possible and is under continuous improvement.

Energy Balance

The initial feedback confirms that energy consumption was consequently reduced, with a consumption of 20kWh/m²/year (primary energy) for the gas boiler and 100kWh/m²/year (primary energy) for the heat pump (heating and cooling). The monitoring measurements of the HVAC systems help us to identify non-optimal performances and enable us to react quickly for improvement. Some problems were found in the heating system, for the alternate functioning of the gas boiler and the heat pump. The boiler should take over when outside conditions do not permit reaching a coefficient of performance (COP) of 2,5 (2,5 is the French conversion factor for primary energy). Adjustments required maintenance service interventions.

Comfort : First Results

Investigation of occupants' satisfaction with the indoor environmental quality helps to detect impacts on well-being and productivity. A first analysis of the measurements showed that renovation was beneficial for the users' comfort. In order to know their feelings, a survey was established in December 2008. Workers were surveyed by questionnaire dealing with their overall comfort. 30 persons answered: 26 women and 4 men. They were from 22 to 57 years old with a mean around 40. The results are surprising: 100% were dissatisfied with at least one parameter. The main complaints were focused on hygrothermal comfort: too warm or too cold, difference of temperature between head and foot, air dryness. The second problem highlighted is about the system itself; the fact that the heating is done by an air system causes a feeling of draught, noise, a rapid change of temperature when the system is stopping and the fear of hygienic/sanitary problems. The last point is about the difficulty to act on the thermostat and the lack of possibilities to control one's work environment. Interestingly, neither the orientation of the offices nor the floor level has an influence on the results. Women were largely over-represented in the study sample, and gender based differences exist both for physiological and psychosocial factors.

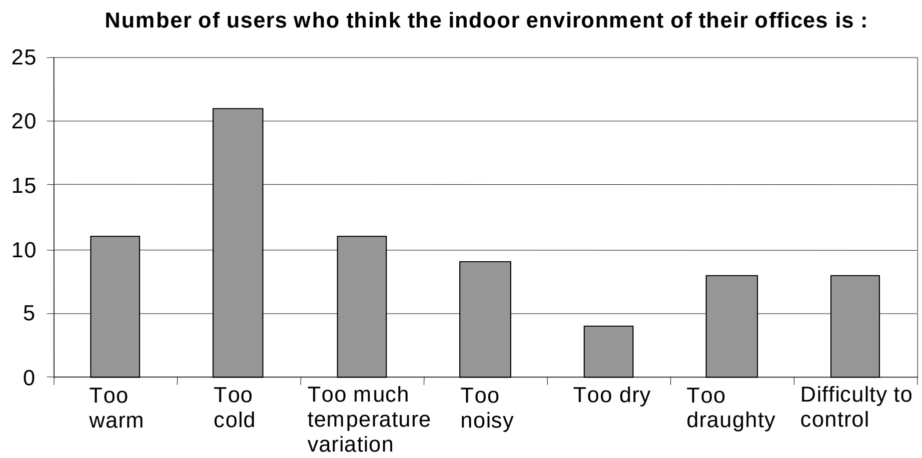

Table 1. Results of the first users' survey (30 persons answered)

Some criticisms seem excessive and reveal a lack of adaptability. Hence users contest that offices are warmer in summer than in winter and they do not wear appropriate clothes during colder periods. Distrust and resistance towards the new system spread among the occupants. Inconsistent behaviours were also revealed during a visit of the building. For example, heating is on and windows are open. Visual comfort seems also to be a key point, as despite the new efficient artificial lighting system, some occupants continue to use their individual halogen lamp. Users were not informed enough about the behaviour to adopt in coherence with the renovation. Furthermore some employees were uncomfortable with the HVAC and automatic regulation of lighting. Means of control to adjust the indoor environment to their own requirements need to be improved. Adaptive strategies have to be implemented. Anyway the level of acceptance and adaptation varies from one person to another and it is not possible to generalize.

This case study shows that it is important to promote communication and co-operation between the various partners involved with the operation and the non-expert users of the buildings, and that, from the very beginning of the process. Research has shown that human perception of thermal comfort is a mixture of the physiological and psychological factor [4]. According to Lahtinen and colleagues [5], those who perceived their psychosocial work environment more negatively had more complaints regarding the indoor environment.

Ways of Investigation

The difficulty in defining the monitoring instrumentation is that the different parties (employees, managers, buildings owners, technical experts, safety personnel) have different perceptions of the problems and different expectations. Here the choice was made to focus on energy and improvement of the building. But finally, the role of the occupants appears to be central to achieve the goals of the refurbishment. Now that the building has been renovated and that dysfunctions of HVAC systems have been fixed, it is essential to focus on occupants perceptions. A more precise comfort survey will be carried out, comprising measurements and simultaneously gathered questionnaire data by office occupants. For measurements, a mobile unit (Fig. 4) equipped with air temperature, air humidity, vertical air temperature difference, radiant temperature asymmetry, illuminance and air velocity sensors will be used. The survey will allow comparison of the measured data with the subjective statements given by the occupants.

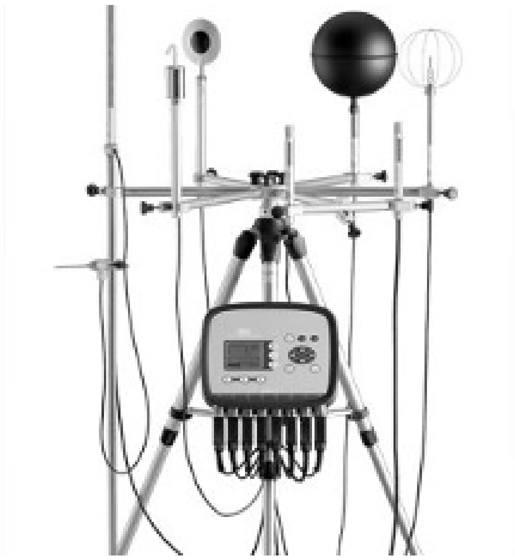

Figure 4. Mobile unit of thermal microclimate data logger

Indoor air quality (IAQ) is also planned to be checked, including CO and CO2 quantity, radon, volatile organic compounds (VOC), and particles. A detailed study of visual comfort will be intended as well, in order to underline the overall quality of office lighting system, possible inconveniences (glare or excessive contrast) and limits of artificial lighting regulation [6]. New software should be used for this purpose (DaySim in parallel with Energy Plus). A CFD model is also considered in order to model in detail air movement and thermal flux inside a room.

Conclusion

In the construction sector, refurbishment of old buildings stock has been highlighted as an area which has a significant potential for improvement and which could have a huge impact on energy savings.

The impact of the ALLP renovation on energy consumption of the building is positive. And generally the retrofit improves comfort although some claims remain about thermal and visual perception. The notion of occupants' well-being is too often neglected in energy-efficiency programs. It is very difficult to value the various attendant effects of comfort because of its inherent subjectivity and also because there has been so little empirical work undertaken in the area.

In order to succeed, the renovation process has to be as transparent as possible. As this case study revealed, there is a true need to relate occupants and their behaviour to the energy performance of the building early on the conception phase. Human interactions with the systems were not fully taken into account in the simulation and we now try to evaluate real occupants' impacts on the building behaviour.

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Value Oriented Product/Service Offerings for Sustainable Living Buildings

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Value Oriented Product/Service Offerings for Sustainable Living Buildings

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Abstract

Current business offerings in construction assume that client needs remain fixed over the lifetime of a building. Buildings are therefore not fully capable of meeting changing user, social and environmental needs. The current cradle-to-grave thinking causes substantial waste, environmental damage and destruction of capital. Buildings underperform from an economical and ecological perspective. This paper presents a new business concept in the form of value oriented Product Service Offerings for Living Buildings. A provider of Living Building services adds value to the business of its clients and is rewarded for that. A provider is proactive and manages a portfolio of industrially produced, customizable solutions. During operation, user processes as well as social and environmental processes are closely monitored, and the building is kept fit-for-use during its entire functional life. Modules, components and materials that are released from a building after they have become dysfunctional, are remanufactured for reuse in the same or other buildings. This reduces waste, reduces the energy-intensive production of base materials for new buildings and saves construction costs. Living Buildings are expected to be less vulnerable for depreciation than traditional buildings and offer therefore an attractive alternative for investors. A first pilot project is currently realized for a school in Veenendaal, the Netherlands.

Keywords: living buildings, business innovation, value creation, lifecycle management, cradle-to-cradle, remanufacturing, product-service system

Introduction

Current business models in construction, as well as current forms of contracting, assume that client/market/ and social needs remain fixed over the lifetime of a building. Requirements are pinned down in specifications and contracts. Deviations from an agreed specification often lead to time/and budget-overruns or, even worse, to legal disputes.

But in reality, user needs and social or environmental boundary conditions change continuously. Static infrastructures, buildings and servicing processes, such as maintenance, may therefore soon result in underperformance. Given the huge capital investments needed for the creation of new buildings and infrastructures, and given the often irreversible impact of building permissions on landscapes and townscapes, this causes high risks for investors, users and governments.

The current static approach often results in an over-specification of requirements, and in an over-dimensioning of built artifacts. After all, if a building is assumed to exist 30 years or more, the client cannot just define only present requirements, but has to predict also long term future requirements. Such requirements often depend on external factors that clients cannot control, such as social and environmental factors. And reversely, if a designer has to assure performance and quality for a long period of time, he or she will choose durable but costly materials and over-dimension the design. Planned maintenance procedures are intended to keep the artifact in its original state.

This makes no sense if user and societal requirements, as well as environmental conditions, change. For many building types, such as hospitals, schools, retail centres, office buildings, transfer centres and factories, requirements may change every 5 to 10 years. If the building cannot be modified adequately, three options exist: (a) users stay in the building but have to accept a sub-optimal solution, (b) the original users leave, so that the building gets a function for which it was not originally designed, or (c) the building will be demolished. In all cases the value of the building decreases, which poses a serious risk for the investor.

Figure 1. Many buildings are demolished and end up as landfill, because they do not meet today's standards for usage, and because they are not designed for disassembly and reuse

The recent crash of the financial system has demonstrated these risks once more. Most construction projects are funded through loans from a bank. For a bank, the artifact is collateral for the loan. If the lender cannot meet his or her financial obligations, the bank is entitled to sell the collateral on the open market. But if such a market does not exist, the collateral has no value. Banks will perceive such loans as too risky. In the best case the bank will provide the credit but asks a high interest percentage in order to compensate the risk.

It is of course possible to produce buildings with a shorter lifetime. But the capital investments in buildings are usually so high that they cannot be written off in a short period of time. Moreover, the need to demolish a building after a short period worsens the already existing problem of excessive waste.

Dynamic thinking in construction is not new. Several initiatives have been taken in the past to realize buildings, often using industrial production techniques that can be changed if user requirements change. Probably the most well known concept in this respect is Open Building [Kendall 1999, Habraken 1988]. An Open Building has a fixed, durable, main structure, and a flexible infill. The Open building concept is primarily an architectural - and partially technical - answer to the problem.

More and more construction companies offer today mass-customized solutions, based on industrially manufactured building systems and production automation. Clearly, these are steps in the right direction to improve the efficiency and quality of construction.

But most industrial solutions are however positioned as alternatives for traditional contracting and rely therefore primarily on the reduction of initial (capital) costs, not on reduced Total Lifecycle Costs, reduced risks or increased client value. Furthermore, a building that is customized and made fit-for-use at the beginning of its lifecycle, may not remain fit-for-use at a later stage. Buildings that deviate from average market requirements are perceived as risky investments but will never be optimal solutions for users.

Objectives

This paper describes a new business model for construction that recognizes changing user demands as well as changing social and environmental demands. Not by trying to predict the future, but by realizing product/service combinations through which buildings can de adapted continuously, without destroying capital value and without causing waste and environmental damage. The research examines also the required change of contractual relationship between client and provider.

Background

In 2002, the national parliament of the Netherlands held an enquiry about fraud and cartel agreements in the Dutch construction sector. It was concluded that the sector had to reorganize itself. In order to support the transition process, a research and development programme called PSI Bouw was executed between 2004 and 2007. One of the most challenging concepts that came out of this programme was the Living Building Concept [de Ridder 2006]. A few companies now try to implement this concept in practice.

Chapter 1 presents a model of four levels of business efficiency. It clarifies the difference between the Living Building Concept as a Product Service System (PSS) and current business offerings in construction. Chapter 2 describes the lifecycle model of adaptable, sustainable buildings.

Chapter 3 discusses the processes of condition and performance monitoring, vitalization and remanufacturing. Chapter 4 addresses financing and value creation, and chapter 5 describes a pilot project in Veenendaal, the Netherlands.

The Business Model

Four Levels of Business Effectiveness

The type of business offering that is most appropriate for the new concept is a value oriented Product/Service combination. It differs fundamentally from existing business offerings in construction. The differences will be explained here.

The efficiency of a modern enterprise with respect to the delivery of client value can be expressed on a scale that has four distinctive levels [Gielingh, 2006]; see also Figure 2.

a) An enterprise that offers capacity, such as human capacity, is paid based on time spent on a job. It does not sell the results or the way in which these results are obtained. Risks are minimal for the provider, but maximal for the client.

b) On the second level, enterprises offer processes, such as in the form of projects. They commit themselves to execute a project within time and budget. Results are variable and differ from project to project.

c) On the third level, enterprises offer products or services to their clients. They commit themselves to time, budget and results, but not to (end) user value. Most industrial enterprises, such as car manufacturers and producers of household appliances, belong to this category.

d) On the fourth level, providers commit themselves to the maximization of user value. They do this by means of integrated packages of products and services that are optimized for the user at any time of a contractual agreement. Usually they own the products so that these can be replaced by others in order to reduce the risks of the client. This offering, often called a Product/Service System (PSS), goes beyond pure leasing, as the latter is mainly restricted to financing. In a PSS, user value is optimized by an additional servicing package that ensures that the product remains fit-for-use, also if user requirements, client budget and other conditions change. Risks are minimal for the client, but maximal for the provider.

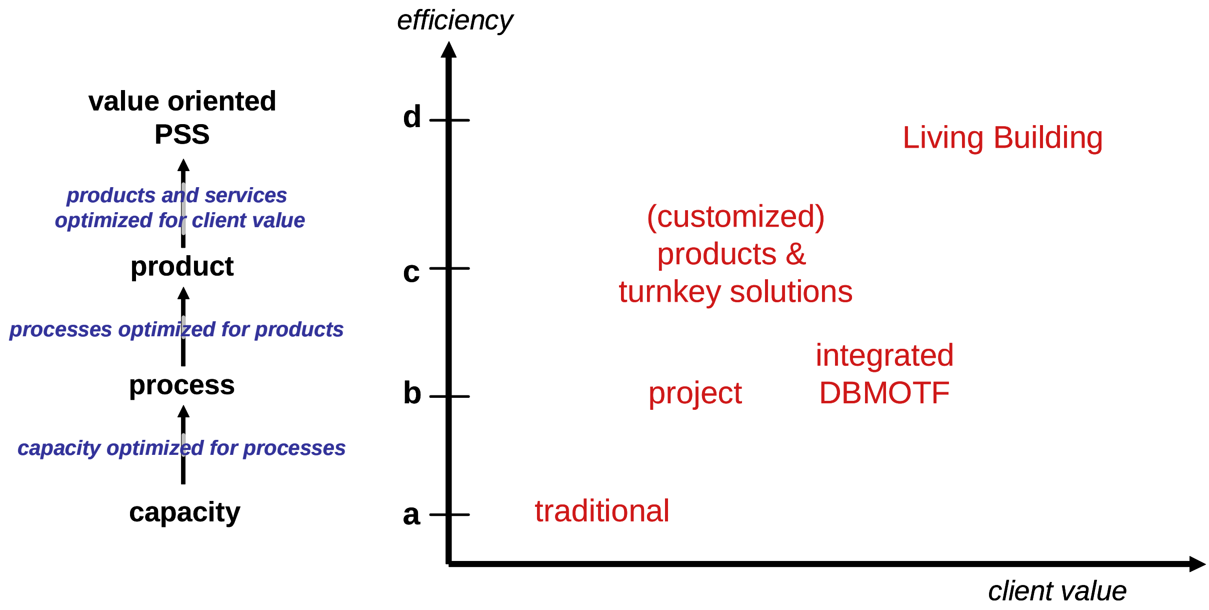

Figure 2. Four levels of business efficiency (left) versus client value

The most widely applied business model in construction today is the offering of capacity. Competences are brought together and the risk is spread by forming consortia. Processes depend on client order. Business ICT is mainly restricted to Enterprise Resource Planning (ERP).

Some construction companies apply process orientation. Such companies are specialised in project- or process management. They run their businesses often without personnel doing the actual work; personnel is hired from capacity oriented companies. From an ICT point of view they apply workflow and document management systems. Well known applications in construction are the seamless team approach and integrated DB(MFO) projects.

Product orientation is characterised by the fact that enterprises have a portfolio of predetermined solutions that exist independent of client orders. These solutions can be configured and customized to comply with specific client needs. Processes do not depend on client order but are optimized for the product being delivered. Enterprises that offer products usually apply advanced 3D or nD (parametric) CAD systems that are integrated with Computer Numerically Controlled (CNC) production automation technology. They have fixed (order independent) supply chains that can be optimized for collaborative engineering and for logistics. Examples in construction are advanced suppliers of building systems and turnkey solution providers.

Value oriented product/service systems form the fourth level. A combination of products and services aims at the delivery of the highest client value for the lowest costs. In terms of ICT, enterprises use most - if not all - of the above mentioned applications as well as Customer Relationship Management systems. Value oriented PSS offerings are still rare in most industries as well as in construction. The concept will be described in more depth in section 2.2.

The four levels form essentially a stack: each level makes use of the efficiency gains at a lower level. Hence, the offering of value oriented product/service combinations is not possible without having products and services.

Figure 2 shows the four levels of business efficiency and effectiveness on the left. Current business offerings in construction can be placed in a diagram with two orthogonal axes: (a) business efficiency and (b) client value. Integrated DBM(FO) projects aim at offering high client value, but as they are not based on predefined and optimised products and services, they cannot do this efficiently. Such projects are at best process based. Turnkey solutions, using industrially produced (prefabricated) systems and components, apply more efficient processes which normally result in lower costs. But they do not necessarily result in higher client value, nor do they minimise client risks.

Product Service Systems

A Product Service System is defined by [Goedkoop et.al. 1999] as "a marketable set of products and services capable of jointly fulfilling a user’s need". Key factors of success are:

- to create value for clients, in economic sense or by adding quality and comfort,
- to customize solutions to meet specific client needs,
- to create new functions, or to make unique combinations of functions,
- to decrease the threshold and risk of capital investment by sharing, leasing or renting,
- to reduce environmental load and to deliver eco-benefits,
- to respond better to changing client needs.

Product Service Systems introduce a different way of doing business and require new kinds of contractual arrangements. They have the potential to decouple environmental pressure from economic growth [Mont 2002, Manzini and Vezzoli].

An example of a Product Service System is that offered by producers of printing and copying machines, such as Xerox and Océ [Kerr 2001, Steinhilper 1998]. In their PSS business models these companies do not sell machines, but a printing or copying function. Clients pay for the output of a machine and for quality and reliability. The combination of product and service is designed to deliver performance. If a machine runs out of toner, it automatically orders a new cartridge which may be delivered and installed by the provider. The condition of operational machines is monitored through sensors that record the number of copies made, paper jams, heat and/or other critical performance criteria. Before a machine breaks it can thus be repaired or replaced by a 'new', more reliable one. If the requirements of a client change, the provider replaces a machine by a new one. 'Old' machines are taken back and are disassembled. The parts are remanufactured and used again for the production of new machines. This reduces waste and the costs of making completely new machines from fresh natural resources.

Figure 3. Disassembly line of copying machines for the reuse of parts [Steinhilper 1999]

The Living Building Concept

The Living Building Concept [de Ridder 2006, de Ridder and Vrijhoef 2007] is an idea for a Product Service offering for construction. An LB provider takes full Extended Lifecycle responsibility for buildings and their parts. The provider is thus not hindered by the current fragmentation in the construction sector. Very much like common practice in other industries, LB providers have a supply chain which is strategic and thus independent of client orders.

Providers develop a portfolio of solutions for specific product/service - market combinations, such as for housing, education (schools), health care (hospitals), retail (shops, retail centres, airports), business (offices) or infrastructures (bridges, tunnels, roads). A solution consists of a building concept and a suite of services that both can be customized to specific client needs.

An LB contract aims at the delivery of maximum value for minimal money; it does not freeze user requirements or building performance. If user requirements or external conditions change such that the building no longer offers the best solution, it will be changed. The goal of the LB concept is therefore to keep a building fit-for-use, not just once, but always!

A provider does not wait until clients or users start to complain. The provider understands the type of processes that are facilitated by the building, and is proactive. User processes, social and environmental boundary conditions, as well as building performance, are continuously monitored. If any of these conditions change such that the building becomes sub-optimal, the provider may adapt the building and/or service. Depending on details in the service level agreement and impact on the agreed price, the provider can do this autonomously or by mutual agreement with client and/or user.

For each modification requirement, there may be zero, one or more solutions. Each solution will have its benefits and implications. These benefits and implications are considered in a broader context: change requirements can be addressed more economically by combining them into a single solution. Decisions about modifications are thus based on a rationale, in which integral benefits are weighed against integral implications.

An LB contract does not specify a fixed performance for a fixed price, but defines an agreed value-cost balance. Within such an arrangement, the process is dynamically controlled: clients can alter their initial demand and calculate the impact on the initial price, and vice versa. Providers are encouraged to propose new solutions that reduce costs or deliver additional value. An initial price will grow within this dynamic process in a controlled way to a final price. Instead of enforcing the initial planned value against a fixed price calculated in the first phase of the process, the price is based on actual delivered value during the process. The range between basic price and the client's financial budget can be considered as the client's "control budget". On the supply side, providers are enabled to reduce costs or increase value.

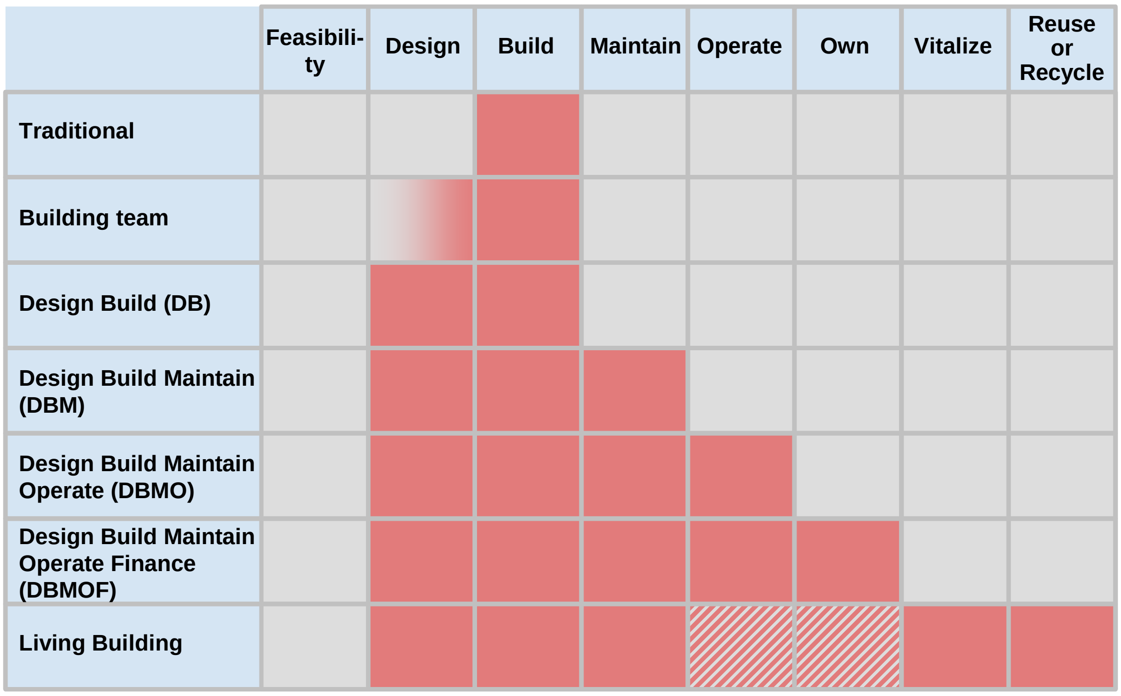

Figure 4. A comparison in lifecycle coverage of existing contract types and the Living Building concept. In the ideal situation, the provider also covers operation and ownership. In a minimal scenario, operation and ownership may remain the client's responsibility

Given the possibility that buildings may change quite drastically during their life, it makes sense that the providers legally own the buildings; not the clients. However, providers do not rent or lease out buildings, but facilitate user processes. Hence, buildings may be multifunctional to facilitate the processes of multiple clients. This creates new business opportunities for clients and results in substantial cost efficiencies.

Figure 4 shows the lifecycle coverage of Living Building services compared with some well known contract types, where D=Design, B=Build, M=Maintain, O=Operate and F=Finance. Living Building services comprise in principle all of these stages plus vitalization and reuse or recycling. But the concept goes beyond mere lifecycle coverage and financing: it aims at the delivery of client value. Further, it can only be successful if a sufficiently large implementation base exists so that industrial production techniques can be used and a sufficiently large pool of interchangeable components can be built up.

Measuring Value

Values and costs are not limited to financial values and costs. Amongst the factors that can be incorporated in a value/cost model are social, cultural, environmental, ethical and aesthetical values, as well as risks, wellbeing and health.

A complicating factor is that economical values may have to be weighed against non-economical costs. Reversely, non-economical values may also have to be weighed against economical costs. The fact that 'costs' and 'values' of different kind have to be weighed against each other forms a special challenge for the concept. This problem is, however, not limited to the new business concept: clients in construction always have to weigh financial costs and environmental damage against economical, social and/or cultural benefits.

There exist a few concepts that try to tackle this problem, of which the best known is the Balanced Scorecard method [Kaplan and Norton 1996]. This method does however not project all different values and costs on a single scale. The consequence is that weighing between different types of values and costs, such as the financial value of the natural habitat of an endemic plant, or the costs of emitting one kg of CO_2, remains a subjective human task.

It is currently common practice to express all values and costs in terms of money. In the medical sector, even the value of a human life is expressed in terms of money. Money has however specific characteristics, such as interest, inflation, artificial scarcity and relationship with debt, that makes it less suited for the expression of non-commercial values. Central banks can simply print money if needed so that it is a highly elastic yardstick. This is especially important for products with a long lifetime such as buildings.

As an example: an investment in an installation for solar energy that gives an annual return of 3 % may be perceived as non-economical: the return on investment is seemingly lower than 3.5% annual interest that can be earned if the money is deposited in a bank. But money is subject to inflation (i.e. it loses value over time), while the price of energy is expected to increase over time, even faster than inflation.

The former banker Lietaer designed new kinds of money that are better suited for the expression and exchange of social and environmental values than current money [Lietaer 2001]. Amongst these types of new money are ‘currencies’ for the trading of care, education and energy. The Kyoto treaty has introduced the international trading of CO_2 emission rights. But again, these specialised currencies cannot be used for trading between values of different kind.

Another problem is the time-factor. Current values are determined by current trading. There is no trading between today and the future. This is why it seems ‘economical’ to exploit planet Earth today, and not to leave its resources untouched for use by future generations.

A very interesting solution for both problems may be the Terra Trade Reference Currency [Kiuchi 2004]. The Terra is not intended as a currency for direct usage, but as a reference currency against which the value of normal currencies, such as the dollar, euro, yen and pound can be measured. Although the Terra starts with a unit price, the value development as a factor of time differentiates based on the type of value being measured. The Terra is not created by banks but is coupled to real world values such as grain, rice, water, oil, copper, steel and human labour. It has no interest and is indifferent to inflation. Unfortunately, the Terra is still a concept and is not yet used in practice.

Sustainable Lifecycle Management

Three kinds of facility lifetime

We may distinguish three categories of lifetime that are relevant for buildings and any of its systems or components [Gielingh et al 2007]:

- *Usage lifetime*: the time in which there is a user need for the offered solution. Sometimes this is also called Functional lifetime.
- *Technological and fashion lifetime*: the time in which the offered solution is acceptable, compared with other alternatives. Technological innovation or changes in fashion may offer more attractive alternatives for the user.
- *Physical lifetime*: the time in which the physical properties of the solution remain within an acceptable tolerance-zone from its intended properties. If these properties deviate too much from intended properties, the facility may break or become less attractive. The physical lifetime of an artefact is usually determined by factors such as wear, tear, corrosion or accidental damage. Traditional maintenance activities focus primarily on the extension of physical lifetime.

The first two lifetimes determine the *value lifetime* [Tomiyama 1997, Umeda et al 2000]. An artefact has only value as long as there is a user need for it and as long as there are no better or more attractive alternatives for it.

These different kinds of lifetime do not just occur for a building as a whole, but for every component or (sub)system individually. The effective lifetime can be different on each level.

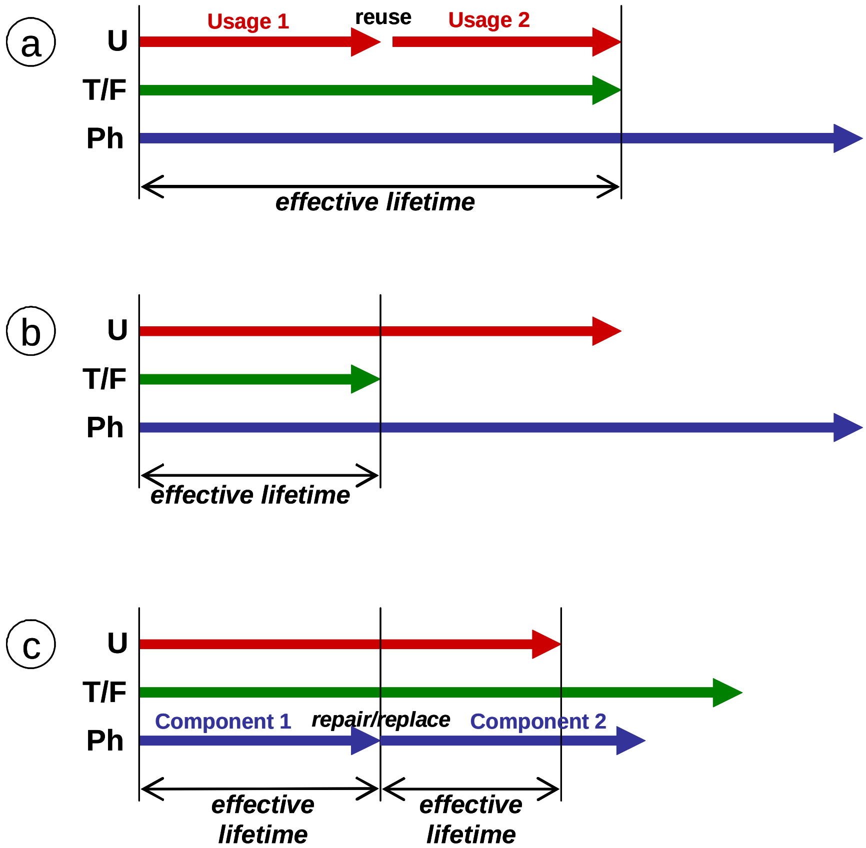

Figure 5. Combinations of Usage (U) Technology and Fashion (T/F) and Physical (Ph) lifetime determine the effective lifetime

Figure 5 shows what happens if these kinds of lifetime are combined. Together, usage (U), technological and fashion (TF) and physical (Ph) lifetime determine the effective lifetime of a facility, component or (sub)system.

(a) On top a situation is depicted where physical and technological lifetimes are longer than usage lifetime. An example is a house that is bought by someone whose personal conditions change, for instance because of a divorce or because of new work in another part of the country. The user needs have changed, but the object itself is potentially reusable and can be sold to another person.

(b) The object in the middle has a long physical lifetime and a long usage lifetime, but a short technological or fashion lifetime. Although the user needs may not have changed after t=To, the component may be replaced because technologically superior or more fashionable alternatives have entered the marketplace. This is most prominent today for products such as mobile telephones, computers, cars and clothing.

(c) The component shown in (c) has a short physical lifetime. User needs and technology hardly change. The component will then be replaced during maintenance. Most current lifecycle models are based on this scenario. They assume - often incorrectly - that user needs and technologies do not seriously change

Sustainable Buildings and Lifecycle Differentiation

Each (sub)system and each component of a facility has thus its own lifetime scenario. The primary function that is facilitated may exist considerably longer than the facility itself.

For example, the functional life of a hospital may span more than 200 years, while buildings normally have an estimated lifetime of 30 to 60 years. But sub-functions of a hospital have a considerable shorter lifetime than the main function. For hospitals we may refer to changing diagnostics technologies, such as the introduction of magnetic resonance (MRI) technologies during the last decades. An MRI scanner is a very heavy object that cannot be placed on a floor that is designed for regular loads. Also the recent policy to reduce the hospitalization time of patients and to increase the number of polyclinic treatments had an impact on the functional requirements for hospitals. Of even more importance can be changes in organization. For reasons of efficiency it can be decided that three existing hospitals merge into one, and that certain locations are no longer needed because of improved infrastructure. Such changes have a dramatic impact on the building. Does it have to be written off, even though it is still in good condition? Can it be given a new destination? Without any doubt, the future will bring more changes. But these are difficult to forecast.

Differences between the three types of lifetime require changes in the state or configuration of an artefact. Systems or components that need to be replaced but have not reached the end of their physical or technological life may be reused in the same or in another facility.

In case systems or components cannot be reused as such, the materials from which they are made can be reused. To trash components or materials, just because the user need has changed or disappeared, would be a waste of capital, and an abuse of scarce natural resources.

The Living Building Concept aims therefore at the reuse of components that have finished their usage lifetime but not their physical or technological lifetime. For components that have finished their physical and technological lifetime, it aims at the recycling of materials from which they are composed.

As a consequence, the Living Building Service Provider has to manage various lifecycles and a dynamic configuration structure. A reference model that can handle such configuration changes is published by [Gielingh 2008].

The business process that supports Living Buildings

Monitoring usage, environmental condition and building performance

The monitoring function of Living Buildings is an alternative for the current practice of trying to forecast the future.

A provider of Product/Service combinations for Living Buildings cannot assume that user requirements never change. Instead of waiting for users to complain, he must be proactive, so that new services can be developed. In order to keep the building fit-for-use he must understand the activities that are facilitated by the building, understand the conditions under which they take place, and understand trends. The provider must follow demographic trends of the community in which his building is located so that he can anticipate changes in required capacity. He must also understand trends in the processes that are facilitated, such as new teaching methods, new types of medical treatment, and new quality and comfort levels that users demand.

The appreciation of the performance of a building depends not only on the building itself, but also on the activities of the user and on environmental conditions. A room in which people are in motion requires a lower temperature than a room in which people are passive. Figure 6 (top) gives an example of five building related, two usage related and two environmental related parameters that may affect perceived thermal comfort in a room [Säteri 2004].

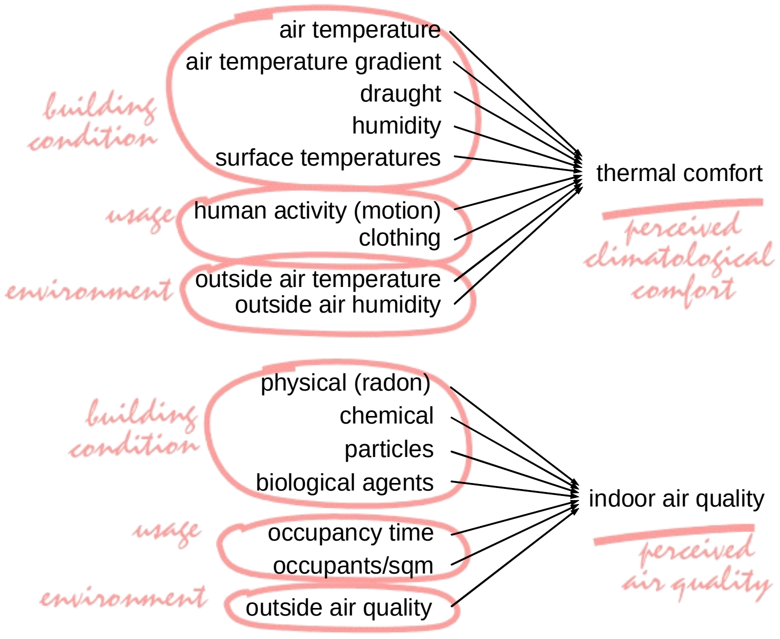

Figure 6. Two examples of the need to monitor room condition, room usage and environment for the determination of perceived room performance

Hence, an essential part of providing adequate services and adequate performance is to monitor the building, its usage and its environment. Some of these monitoring functions can be done automatically with electronic equipment, but others require human action. Certain performance criteria cannot be met by the building alone, but require additional servicing. Cleaning, supply of consumables and light maintenance are well known examples. But also the optimization of health, safety and security conditions can be developed as a service by the provider.

Vitalization

The term 'maintenance' is used today for the servicing activity that keeps a facility in its original state. This term reflects the current static view on the functional needs for a facility. It assumes that these needs do not change.

The servicing activity that aims at the maximization of yield (= integral values divided by integral costs) is described by the term 'vitalization'. It incorporates not only traditional maintenance, but also modification of the facility to serve changing user needs and changing trends in technology and fashion.

Whereas most buildings meet only the user and community criteria that were defined at design stage, a living building aims at meeting actual criteria. This does not imply that the building is changed continuously, as the costs of change will have to be weighed against increased value. But, in principle, the building will be adapted on a regular basis in order to keep users satisfied and in order to meet changing standards such as for safety, health and energy. Vitalization of a building may mean that the building has to be made larger or smaller. In the latter case, building components will be released. If the Living Building concept would be applied according to traditional cradle-to-grave thinking, downscaling would be identical to (partial) demolition, which creates substantial waste. According to [Krutwagen et al 2004] construction is today responsible for 10.7% of the depletion of the Earth’s natural resources.

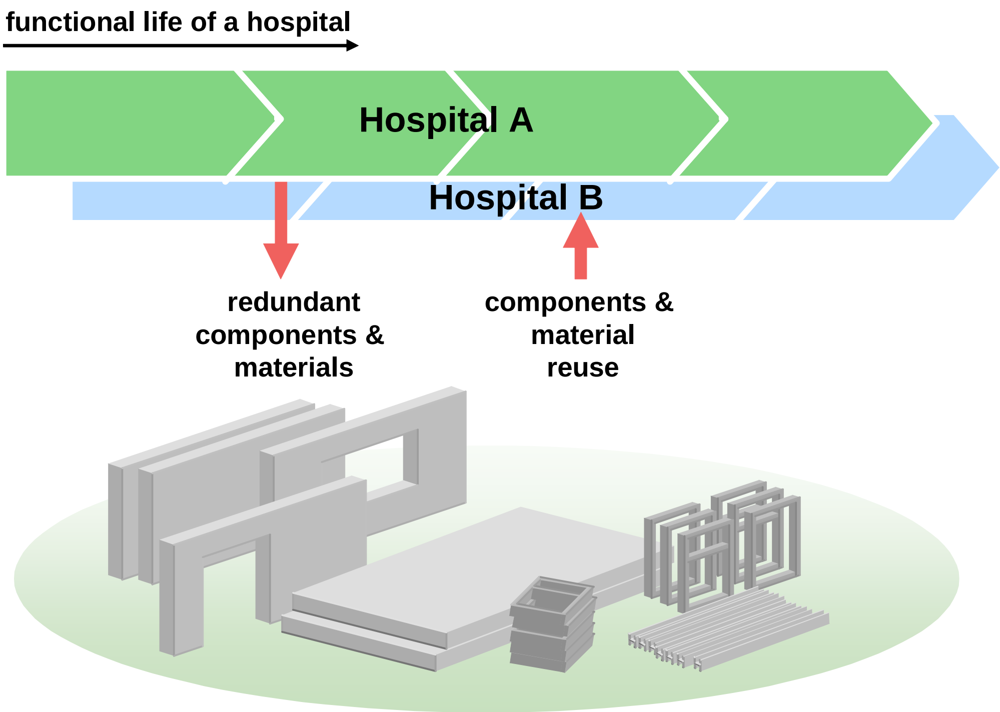

Figure 7. A Living Building, such as a hospital, will be continuously modified to satisfy user needs. This causes the release of redundant components and materials. Some of these components and materials may be reused for the vitalization of other Living Buildings.

The Living Building concept adopts therefore the cradle-to-cradle principle [Braungart et al 2007, McDonough et al 2002]. Modules or components that are released from a building, simply because their functional need has disappeared, will, as far as possible, be reused in another building. As these modules and components will not be as good as new, they may have to undergo a process of remanufacturing, such as cleaning, repainting, surface treatment or repair.

This approach is in line with future developments in construction. The European Parliament accepted in 2008 a directive on waste elimination which states that by 2020 measures shall be taken by all member states such that 70% of non-hazardous and non-natural construction materials will be reused or recycled [European Parliament 2008].

Remanufacturing

Recycling of construction materials, such as by the melting of metals and glass, or by the pulverization of stone and concrete, costs huge amounts of energy. The production of materials from fresh resources requires even more energy. Table 1 gives an example of the ‘cradle-to-gate’ embodied energy and embodied carbon of some popular construction materials [Hammond and Jones, 2008]. Cradle-to-gate refers to the energy use needed for the production of the base material itself; it does not include transportation, processing on site, maintenance and demolition. Total lifecycle energy and carbon will therefore be substantially higher. Especially the demolition of concrete requires huge amounts of energy, and may be of the same order as the energy needed for production. Given the fact that the cement industry alone contributes 5% to all global anthropogenic CO_2 emissions, it is clear that the carbon footprint of construction materials is huge. The middle column gives Embodied Energy in Mega Joules per kg of material, the right column Embodied Carbon as kg of CO_2 per kg of material.

Table 1. Embodied energy and carbon, cradle-to-gate, of some construction materials [Hammond and Jones, 2008]

Material	Embodied Energy MJ/kg	Embodied Carbon $kgCO_2/kg$
Aluminum (virgin)	218.0	11.46
Aluminum (recycled)	28.8	1.69
Bricks	3.0	0.22
Cement	4.6	0.83
Ceramics	10.0	0.65
Concrete (pure)	0.95	0.13
Concrete (reinforced, prefab)	2.0	0.22
Glass	15.0	0.85
Lime	5.3	0.74
Plastics (general)	80.5	2.53
Steel (virgin)	35.3	2.75
Steel (recycled)	9.5	0.43
Stone (general)	1.0	0.06
Timber (plywood)	15.0	0.81
Timber (sawn softwood)	7.4	0.45
Timber (veneer particleboard)	23.0	1.24
Vinyl flooring	65.6	2.29

A detailed study of the lifecycle energy of twenty Australian schools indicates that the total embodied energy in a building (for its full lifecycle, thus incorporating initial and recurrent embodied energy) can be as much as 37 years of operational energy [Ding 2007].

In addition, it should be realised that the production of materials such as cement, brick, steel and glass require very high temperatures that currently can only be realised through the burning of hydrocarbons. For the heating and electricity consumption of buildings there are other - more environment friendly - energy sources available.

Given the expected rise of energy costs in the far future, and the need to reduce CO2 emissions, it makes sense to explore the possibilities for reuse. But as used components do not have the same 'look and feel' of new products, these components require some treatment, such as the repair of dents and scratches, surface finishing and coating. This principle is called remanufacturing.

The idea of remanufacturing originated in the automotive sector, where demolition firms started to disassemble cars, refurbish their components, and sell these as spare parts for similar types of cars. Remanufactured parts can be produced at around 50% of the costs, and can save up to 80% of the energy and CO2 emissions as compared with the production of new parts [Steinhilper 1998]. Remanufacturing saves the Earth's limited resources and reduces the production of waste.

Up to now, take-back policies for certain products are implemented collectively, often through government interference. But [Webster and Mitra, 2007] found that individual take-back policies, enforced by law, will lead to a structural change of industry and will make reuse and remanufacturing a profitable business where today it is considered as non-profitable. In these cases, manufacturers design their products so that they are not just easy to assemble, but also easy to disassemble and remanufacture. Advanced manufacturing technologies used today for production can also be applied for disassembly and reuse.

Apart from cleaning, remanufacturing often includes surface treatment, such as the removal of corrosion and paint, repair of scratches and dents, and the addition of new coating layers. In some cases, remanufacturing may require shape modifications. In a few cases it includes melting or chemical processing, so that the base materials can still be reused. Reuse of components or modules, without melting or chemical processing, has the least environmental impact and is therefore preferred [Tomiyama 1997, Umeda 2000].

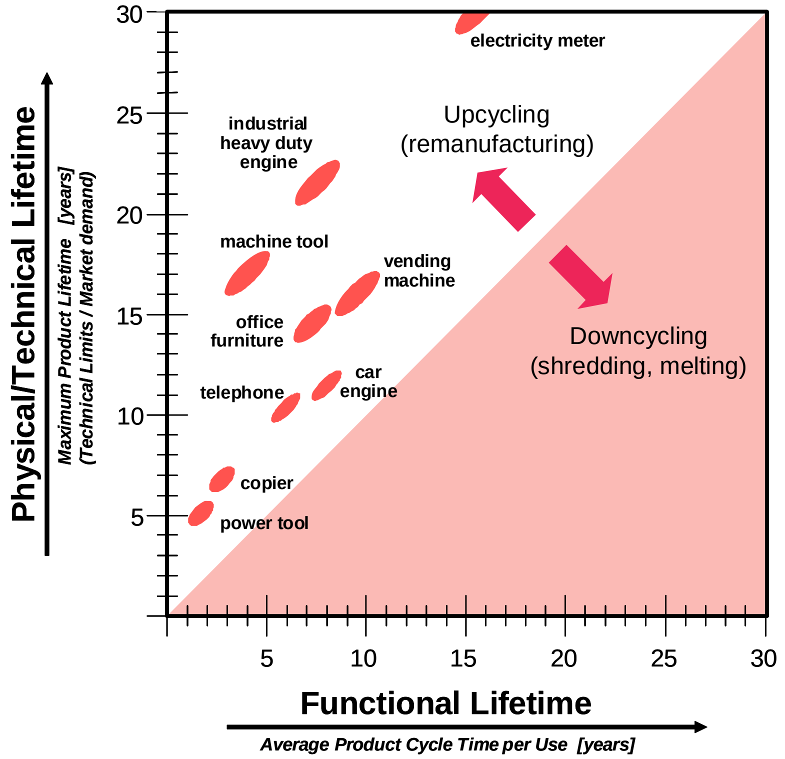

Figure 8. If the physical or technical lifetime of products or its components is longer than its functional life, there is a case for remanufacturing (or 'upcycling'). Diagram derived from [Steinhilper 1998]

Given the increasing costs of raw materials and energy, companies that master this process well will have a leading edge over companies that apply cradle-to-grave thinking [Goedkoop et al 1999].

The business case for remanufacturing may even be greater for construction than for other sectors. This is because:

a) Buildings and other constructed artefacts are massive relative to other products so that there is a higher incentive for reusing materials,

b) the technical and physical lifetime of components and materials used for construction is generally longer than their functional lifetime, and

c) remanufacturing, in combination with vitalization, extends the value lifetime of buildings and thus reduces the risks of capital investments.

Design for disassembly

An important prerequisite for vitalization, reuse and remanufacturing is that building structures can be (partially) disassembled without endangering the main structure of the building or any of its systems, and without damaging the components. In an ideal situation, it must be possible to vitalize a building without disrupting any of the activities that it facilitates.

A study of the technical implications of design for disassembly in construction was done by Durmisevic [Durmisevic and Brouwer 2002, Durmisevic 2006]. Guidelines for design include the separation of building functions, minimisation of the number of relations between assemblies in a building, a separation between main structure and infill, the connection of components of an assembly with a base part that connects the entire assembly with other assemblies, parallel assembly sequences, dry joining techniques and separation of components in different assemblies.

The Living Building Process

The envisioned process of a Living Building product/service provider is shown in Figure 9. The left side of this diagram shows, from bottom to top, indicated with red arrows, the full construction process that starts traditionally with the extraction of raw materials from natural resources. Raw materials are chemically and often thermally processed for the production of base materials. Base materials are subsequently manufactured to become components for assembly.

In case changes of the building are needed during its operational life, the building will be partially disassembled and re-assembled. Removed modules may be reused for assembly in the same or another building. If modules cannot be reused as a whole, they will be disassembled into components. Disassembly can be drastically simplified if fixtures of components and modules are designed for that purpose. Further, given the fact that vitalization may take place in a fully operational building, main disassembly and reassembly should be designed such that ongoing activities in the building can continue with little or no disturbance.

Remanufactured components or modules are stored in a warehouse. As these components or modules are then readily available, the construction process can be very fast compared with traditional building processes.

Ultimately, all buildings produced by the provider will be a mixture of remanufactured and newly manufactured components and systems. Remanufacturing extends the technical lifetime of components so that overall construction costs and building lifecycle costs will reduce.

This concept even enables differentiated service offerings, such as luxury buildings made predominantly from new components, and 'economy class' buildings made from remanufactured components.

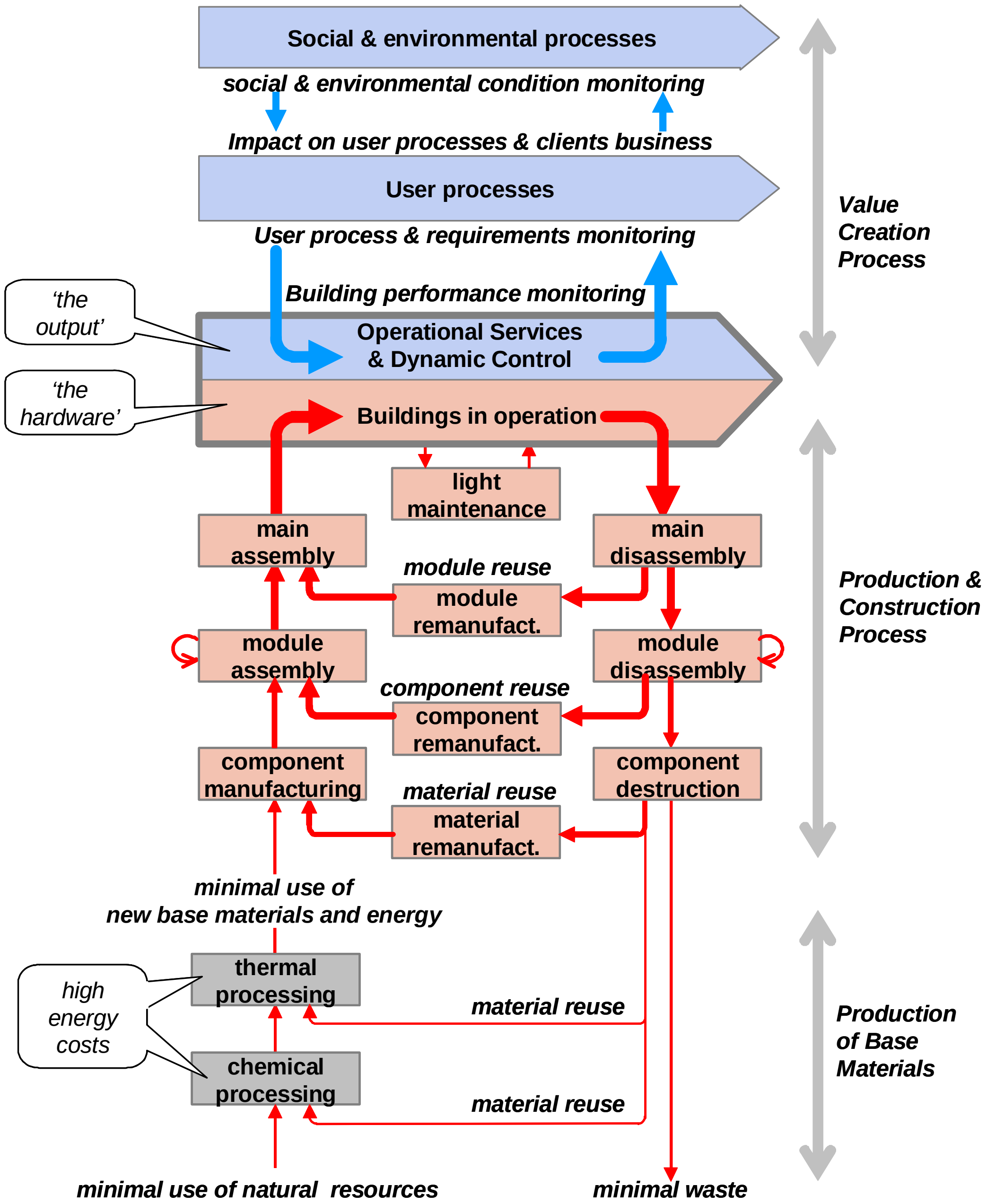

Figure 9. The process of a Living Building provider aims at reducing costs and use of natural resources in the construction process (red) and the increase of client value (blue)

The top of Figure 9 shows, with blue arrows, the value creation process. The goal of this process is to anticipate changing client and user needs, so that adequate solutions can be developed as part of the product, the service, or both. This process is supported by three monitoring functions: (a) the monitoring of social and environmental conditions that may affect user processes and perceived building performance, (b) the monitoring of actual user processes, and (c) the monitoring of actual building characteristics and performance. A building can only be kept fit-for-use if its perceived performance remains high. Factors that affect perceived performance are fashion and market trends, new social insights and new technologies. Further, buildings such as schools, retail centres, airports, hospitals, hotels, offices and also houses support processes that may frequently change, perhaps even every 5 to 10 years.

Financing and Value Creation

The long term capital value of Living Buildings will be substantially higher than that of traditionally built buildings. Figure 10 shows the capital value of a building with an estimated lifetime of 50 years.

Traditional buildings have to be demolished, so that they end up having negative value near the end of their life (Figure 10 top). Remanufacturing turns 'waste' into a capital resource for the production of new buildings (Figure 10 middle). If combined with regular vitalization, a Living Building will remain always fit-for-use, and thus retain a high capital value during its entire (indefinite) functional life.

This has two major implications for financing.

The first is that the risks of investments in Living Buildings are substantially lower than in traditional buildings. A Living Building can be modified according to changing user needs, it can be given a new function, and it can even be disassembled and rebuilt on another location if needed. Its sustained value is important because it serves as collateral for the creditor. If the long term value of the collateral is insecure, or if there is simply no market for it, the creditor risks a heavy loss on this loan in case the lender goes bankrupt. This risk is normally compensated by asking a high interest on the loan. As a Living Building may be perceived as a less risky investment, a lower interest rate on the loan may be negotiated with the creditor. This will reduce the lifecycle costs of the building.

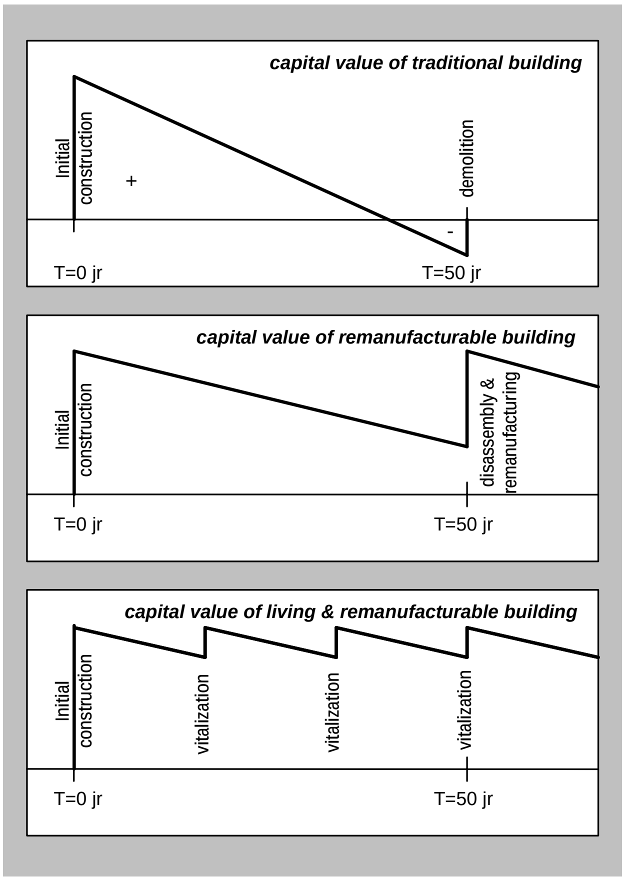

Figure 10. The capital value of a building as a function of time, (a) for a traditional building, (b) based on remanufacturing at the end of functional life, and (c) for a Living Building

The second implication is that Living Buildings do not have to be written off, and that they may even rise in value compared to new but traditionally built buildings. The reason is that it is very likely that in the near and far future natural resources and energy will cost more than today. It has been mentioned in section 3.3 that the production of new materials from fresh resources, or the recycling of existing materials, requires much energy. This energy can be saved if materials and components are designed for reuse. Given the fact that material resources on planet Earth are finite, the long term value of such reusable materials and components will grow more rapidly than interest on a bank account. The amount of money in the two main economic zones, the US and Europe, grows on average between 8 and 10% per year. But only that what can be bought with money determines its real value, and the amount of available material resources does not grow at a similar rate.

Hence, the components of a Living Building do not have to be written off as quickly as a conventional building. They may even rise in value, similar to futures that relate to natural resources. An investment in a Living Building may thus be regarded as an inflation-proof investment.

Case studies

Pilot projects

Several construction projects were selected for experimentation with the Living Building Concept, all located in the Netherlands. The most prominent are:

- a secondary school in Veenendaal. Construction started in May 2009, and is expected to finish in August 2010.
- a hospital in Den Helder. A feasibility study is completed, but the project itself has not yet started because of a complication with financing.
- a canal and sluice valve complex in the province of Zeeland. This project is planned to start in 2010.

As the secondary school is currently the most advanced, more information will be given about it.

The idea of applying the Living Building concept to this school emerged when the concept was little more than a rough idea. Hence, there was no clear picture of the process and the contractual implications. M3V, a consultancy firm that advised the client, proposed the idea to the school board and the local government. The running process was traditional, with a design made by an architect, and a bidding, based on lowest initial cost. Just after winning the contract, the selected contractor went bankrupt for reasons that had nothing to do with the concept. A new bidding procedure started, this time covering integrated detailed design, construction, maintenance and vitalization, based on a number of possible scenarios that require future change. The provider that offered the best value/cost ratio was selected.

Although the Living Building concept is, by itself, new, there were several construction firms that already offered flexible solutions, and which had an interest in expanding their business by covering extended lifecycle services. Of these, the company Matrix Onderwijshuisvesting, a subsidiary of ASVB holdings, won the competition.

Technical aspects

The construction method applied is based on standardized and prefabricated concrete elements, for the exterior walls; standardized, prefabricated floor elements; and steel columns. The wall elements are load bearing. Wall elements that face the exterior of the building have holes for windows and have thermal isolation, and wall elements that face the interior are fire resistant. Both the wall elements and the floor elements contain cabling and piping for heating and ventilation. See also Figure 11.

The only ‘fixed’ part of the structure is the core, where vertical transportation (elevator, stairs) and ‘wet functions’ (lavatory, kitchen) are concentrated. For the rest, the entire structure is flexible. This means that floors can be added or removed, and that the building can be extended. The light interior walls needed for compartmentation can be placed anywhere on a 30 cm grid.

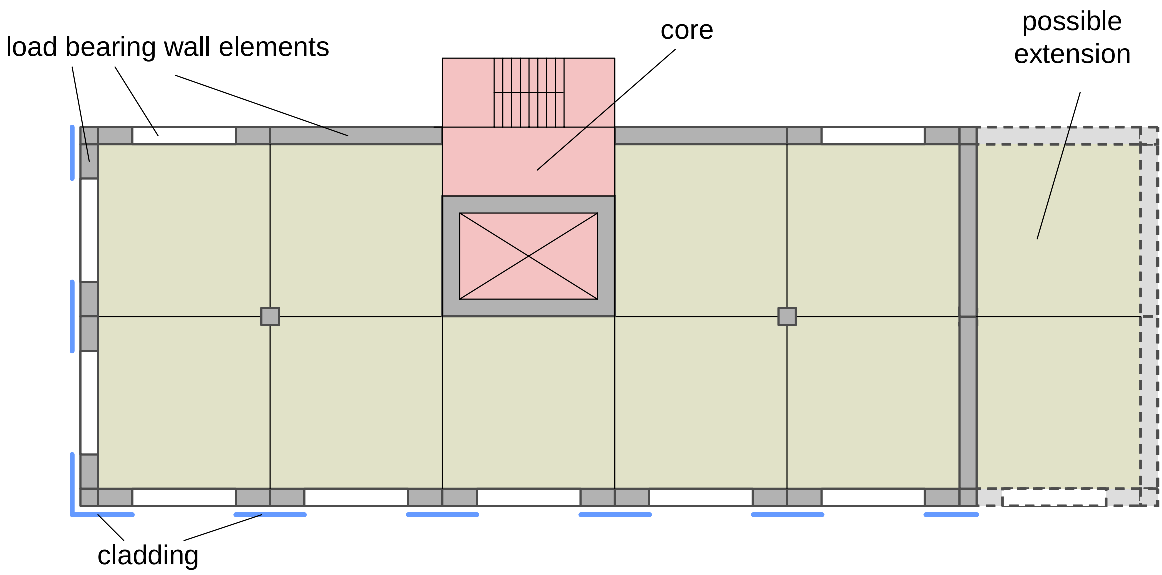

Figure 11. Schematic floor plan of one block of rooms, without infill

The cladding, i.e. the visible part of the exterior wall, is mounted on the load bearing wall elements and can be replaced.

The building has two blocks of this kind, placed in an angle. The space between these blocks is used as an atrium. In the initial design, the building has four floors, but it is possible to add a few more or to remove some.

It is possible to change the function of the building as a whole, or any of its parts, such as a wing or one or two floors. Example designs exist for use as office and even condominiums. Hence, functionality can change.

All components and elements are joined with dry connections, and can thus be easily disassembled. The provider estimates that the main structural elements have a lifetime of more than 120 years. The cladding is estimated at 30 years, mainly for reasons of fashion. In other words, every 30 years (or sooner or later, whatever the client wants) the cladding can be replaced by another one, giving the building a more contemporary, 'new' appearance. Interior walls are estimated to be moved once every 10 years (on average) and have a lifetime of 30 years.

Thanks to the choice of using standardized prefabricated elements and components, the entire building can be erected in slightly more than one year.

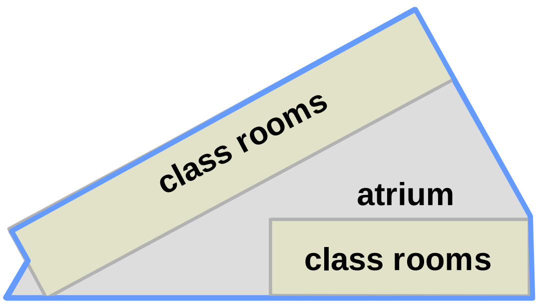

Figure 12. Plan of the school, with two blocks of class rooms. Between these blocks is meeting and circulation space

Figure 13. Computer rendering of the exterior of the secondary school in Veenendaal; the first pilot project contracted according to the Living Building Concept

Figure 14. Computer rendering of the interior of the secondary school in Veenendaal

Financial and contractual aspects

There is little doubt about the feasibility of the concept from a technical/technological viewpoint. But the contractual and financial aspects appeared to be less easy to implement. The provider also offered the client a financial solution, in the sense that the provider remained owner of the physical building and the client pays for the performance of the building and related services; fully in line with the concept that is outlined in this paper.

This appeared to be ‘a bridge too far’ for the client. In the Netherlands, schools fall under the responsibility of local governments. They reserve separate budgets for school building, operation and maintenance, and this was the case with this school. Also, the idea that a school building would be legally owned by a private (commercial) party felt risky. A factor that may have contributed to this perception was the bankruptcy of the former contractor. Hence, the building, once ready, will be owned and operated by the local government.

The consequence of this decision was that the initial costs had to be kept within the available (tight) budget, and that the provider cannot be rewarded for the offering of added value such as discussed in this paper. The provider, for instance, planned to install solar panels on the roof of the building, so that the school could become energy neutral. But this feature had to be dropped in order to stay within budget.

Another complication was that, due to ownership by the local government, the normal accounting rules used by this body applied. Consequently, the building as a whole will be written off in a period of 40 years, just as other similar public buildings. Although the users are happy with the new adaptable building, the specific advantages of the concept could not be made explicit.

Hence, it can be concluded that the new concept requires a drastic change in thinking by the clients.
Nonetheless, the provider, Matrix, has become very enthusiastic and plans to offer future clients the full package. It sees that clients need to be better informed about the concept, so that all parties will eventually reap the benefits. More work is also needed to express the added value through a leasing construction that includes a new form of financing and insurance.

Figure 15. Construction of the school, summer 2009 (almost same point of view as Figure 14)

Results

A new business model for construction is described, based on a combination of products and services, in which – ideally – the provider owns the material building and is paid for the performance that the building provides to its users. The building is constructed from reusable components and materials that may have a lifetime which is considerably longer than the functional lifetime. The building can be adapted continuously to changing needs.

Several pilot projects are planned in the Netherlands. Of these, the project for a 'living school' in Veenendaal is currently (November 2009) in construction phase. In 2010 the realization of a 'living hospital' in Den Helder and a 'living canal and sluice complex' are expected to start.

The project in Veenendaal started as a unique experiment. But the company that built the school has now plans to form a joint venture with two consultancy firms and its main supplier that offers the integrated Product Service combination to the market. The ambition is to build a series of schools – which may all look different and unique from architectural perspective – all according to the same concept. It is expected that lifecycle costs can be reduced, while the risks for the local governments will diminish. This is contrary to the common belief that sustainable buildings cost more than traditional buildings. The concept is in particular interesting for regions that are faced with a shrinking population.

Conclusions

The Living Building concept seems to be a feasible and powerful business concept for the realization of sustainable buildings. An important advantage, as compared with other business models, is the extended lifetime of material components, resulting in considerable savings on embodied energy and CO_2 emissions. In addition, 'living buildings' can always be adapted to changing user needs and changing social and environmental insights and requirements. Hence, the lifecycle value will increase. As the continuous modification of buildings will require human effort, it can be stated that, from an economical point of view, the concept shifts the application of capital investments from energy and material resources to labour. The higher labour intensity should not be seen as a factor that increases costs, because building vitalization is always done to keep the building 'fit-for-use'. Decisions about change will always be backed up by a cost/value analysis.

The pilot in Veenendaal shows that the concept is technically feasible, although certain improvements remain always possible. Thanks to the use of prefabricated, standardized components, construction time is very short. If in the future remanufactured components will be used, construction time can be even shorter. However, clients and investors, as well as their advisors, need to get used to the idea. They tend to stick to old thinking patterns, which restrain the effectiveness of the concept. More work is needed to examine the financial implications, as well as the contractual and legal implications. Important risks such as bankruptcy of a provider and changing standards for reusable components need to be addressed.

Acknowledgements

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14

Integrated Practice for Sustainable Design and Facilities Management: Aspiration in a Fragmented Industry

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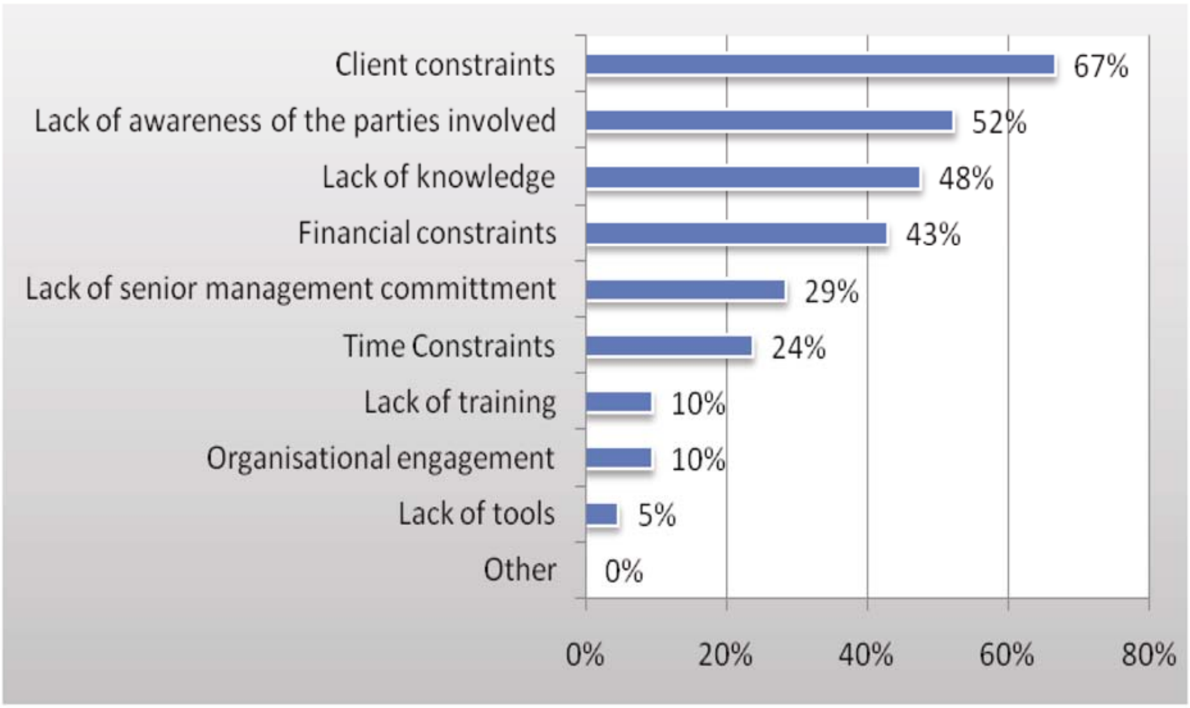

Integrated Practice for Sustainable Design and Facilities Management: Aspiration in a Fragmented Industry

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Abstract

The goal within construction is to deliver a well designed, quality product that meets clients' requirements, on time and within budget and with little impact on the environment. But often this is not the case. The fragmentation of the construction process has led to lack of co-ordination and communication between parties and the separation of design from operation. Facilities Management (FM) is a relatively new profession. It is argued that effectiveness and efficiency of an organisation is linked to the physical environment in which it operates. As designers often struggle due to their lack of knowledge of the end-user, FM can inform the designers of a new building about end-users needs. Questionnaires were used as a method for data collection. The aim was to gain knowledge in topics of sustainability and FM within the construction industry. This research highlighted that FM knowledge can be communicated at the design phase to provide efficient solutions. They can take on user functionality as well as form and ensure deliverability as well as flexibility. The responses to both questionnaires were such that the knowledge of FM is rarely implemented at the briefing and design phases of a project. However, they are recognised for bringing end-user knowledge to a fragmented process to drive towards sustainable development. This renders the integrated approach to sustainable design and FM as industry's aspiration. This has a materialised education and training consequences. Skills and training provision, traditionally offered separately to designers, managers and FM, needs to be re-evaluated. Education and training programmes should be developed to provide effective structures and processes to apply sustainability throughout the construction and FM industries coherently, and as a common practice.

Keywords: construction industry, sustainable design, facilities management, sustainability, and policy

Introduction

This chapter attempts to highlight the point that it is very unlikely for a new sustainable building to successfully meet all the needs of the end-user, particularly the Facilities Management (FM), without their knowledge input at the early phases of a construction project. Many organisations employ FM to control their facilities during the operational phases of construction although their knowledge of the building in use is rarely utilised at an early stage in the process. Attitudes from a range of construction professionals were researched to investigate whether the inclusion of FM at the briefing and design phases of construction will meet the end-user objectives and provide a pathway to more sustainable building.

Sustainable Facilities Management and Construction

A Facilities Management (FM) has an enormous amount of influence over the productivity and profitability of an organisation (Hodges 2004). FM started life as a service as small as security provisions within a building and has grown to integrate the planning and management of ‘hard services’ (building fabric) and ‘soft services’ (cleaning, security, health and safety) to achieve better quality and economies of scale (Shah 2007). The formation of the British Institute of Facilities Management in 1993 gave the final drive towards FM integration in organisations, followed by the development of specialised training and qualifications.

Since 1940, the fragmented nature of the construction industry has been continually criticised for its poor performance in its operations and providing value to the customer (Barrett 2008). The most documented examples include the reports by Sir Michael Latham (1994) and Sir John Egan (1998) where a collaborative approach was encouraged to meet the requirements of the client in terms of time and cost. Egan (1994) suggested that the industry is still experiencing similar problems surrounding the fragmented nature of construction which greatly inhibits the process of innovation and performance improvements (Egan 1998). These problems still abound within the industry more than ten years after publication of these two major reports. The reality of such fragmentation and the overriding aim of design, construction and FM constituencies’ pursuit of financial interest have great implications on sustainable design management and the drive for sustainability agenda (Elmualim *et al.* 2009).

Sustainable development has significantly grown in importance largely due to EU legislation and the UK government forcing the construction industry to improve energy efficiency and reduce carbon emissions (Stern 2006). An example is the recent government set targets to reduce carbon emissions by 80% by 2050 compared with 1990 levels. The construction industry poses a huge detriment on the environment due to its large resource consumption and level of Green House Gas emissions *(*Kibert and Sendzimir 2000, Cole 2000, Pearce 2006)*.* The benefits of sustainability and green buildings are therefore, well established (Adis and Talbot 2001). Hodges (2004) recognises these benefits as the reduction in energy consumption, increased user productivity, waste reductions and many other issues. A number of FM involved in sustainability aim to make these savings at the operational phase. However, the physical aspect of a building still dominates the design and construction within the built environment with no considerations for in-use or FM. There is a need for involving FM in the design and construction processes to lay bare the sustainability goals (Elmualim *et al.* 2009). Popular methods for designing and building facilities leads to 40-50% consumption of energy produced on a popular basis, therefore small strides forward will equal big savings (Hodges 2004).

Design management is considered the holy grail of sustainability. However, sustainable design management, often exclusive of other processes, is resulting in an increasing number of case studies leading sustainable design and innovation which fail to demonstrate changes or materialise in common practice (Elmualim *et al.* 2009). Designers should be required to look at the life cycle of a building when assessing green alternatives (Hodges 2004). The chapter analyses whether the knowledge of FM at the operational phases can contribute to the early briefing and design phases of construction and create more sustainable buildings that fully meet the needs of the end-user of the facility. The investigation will also consider the common barriers restricting their inclusion, of paramount importance is the inclusion of Sustainable FM at the briefing and design phases of construction. The research focuses on the attitudes of different professionals and informs the industry of the potential benefits of sustainable FM and barriers restricting their inclusion within the early phases of construction.

The performance of the construction industry within the UK has been recognised considerably for its poor performance and the production of buildings that present high end-user dissatisfaction. Therefore, change within the industry is required to meet the needs of the end-user and provide a more sustainable facility. The history of the industry and its performance has been an essential research topic in understanding the current shortfalls of construction and will be discussed within this chapter.

Objectives

The aim of the work is to investigate the inclusion of Sustainable FM at the briefing and design phases of construction. The research focuses on the attitudes of different professionals and informs the industry of the potential benefits of sustainable facilities management and barriers restricting their inclusion within the early phases of construction. To achieve the aim; the objectives of the research are as follows:

- To explore the sustainability agenda and the implication for the construction industry.
- To establish a criterion for sustainable FM and the extent to which it can be used at the briefing and design phases of a new building, along with its benefits and potential barriers.
- To examine the potential knowledge chasm between different professionals regarding Sustainable Development and FM.
- To establish whether FM at the briefing and design phases of construction is a possible route towards sustainable development and meeting end-user requirements.

The research has been designed in three stages. The first stage uses a comprehensive literature review to understand the background to the theory surrounding sustainable development, the construction industry and FM.

Using the knowledge from the literature review, two structured questionnaires were sent to a sample of construction professionals and analysed accordingly to empirically understand the subject under research. The first questionnaire was distributed mainly to the FM professional via the British Institute of Facilities Management (BIFM). The secondary questionnaire which was structured in a similar format to the first questionnaire, further probed industry professionals regarding their attitudes towards the practice of sustainable FM at the design phases of construction. Potential barriers will be identified for their lack of inclusion within design.

Background

The Construction Industry

Since the 1940's, the construction industry has been continually pressured to improve its practices, sustaining criticism for its less optimal performance by several government and institutional reports. Most conclude the fragmented nature of the industry, lack of co-ordination and communication between parties, informal and unstructured learning process and lack of customer focus inhibits overall performance (Barrett 2008).

Construction accounts for over 4.5% of employment within the UK (Dainty *et al.* 2007) warn those that choose to work in the industry experience environments characterised by structural fragmentation with wide diversity of employment practices and an endless succession of short term projects. Each project is different in terms of both the product and the people involved. Diverse groups of people are expected to readily establish co-operative working relationships while engaged on different terms and conditions (Dainty *et al.* 2007).

Four main professional groups play a vital role in construction projects. These include Architects, Engineers, Quantity Surveyors and Construction Managers. Fragmentation exists in the division of responsibility between the professions, professionals and contractors. These groups usually operate outside construction firms as independent consultants generating a high degree of misunderstanding and hostility (Morton 2008). These conditions are the basis of the adversarial culture between contractors, sub-contractors, suppliers and their clients.

Fragmentation of the industry has stifled value for money as each party wants to meet their own goals and priorities. Each party will have their own agenda and will mobilise their resources, knowledge and practices, as part of the project, to meet their interests. These interests are mainly financial to achieve a competitive edge over their competitors (Elmualim *et al.* 2009). The goal within construction is to deliver a well designed, quality product to meet clients' requirements, on time and within budget (Adamson and Pollington 2006). However, this is rarely the case.

The evolution of the industry

Construction has for centuries been the work of independent craftsmen working for a client. New forms of construction have required new organisation to cope with massive demand, such as the organisation of the process by the general contractor. Today, the industry relies heavily on subcontracting which has prevented effective teamwork and communication between the parties to a construction contract. Demand is very different to other industries as clients define their requirements and the building is built to their specification (Morton 2008).

Design Status Quo

"The industry continues to design resource inefficient buildings, utilising polluting materials, overspecifying inefficient equipment, with poor attention to long-term communities" (Halliday 2008). The problems of poor industry performance can be associated with the common model for UK construction. The client commissions an architect who designs and then builders are found to build (Layard *et al.* 2001). The architect then relies on the services engineer to make them habitable (Turrent 2007). Although there has been a shift towards construction managers taking control of the whole design and build process, work is still predominantly based on this common model. Issues of buildability are restricted at the design stage which inhibits speed, effective learning and cost control. Cost saving has dominated the construction industry's decision making which does not always provide value (Halliday 2008).

The traditional design method of construction gives little thought to the operational phase particularly from sustainable design point of view *(*Sassi 2006)*.* The client finds it hard to imagine how they or the end-users will operate within a building. Without engaging the end-user, the creative design process is lost, which often leads to long term dissatisfaction. A common industry complaint is that members of design teams act independently of each other or may act against each other (Blyth and Worthington 2001).

The need for change

Clients and end-users argue a building takes too long, costs too much or is of poor quality standards. "Why when so much has changed has so much stayed the same?" (Morton 2008). The most documented examples include the early reports by Sir Michael Latham titled 'Constructing the team' and Sir John Egan titled 'Rethinking Construction' which both demand the ultimate goal of further satisfying clients' requirements. The Latham report of 1994 aimed to make the customer the leader of the process. Prior to the 1990's, he saw the industry as fragmented and hierarchical with a reluctance to introduce innovative solutions to customers' requirements. Clients did not always get what they asked for. Recommendations aimed to align the design function with the interests of the client, with particular regard to the organisation and management of the construction process (Adamson and Pollington 2006). Latham gave a significant role to clients in promoting good design to provide value for money in terms of both cost and cost in use. A well designed building may not require a high level of specification, yet many buildings in the UK are over specified at an unnecessary cost. Problems emerge through lack of co-ordination between design and construction (Latham 1994, Egan 1998).

Following the substantial critique of the Latham report, the Egan report of 1998 proposed a change revolution. There was deep concern that the industry was under-achieving in terms of meeting its own needs and those of the client. Egan found there were too many clients that still equate price with cost driving them to select designers almost exclusively on the basis of tendered price. The drivers for change include:

- Committed leadership of management to drive improvement.
- Customer focus and end-user value.
- Drive quality through innovation, on budget, on time, reduce wastage, after-sales care and reduced operational costs (Egan 1998).

A fundamental shortfall in the industry is the separation of design from the project process which results in poor building performance in terms of flexibility in use, operating and maintenance costs and sustainability. Designers must work in close collaboration with other participants in the project process and design for whole life costs. However, the same problems can still be observed today, well over ten years after publication. Inefficiency and waste accounts for almost 30% of the capital costs of construction and much of this could be avoided through co-operative working (Laud 2008). Design is still fragmented from the construction and operational phases and buildings are not performing to their intended outputs. This fragmentation inhibits performance improvements and prevented continuity of teams that are essential for efficiency (Egan 1998).

The shortfalls of the UK Construction Industry require significant changes in culture, attitudes and working practices. The trend in construction procurement is to move away from fee competition towards a selection process based on the balance of quality and price. Competitive tendering based on lowest cost could become a thing of the past (Nicholson and Quentin 2005). Collaboration throughout the construction process is becoming essential.

A holistic view of construction taking into account design and construction, management of the facility and demolition should be used (Martin and Guerin 2006, Duffy 2000). This idea can be orientated towards the primary objective of creating and sustaining appropriate built environments for users. This requires a shared vision amongst key stakeholders for maximising value across the life-cycle (Barrett 2008). The conventional construction process is generally planned, designed and constructed; which often acts as a barrier to utilising the skills and knowledge of suppliers and constructors effectively in the design and planning of projects (Egan 1998). He went on to state successful building requires the close involvement of the client as it is the client who knows what they want and produce buildings that will meet occupational needs into the future. The requirements of the end-user also need careful consideration.

Construction Briefing and Design

The importance of good design

The design of a facility must consider the needs and requirements of the end-user to meet organisational requirements. It is primarily in the early stages where a project team fails, due to the difficulties in appreciating the complex technological interrelationship between elements, systems and components used in modern buildings (Clements-Croome 2004). Design decisions should not be limited to one person, but involve a number of professions to consider all possible outcomes. It is important to get the design right as more can be done to enhance value and meet the needs of end-users. Design decisions should focus on the end-product (Atkin *et al.* 2003). Class (2008) calls for extensive communication between building design and construction, and maintenance. If a building costs £10million to construct, then in 20 years the building will have cost £20m to operate and maintain. Other debated ratios include 1:5:200 where for every one pound spent on design and construction there are £5 spent on maintenance and £200 on the running cost of business. Therefore, design is the most crucial stage in the process and should have scope for adaptation throughout the construction stage. Most of the effort in construction is in reducing the 1, but designers need to reduce the 5 and 200 through good briefing and design (Macmillan 2004).

Briefing is the process by which options are reviewed and requirements of the client are articulated to produce a brief which will form the design of the building. As users have become more demanding, the brief has become essential for Architects to design what the customer actually wants, rather than what the designer thinks they want (Fisher 1986). Flexibility and suitability of building design is currently under scrutiny (Spedding 1994), designing within the parameters of the brief is essential.

Deciding on a final design before fully assessing client and user needs and problems may prove very costly (O'Reilly 1987).

Common problems of meeting end-user needs

If design can have such an impact on functionality and satisfaction, why is the design phase of construction not becoming more advanced to meet end-user needs? Designers have two clients; clients who pay for what is built and clients who will eventually use it. The user client has little choice or control which presents designers with a problem. When users are unknown, designers tend to make assumptions as if they were users (Blyth and Worthington 2001). Therefore, this lack of knowledge regarding the eventual use of a building can severely reduce the effectiveness of the design by the architects. Clients can often find that they are expected to have far greater knowledge and understanding of construction and the implications of what will be built, than they actually do. The clients' expertise is in their business and not within delivering buildings; they rely on the designers and contractors to provide a delivery service that will support business needs (Blyth and Worthington 2001).

Facilities Management (FM)

The FM profession is a relatively new phenomenon yet potentially can bring a number of benefits within the UK construction industry. A definition of FM is required to fully understand these benefits, especially at the briefing and design phases of construction. Their impact within the industry will be considered after the initial introductory information has been presented. The ideas of Sustainability and FM will be discussed in Chapter Four. FM has seen rapid growth during 1990. There is an increasing tendency for organisations to contract out non-core business activities in order to provide the best service at the lowest cost (Shah 2007, Barrett and Baldry 2003). There remains a number of differing opinions of what FM actually is although the most widely accepted concept is provided by the BIFM (ratified by BSI British Standards):

"Facilities Management is the integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities" (BIFM 2008).

The foundation of FM is based upon integration of the planning and management of a range of hard services (e.g. building fabric) and soft services (e.g. catering, cleaning and security) to achieve quality and economies of scale. "FM is concerned with managing not just the building structure but the facilities that are also provided within the structure in order to improve the overall value for money for the client" (BIFM 2008).

Shah (2007) highlights the main FM service categories which are as follows:

- Cleaning
- Data Management and IT
- Building Management and Maintenance
- Ground Management and Maintenance
- Security
- Procurement
- Project Management
- Health and Safety

These categories show the diverse range of services FM can be involved in and the possible efficiency benefits regarding the effective management of each. As an example, building maintenance can affect the longevity of the components within a buildings fabric of services. Inadequate maintenance could result in a costly refurbishments/replacement and reduced employee well-being. These vast competencies of what FM are involved in reflects on the lack of widely accepted definition of the profession.

"Facility managers are people who are actively involved in managing the delivery, operation, maintenance and disposal of their organisations facility or facilities. Many FMs have migrated from building-related professions such as architecture and engineering" (Moller and McCartney 2007).

FM is based on the premise that the effectiveness and efficiency of an organisation is linked to the physical environment in which it operates (Barrett and Baldry 2003). Most FM operations occur at the operational phase of a building lifecycle to ensure the organisations' buildings and infrastructure support business goals. Businesses that can run its facilities more efficiently will have a competitive advantage as well as the possibility of improving its profitability (Leifer 2003). Users and occupants of a building are concerned with getting their work completed with the minimum of disruption. FM provides a service to enable users to get their jobs done and must interact with the client for continuous improvement (Blyth and Worthington 2001). Duffy (2000) claimed the discipline has developed, although cost cutting seems to have become the predominant objective and distinguishing feature of FM in practice.

"The expertise of the FM profession can contribute to almost every stage of the procurement process and hence the final product in an economic, social and environmental sense" (Hadi *et al.* 2006). By moving away from the operational phases of a facility and understanding that little is known regarding a buildings eventual use pattern at the design stages, FM can inform the process of briefing and building design (Clements-Croome 2004). This investment at the design phase can deliver significant benefits in use including minimised capital cost, maximised attributes that contribute to better business operation and minimised financial drain over the life cycle of the building (Halliday 2008). The building can be specified to meet the end-users' core business activities.

Facilities Management and Building Design

Shah (2007) illustrates when the operational performance of a building is not met, whether this is due to the designers not fully understanding their remit or the operators not having the ability to manage the facility, it is the occupants and finances that suffer. Shah (2007) gives the possible reasons for poor design as follows:

- Inadequate communication through the delivery of a facility where the client requirements are not included within the final designs or the FM is involved at a late stage.
- Different agendas of the parties where the client brief does not always capture end-user requirements or the architects design without end-user input.
- Decisions made without the view of long-term maintenance.
- Minimal design timescale results in rushed decisions and fast handover

FMs arguably have the greatest knowledge of facilities in operation and can inform the design of a new building of the end-user requirements. However, there is a tendency for those concerned in running the building not to talk to those who design and provide them (Halliday 2008). The FM must aim to have direct involvement with the Client, Architect and Project Manager to provide operational knowledge at an early stage. Designers need to understand the way people operate in buildings, the way in which they are used and the ways in which their performance and productivity can be maximised to the benefit of the organisation and society at large. Facilities Managers have a great role in advancing sustainability agenda through the continuous practice of sustainable FM (Elmualim *et al.* 2009; Atkin and Brookes 2005).

Methodology

Methodology is a set of working methods and can be defined as a body of practices, procedures and rules used by those who engage in an enquiry. Research has a number of characteristics where data is collected and interpreted systematically with a clear purpose to finding things out. Systematic research is based on logical relationships and not just beliefs with the requirement of a clear purpose (Saunders *et al.* 2003).

Inclusion of both existing data and analysis of new data of a particular set of circumstances forms the basic philosophy of this chapter around interpretivism (Bryman and Bell 2007). The literature was evaluated for its relevance to the research question and the key objectives (Saunders *et al.* 2003). The topics the research was based around include:

- The history of the construction industry, exploring the continual critique from government bodies and environmentalists of poor performance.
- The definitions of FM as a profession along with the roles it encompasses and its relation to construction.
- Sustainable development in the UK and the implications for construction.
- SFM and its contribution to sustainable development in the construction industry.

The advantages of such research are directly linked to the unobtrusive nature of the information along with the possibility of providing comparative and contextual data. The explorative research philosophy requires the search of literature and the talks with experts surrounding the subject (Bryman *et al.* 2007).

Questionnaire one (called BIFM annual survey) was conducted in May 2008 and was distributed widely to the members of the BIFM. The aim of the questionnaire was to collect data regarding the existing level of sustainable knowledge within the FM industry. The survey attempts to find the level of responsibility that FM have within their organisations and the changes required to achieve Best Practice sustainability. While the questionnaire was distributed widely, 168 responses were received.

A second questionnaire was prepared within the parameters of questionnaire one. Comparisons can be made between both sets of data as the design of this questionnaire followed the same parameters as the first survey questions. These were adapted to meet the aim of the research in finding potential barriers restricting the inclusion of FM within the design of new buildings. A representative sample method was primarily chosen for the respondents to have similar characteristics to the population as a whole (Oppenheim 1992). Cluster sampling techniques divided the population into a number of professional units to acquire knowledge from different professions. The system of drawing a sample was crucial as its accuracy is more important than its size (Oppenheim 1992). The questionnaire was piloted prior to electronic distribution to industry professionals. An internet based survey was used for efficiency on the basis of time and costs of posting to respondents. Non-response is inevitable for such surveys and re-administration of the questionnaire to additional organisations was required along with direct contact to prompt questionnaire completion. This increased the level of response. A total of 180 questionnaires were sent to potential respondents (60 in each cluster category). Non-response levels prompted the re-sampling of a further 60 organisations (20 in each cluster category). Reminder e-mails to organisations within the original sample increased the overall response. Responses were selectively analysed in comparison charts and tables to highlight differences in knowledge and opinion regarding sustainable FM.

Both questionnaires incorporate the opinions of FM, construction managers (CM), quantity surveyors and architects. Although open and closed questions were used, most respondents used the pre-determined answers when giving feedback. Questionnaires provide low cost data collection and processing with the ability to reach respondents who are widely dispersed. The sample used organisations throughout the UK for a full analysis of all situations. However, the problem of low response rates was encountered with a lack of opportunity to probe for further detail from the respondents. To make a full enquiry of the views of each profession and cement the conclusions from the survey, interviews were also used as a method within the research design.

Limitations

The control of information was successfully implemented by restricting questionnaires and interviews to a certain group of professionals and academics specialising in areas of work previously mentioned. The sourcing for the first questionnaire was limited to members only within the FM field. As this questionnaire did not contain a question regarding the respondents' profession, it can only be assumed that all respondents were FM. There are risks of bias from the respondents as they are already aware of the BIFM with their continual drive to Best Practice with regard to FM, and were self-selecting. These members could have a higher level of understanding of sustainability issues which may skew the investigation. The second questionnaire used a different sampling approach and spilt the constituents of professionals involved within the construction process into three main categories; Architects, Construction Managers and Quantity Surveyors. This was essential for the direct comparison of opinions and highlights a potential knowledge chasm regarding sustainability. However, these respondents only represent a small number of construction professionals in the process and may not give a holistic view. Time and costs limitations restricted the questioning of a larger number of clusters in the sample.

Results

In questionnaire one (BIFM Questionnaire) the total number of respondents was 168 FM, a large proportion are members of the BIFM (92% have BIFM membership of some form). The 17% associate level of membership requires no level of qualification or experience in FM, whereas other forms, such as Fellow Members requires experience. The level of membership raises the question of whether the results are skewed in favour of those already aware of the BIFM. The majority of respondents are members of end-user organisations with full in-house facilities management (63%).

For questionnaire two (Construction Questionnaire) there were only 21 respondents, over half were practicing as Quantity Surveyors. Questionnaire two included an FM category as a precautionary measure and, therefore, this category will be discarded throughout the analysis. The 'other' category included professionals from Construction Environmental Management and Civil Engineering Contracting.

Sustainability Policy and its Aspects

Figure 1 shows the varying levels of sustainability policy between the professional organisations. Of the 168 respondents to the BIFM survey, 73% of respondents have a sustainability policy implemented within their organisation (Figure 1) which highlights the growing importance of sustainability issues in the FM profession. A lower proportion of construction organisations (67%) have a sustainability policy. However, the poor performance of the construction industry which has been highlighted in the literature review does not match this level of sustainability policy. Therefore, the analysis of the comprehensiveness of these policies will show what organisations define as sustainable. There are many definitions of sustainability, but little information on how to apply it in practice.

Figure 2 highlights the differences in the aspects covered by an organisation's sustainability policy between the two questionnaires. The respondents to the BIFM questionnaire range mostly between Government, Financial and Business services, and Health and Educational organisations. The top three aspects of Waste Management and Recycling, Energy Management and Health and Safety remain proportionally the same for a large proportion of the organisations in both surveys. The importance of these can be linked to the high legislative drivers for these aspects within the UK. Governments at both national and international level are using regulation to reduce carbon emissions and manage demand with much of the burden needing to be picked up by FM (Leifer 2003).

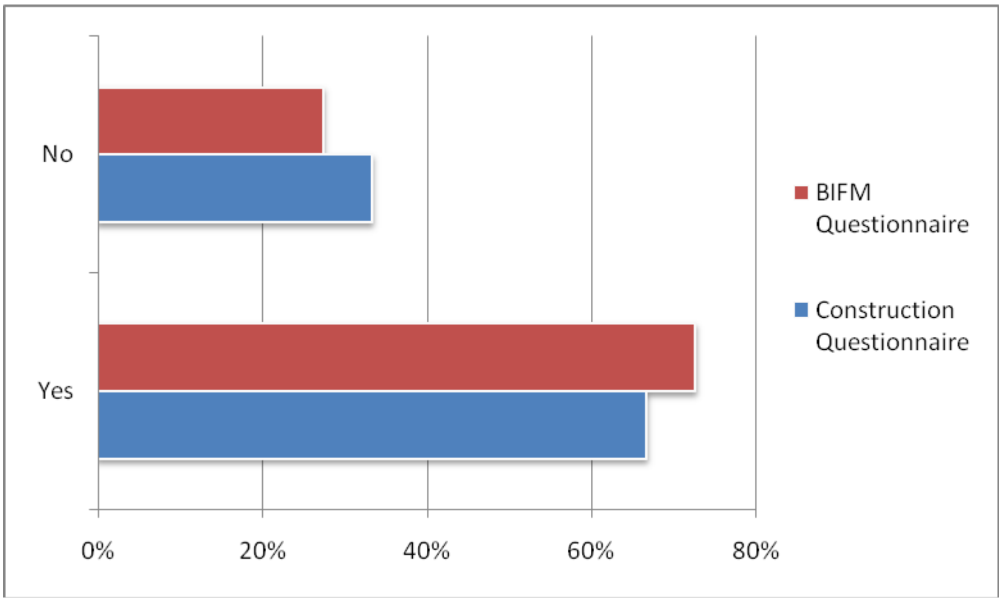

Figure 1. Questionnaire one and two: Does your organisation have a sustainability policy?

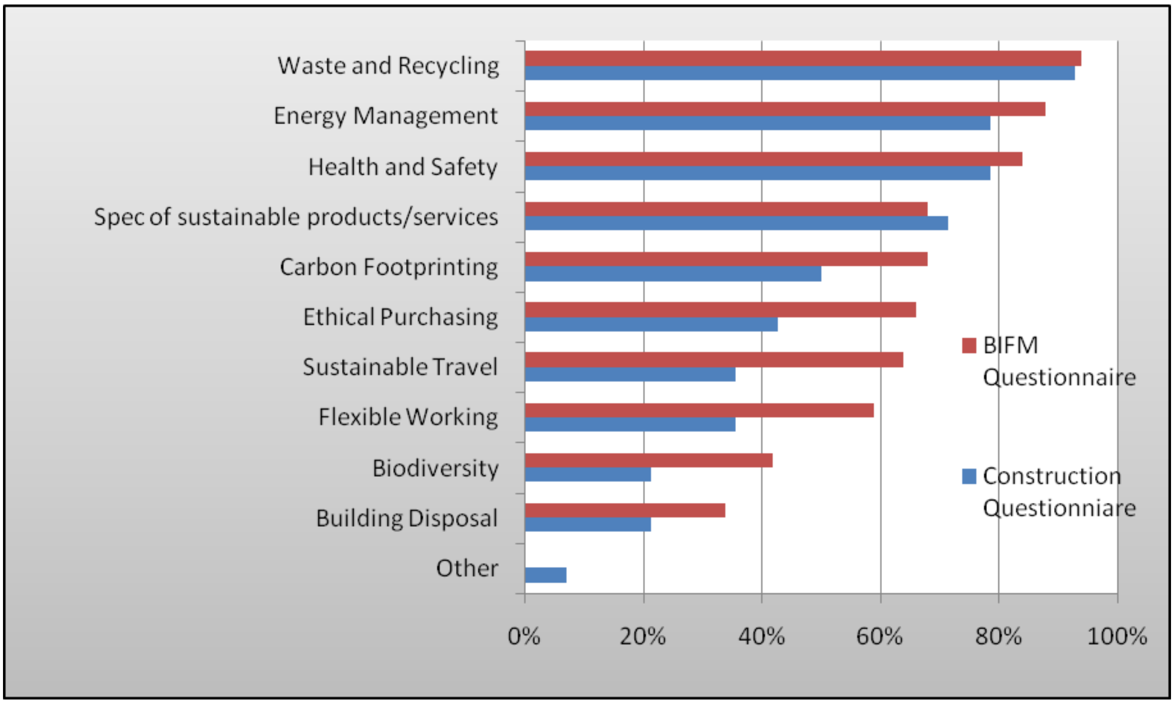

Figure 2. Questionnaire one and two: What aspects are covered by your sustainability policy?

The comparison of both surveys highlights the significance of all construction organisations having fewer aspects covered within their sustainability policies. However, the sequence of importance of each of the aspects is similar. 71% of construction organisations in Figure 2 include the specification of sustainable products and services within their sustainability policy, which is significantly higher than the 64% in the FM survey. All other aspects are lower amongst construction organisations which include building disposal and carbon footprinting. These results show the possibility that organisations with FM departments or organisations that provide FM services implement more comprehensive sustainability policies. The wide range of aspects selected within each graph shows the lack of recognition of what sustainability actually is and how it should be implemented or applied in practice (Sassi 2006).

Sustainability Drivers and Management

When considering the drivers for organisations to implement sustainability, the stakeholders an organisation reported to will give an insight into these drivers. Stakeholders are having an increasing influence on organisations by requesting them to move towards managing their effects on the environment and society, and publicly. Figure 3 highlights a significant proportion of construction organisations that do not report to any particular stakeholder (43% in comparison to 11% from the BIFM survey). The smaller number of aspects covered by an organisations sustainability policy within the construction industry can be linked to the lack of stakeholder significance. Of the remaining construction respondents, most report sustainability to their clients and customers along with a greater significance towards government and local community stakeholders. The level of customer/client reporting within both questionnaires could highlight the drive for better practices or the importance of sustainability for marketing. How companies perform on sustainability is an important factor for external stakeholders since they are affected by corporate strategies and actions (Atkin *et al.* 2005).

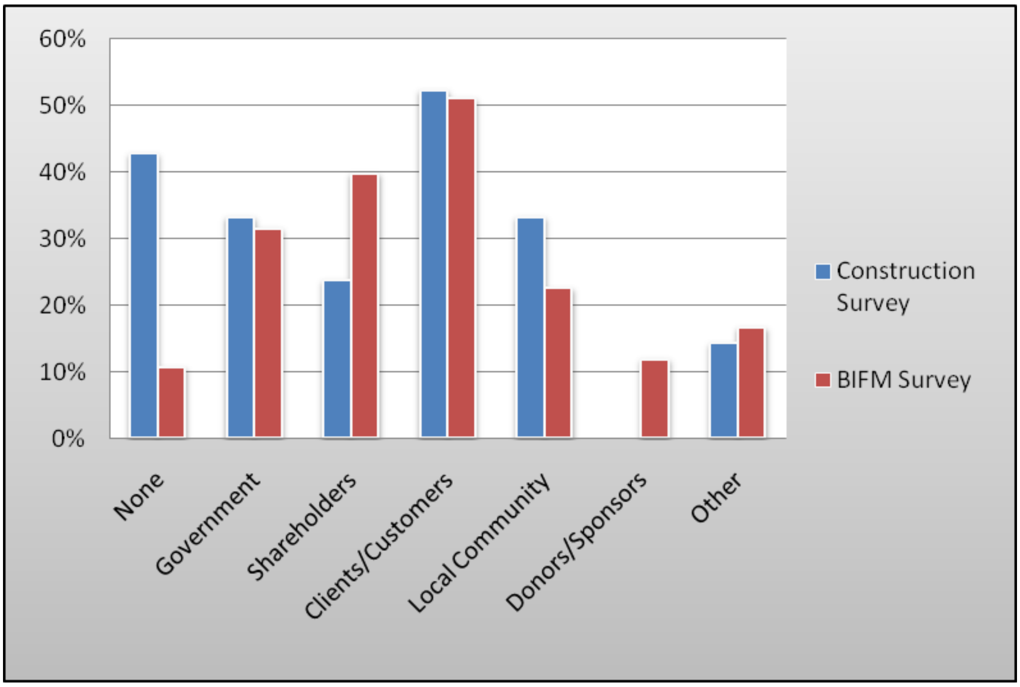

Figure 3. Questionnaire one and two: Comparison between stakeholders reported to

Both surveys questioned the respondents' opinion of the effectiveness of their organisations management of sustainability responsibilities (Figure 4). The opinions of the construction professions range from inconsistent to very good, with no response relating to poor management, although there is a 38% level of inconsistency. The results do not coincide with the comprehensiveness of the construction organisations sustainability policies and can be linked to the lack of understanding of what sustainability actually is and how it is implemented. FM can be assumed to have more active management in the sustainability activities of an organisation due to their link with non-core activities which would give a more accurate description.

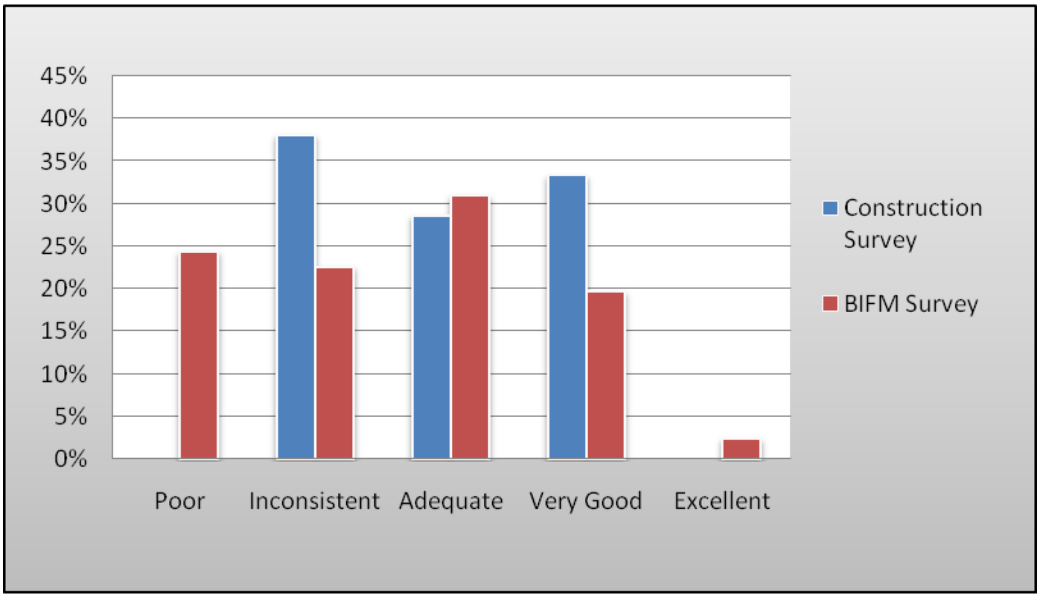

Figure 4. Questionnaire one and two: Comparison between the organisations management of sustainability responsibilities

The results showed that 76% of FM have some level of formal or informal management of sustainable activities. 16% of FM respondents have no management responsibility regarding sustainable activities of their organisations. This figure is less than the number of respondents who rated their organisations as either inconsistent or poor in terms of managing their sustainability responsibilities; whether this is due to them not having full remit over those responsibilities, experiencing hindrance in that role or rating their own performance as badly is uncertain. There is also a link with the level of responsibility of the FM and the barriers preventing effective management of sustainability responsibilities. Greater levels of FM responsibility result in fewer barriers to effective sustainability management, especially when assigned to dedicated staff/teams. Formal management of sustainability reduces barriers and increases organisational sustainability management effectiveness.

Barriers to Effective Management of Sustainability

The organisations responding to the BIFM questionnaire regard financial constraints (40%) as the biggest barrier along with time constraints (38%) and lack of senior management commitment (37%) ranking highly. Many organisations still regard sustainable activities as cost overheads rather than calculating the benefits of efficiency. FM professionals are often at a low level in the organisational hierarchy and require senior management commitment to implement new working technique and ideas. Customer constraints and lack of tools are not regarded as significant barriers within the respondent organisations. Lack of knowledge and training of the FM are significant barriers and ones that should be overcome with better education and stronger sustainability goals.

Figure 5 highlights construction organisations as having significantly higher percentages in most categories. This shows the increased barriers within the construction industry. Time constraints are the most significant barrier within construction firms (67%) along with customer constraints (57%) and financial constraints (52%). In comparison, the organisations responding to the BIFM survey gave results of 38%, 14% and 40% respectively. This links with the customer orientation of the industry where the client demands a bespoke product which must be provided within the period of time stated by the contract and within the budget set upon tendering. New initiatives such as sustainability in construction would experience similar limitations. Lack of awareness of the parties involved features in low proportions to other barriers. These respondents also lack the knowledge and training required to effectively manage sustainability. As there is no clear definition of what sustainability actually is or how to implement it, there is widespread debate on what organisations should be doing to achieve it. This theory links to the barriers and the range of aspects within organisations sustainability policies.

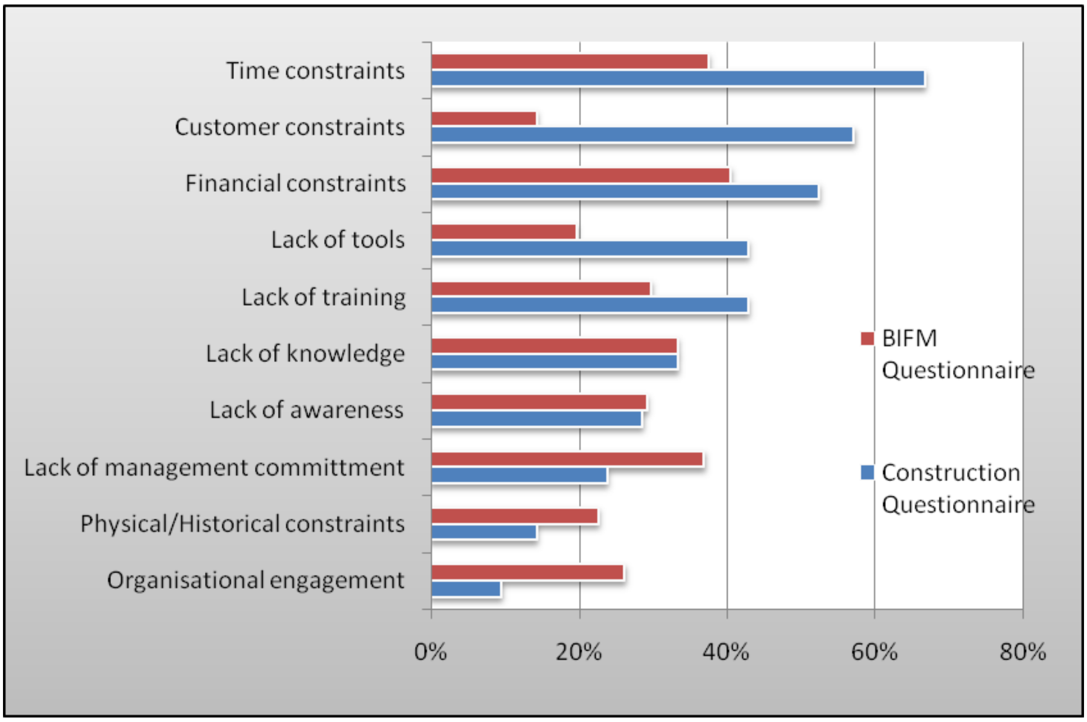

Figure 5. Questionnaire one and two: Comparison between the Barriers preventing effective sustainability management

Sustainable Facilities Management

With the aim to extend the data collection of the BIFM survey, a separate section was included within the construction questionnaire regarding the inclusion of FM specifically at the design phases of construction projects. This builds on the information found within the literature review. The result highlighted that just 14% of construction organisations have an FM department within their organisations. The low percentage of firms with an in-house FM department in comparison with the 63% of organisations in the BIFM questionnaire shows the lack of their inclusion within construction firms at business and project level. Construction has been identified to be unwilling to accept the new profession into its operations which can be directly linked to this result. However, organisations may use an outsourced FM service which means they are utilised within the organisation but not a department within the firm.

The literature review highlighted an advantage of FM within construction by presenting designers with the knowledge of the end-user. The questionnaire therefore relates this theory to the knowledge of construction professionals in the process. Figure 6 shows 38% of all respondents had little or no opinion on the topic. This can be linked to FM at the design phase of construction being new practice which is rarely implemented. This links with the low percentage of companies with an in-house FM department identified in Figure 6. 39% of construction professionals either strongly agree or agree that FM involved within the design of a new building ensures it meets the needs of the end-user with 24% disagreeing with this theory. The organisations with an FM department also disagree.

FM has been identified to provide end-user knowledge to the construction process, but a significant barrier in the construction process is identifying who the end-user will actually be in the future. The client is rarely the end-user but is the party who will finalise the design of a new building. Shah (2007) also raised the question as to whether the FM actually has enough knowledge of the end-user to inform the design and construction processes.

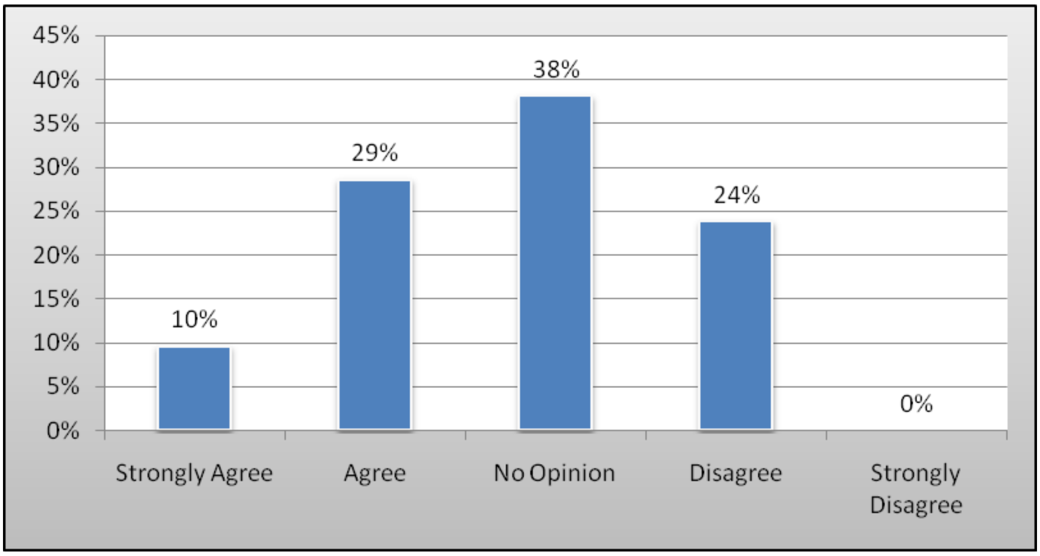

Figure 6. Does FM ensure the design of a new building meets the needs of the end-user?

The literature review highlighted the importance of the brief within the early project stages and the challenge when the end-user is unknown at the time of design. 81% of all respondents from a construction background claim that the knowledge of FM is not utilised at the briefing and design phases. Interestingly, FMs are said to be able to inform the construction process of end-user requirements and therefore present advantages to the process. Therefore, their lack of integration must be linked with the barriers. 39% of respondents agree that the FM can ensure the design of a new building meets the needs of the end-user, yet 81% highlight that their knowledge is not utilised.

To understand the barriers restricting the inclusion of FM at the briefing and design phases of a construction project, the questionnaire administered to the construction industry included this parameter. Figure 7 shows the top three barriers within the questionnaire include client constraints (67%), lack of awareness of the parties involved (52%) and lack of knowledge (48%). The question included an open ended section to answer other possible barriers. The lack of information provides the assumption that the main barriers fall around these key areas. Client constraints are at a significantly higher level than other results which can be linked to the barriers to effective sustainability management. Clients are the driving force within construction projects as they usually pay for the operations and require certain specifications and design levels, even if they are not the end-users. The lack of awareness of the parties involved can be linked with the lack of awareness of what FM and sustainability actually incorporates and how it can contribute.

The lack of knowledge of FM is a significant barrier which has been highlighted in much of the literature in the research, such as the work of Sunil Shah. This lack of knowledge can be focused around the lack of adequate knowledge of the construction processes, lack of knowledge of design factors and the lack of knowledge of end-user requirements. This can also be interpreted as the lack of knowledge of other construction professionals of the benefits the FM can bring at the design phases of construction. If the FMs do not have the knowledge of design and the requirements of the end-user, then their use within the early stages of the construction is severely limited and would provide little or no benefit.

Financial constraints are a significant barrier for 43% of the construction organisations responding to the survey. Financial constraints can be linked to the cost of the services provided by the FMs and the perceived added costs of changing the traditional processes. If the knowledge of FM is brought into the construction process from a service providing organisation, then there is a potential debate between the professionals. Will the added costs be picked up by the design team in which the FM is adding to the process or the client who is developing the new facility? Time constraints are significant within 24% of organisations and linked with the tight timescales within all construction projects and the limitation of including operational knowledge at this stage.

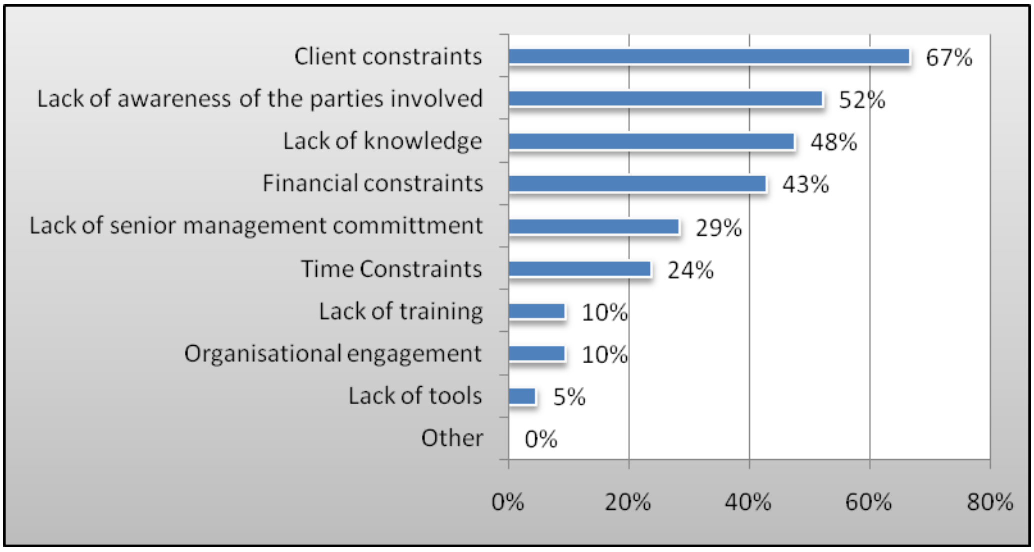

Figure 7. The barriers reducing the inclusion of FM in the Briefing and Design phases of construction

There is substantial literature highlighting how FM can implement sustainable solutions within buildings and how efficiency within buildings can be achieved through effective management of facilities. The maintenance of buildings will reduce the level of fabric and services replacement within these buildings and provide a design which will meet the needs of future users. However, whether this can be a reality within the construction industry is not highlighted within the literature.

Figure 8 illustrates the opinions of the construction professionals regarding whether FM can be a route to sustainable development. 76% of respondents agree with this theory. It can be assumed that this is the result if there were a reduction in the barriers to their implementation in the early phases of a construction project. Until the time, cost and knowledge barriers have all been reduced and awareness of the parties within a project regarding FM issues and benefits have been raised, then the potential of FM surely cannot be fully realised. Just 10% of the construction respondents disagreed with this theory. Based on these results, FM is a strong route to achieving sustainable development in the construction of new buildings and managing their decisions through the operational phases of construction projects. Organisations without a sustainability policy are the only respondents that disagree with the link between FM and sustainable development.

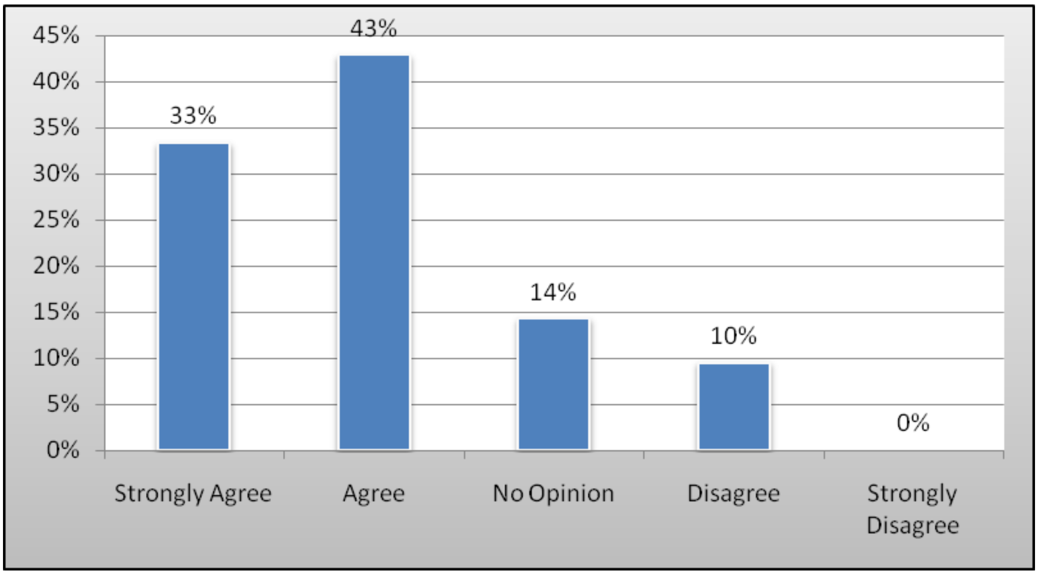

Figure 8. Is the integration of the FM at the Briefing and Design phases of construction a route to achieving sustainable development?

The knowledge of the construction professionals

The separation of the responses between each construction professional (Quantity Surveyor, Building Contracting and the Architect) will highlight differences in the opinions. As all of these professionals are included within a construction contract in the development of a new building, differing views may contribute to further barriers to the inclusion of sustainable FM at an early stage in the construction process as shown in Table 1. The table shows the top three/four barriers reducing the level of integration of FM at the early stages of a construction project. Lack of knowledge rates highly with both the architects and building contractors and can be linked to the knowledge of design, the end-user or management to implement it within a facility. Client constraints are the only top barrier to focus within each profession and are most important in 100% of the design/architecture organisations. This furthers on the focus of construction being around the client as they are the party who will finance the completed facility. Financial constraints also rate at a 100% level within design/architecture organisations which also links with strict budgets they must design within. Financial constraints rate highly with Quantity Surveyors as they understand the process of cost management on construction projects.

The design/architecture organisations are the only professional sector to agree the FM will ensure the design of a new building meets the needs of the end-user. Excluding 9% of quantity surveying respondents, all major respondents agree that the inclusion of FM within the design of a new building is a route to achieving sustainable development. These differing views of the professionals within construction show a knowledge chasm between what can be achieved by including the FM in design. Unless all parties to a contract can agree, then the client is unlikely to be influenced and the barriers will remain.

Table 1. The main barriers reducing the level of FM integration at the briefing and design by profession

	Quantity Surveyors	***Building Contractors***	***Architects***
1	*Lack of awareness*	*Lack of awareness*	*Client Constraints*
2	*Client Constraints*	*Client Constraints*	*Financial Constraints*
3	*Financial Constraints*	*Lack of Management Commitment*	*Lack of Knowledge*
4	*Time Constraints*	*Lack of Knowledge*	

Conclusions

Construction is a fragmented industry, due to its nature as a project delivery industry. Furthermore, the industry has a huge impact on the environment. It is therefore well positioned to leverage the sustainability agenda. The current literature highlighted an abundance of industry criticisms regarding its poor performance, lack of co-ordination, communication and learning processes. The goal of the industry is to deliver well-designed, quality products to fully meet client requirements on time and within budget. This severely clashes with the critique of the Latham (1994) and Egan (1998) reports which highlighted the lack of co-ordination between the design and operational phases that often does not provide value to the end-user. A holistic view of construction is required to provide value throughout lifecycle of project.

Two questionnaire surveys were conducted to evaluate the drivers and barriers for the practice of integrated sustainable design and FM. The research showed the overwhelming fragmentation of interests that currently exists within construction and provides little value to the client/end-user. The results showed that construction professionals agree to a large extent that FM will ensure the design of a new building meets the needs of the end-user. However, a significant barrier within construction is identifying who the end-user will be. The barriers reducing FM inclusion in briefing and design include client constraints, lack of awareness of the parties involved and lack of knowledge. Clients are the driving force within construction and therefore represent the largest barrier. A large proportion of construction respondents state that the knowledge of FM is not utilised at the briefing and design phases. Over three quarters of respondents highlight the inclusion of FM in the design and construction processes as being a route to achieving sustainable development. However, status quo for integrated sustainable design and FM remains the same as future aspirations. This has a direct consequence on the provision of sustainability education and training within the industry. For the construction industry to leverage the sustainability agenda, there is stringent need for sustainability education and training programmes in the Built Environment to be developed to provide effective structures and processes for the integrated sustainable design and FM coherently, and as a common practice.

Acknowledgements

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Authors' Biographies

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A recent graduate at the University of Reading, **Marios Pastou** studied BSc Quantity Surveying on a full time programme. He was involved in the SEED programme at the University where students have the opportunity to undertake project-based assignments in conjunction with external organisations. He worked with the British Institute of Facilities Management (BIFM) project in partnership with the School of Construction Management and Engineering at the University of Reading. The goal was to investigate the impact of the BIFM in implementing Sustainable Facilities Management services across a number of different industries. He is currently working for Rider Levett Bucknall as a Cost Manager. RLB is a global property and construction practice which provides Cost Management, Project Management and Advisory Services. His specialism is within the retail sector and work in conjunction with Tesco Property Services to assist the development of new stores, conversions and refurbishment of existing stores. To date, He has assisted in the value engineering process of new and existing Tesco stores along with the cost planning of the roll-out of new sales floor area in the UK.

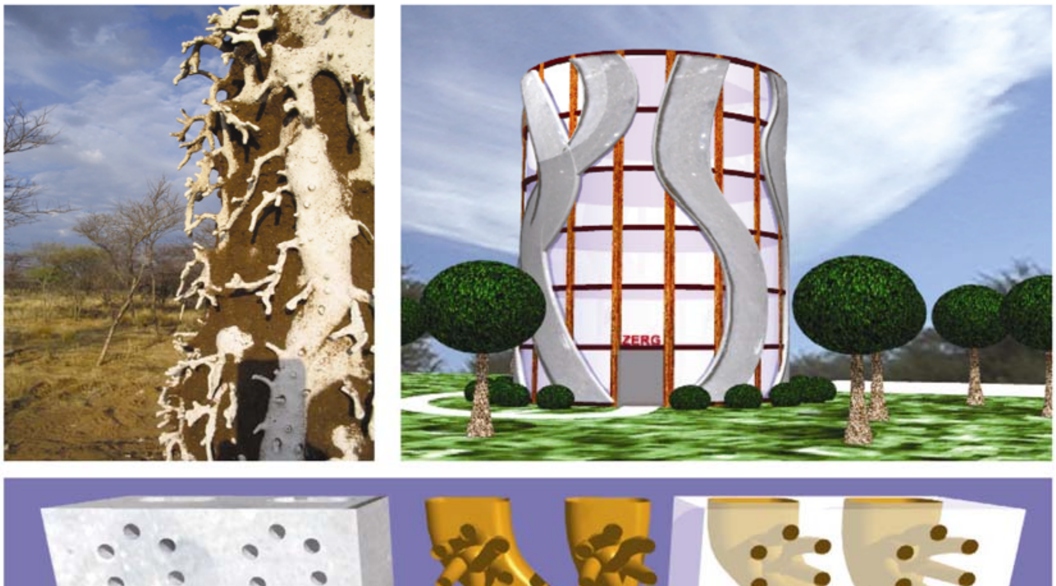
Roberto Valle is a Research Associate in a joint project between the British Institute of Facilities Management and University of Reading. He has a Bsc in Civil Engineering from the Catholic University (UNICA) from Nicaragua and Masters Degrees in Business Administration from the Technologic University of Monterrey (ITESM) from Mexico, and Renewable Energies from Reading University, Reading. Roberto's current research focuses on the development of tools aimed at improving the management of sustainable practices by Facilities Managers. He has a particular interest in sustainable development of rural communities in developing countries.

Michelle Aghahossein is an Engineer Doctorate student at the University of Reading and works at Halcrow Group Ltd as a Research Engineer. She graduated from the University of Surrey in Civil Engineering (BEng) in June 2009. She was awarded the ICE/UniS scholarship during her second year at the University of Surrey (in 2006). During her professional training year, Michelle worked for Systems Geotechnique company at the their A3 Hindhead site where she, as a site engineer, was responsible for controlling the quality of production, enforcing health and safety and managing the team on site. She also worked for Silvatec Ltd as a design engineer, designing timber frame houses, apartments and offices. These experiences combined with her special interest in sustainability and led her to complete her first class BEng dissertation about the viability of timber frame (as the most sustainable construction material) for student accommodation in Guildford.

15

Beyond Biomimicry: What Termites Can Tell Us About Realizing the Living Building

J Scott Turner and Rupert C Soar



Beyond biomimicry: What termites can tell us about realizing the living building

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Abstract

Termites and the structures they build have been used as exemplars of biomimetic designs for climate control in buildings, such as Zimbabwe's Eastgate Centre, and various other "termite-inspired" buildings. Remarkably, these designs are based upon an erroneous conception of how termite mounds actually work. In this article, we review recent knowledge of the structure and function of termite mounds, and outline how new biomimetic building designs could arise from this better understanding. We also suggest that the termite "extended organism" provides a model to take architecture "beyond biomimicry"—from buildings that merely imitate life to buildings that are, in a sense, alive.

Keywords: biomimicry, termite, Eastgate Centre, *Macrotermes*, termite mound, gas exchange, temperature regulation, homeostasis, rapid manufacturing, free-form construction, extended organism

Introduction

Since the mid 1990's, termites and the structures they build have inspired biomimetic designs for passive climate control in buildings. Our recent studies on the structure and function of termite mounds have revealed that termite mounds do not actually work in the way that architects and entomologists have long thought. The actual workings of termite mounds may, in fact, hold a much richer trove of "termite-inspired" designs than has previously been imagined. In this article, we review these recent discoveries, and offer some visions of new biomimetic building designs that could arise from this better understanding of the structure and function of termite mounds.

The Eastgate Centre. A biomimicry watershed

Harare's Eastgate Centre, which opened in 1996, deservedly stands as an iconic biomimetic building (Figure 1). Mick Pearce, the project's lead architect, wanted the building to reflect two tenets of his philosophy of "tropical architecture"—first, that design principles developed in the temperate northern hemisphere are ill-suited to tropical climes like Zimbabwe's; and second, that effective design should draw inspiration from local nature, which is rife with plants and animals that live there comfortably [1].

Where Pearce drew *his* inspiration was from the remarkable mound-building termites of southern Africa (Figure 1). These creatures are themselves architects of sorts, building massive mounds that in some instances tower several metres high. The mound is widely thought to serve as climate-control infrastructure for the termite colony's subterranean nest. Pearce reasoned that the architectural principles of the termite mound, honed to sleek efficiency by the relentless refining of natural selection, could inspire buildings that perform equally well. By all measures, his vision succeeded brilliantly.

For the past several years, we have been studying the structure and function of the termite mounds that inspired Mick Pearce. In the process, we have learned many things, among them something quite remarkable: the Eastgate Centre is modeled on an erroneous conception of how termite mounds actually work. This is not intended to be a criticism, of course: Pearce was only following the prevailing ideas of the day, and the end result was a successful building anyway. But termite mounds turn out to be much more interesting in their function than had previously been imagined. We believe this betokens expansive possibilities for new “termite-inspired” building designs that go beyond Pearce’s original vision: buildings that are not simply inspired by life - biomimetic buildings - but that are, in a sense, as alive as their inhabitants and the living nature in which they are embedded.

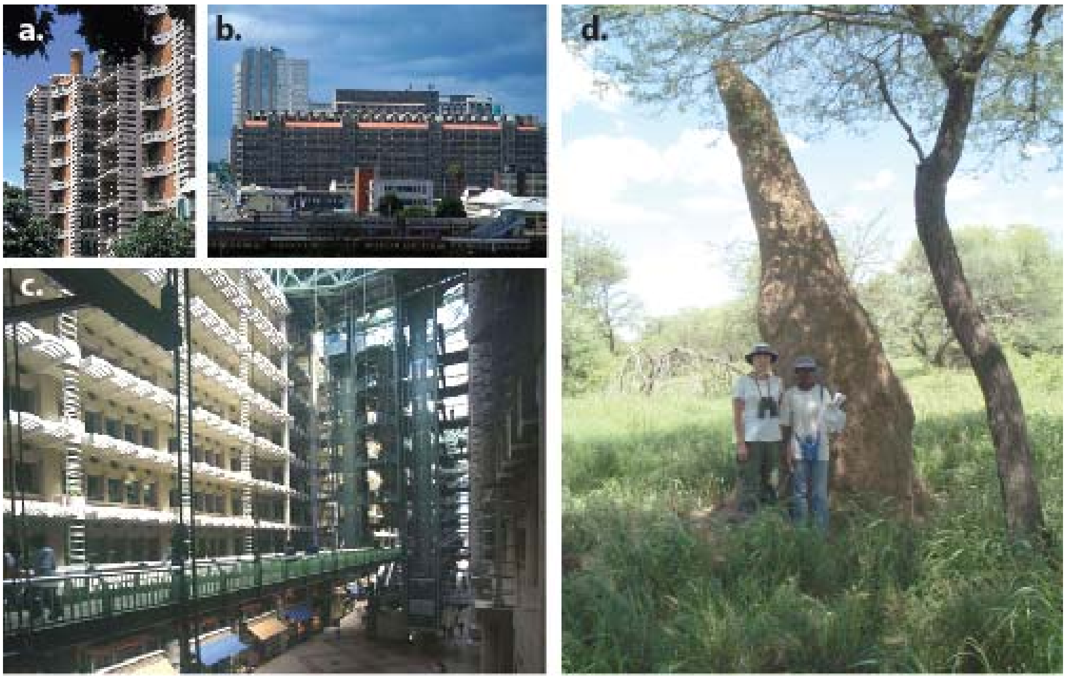

Figure 1. The Eastgate Centre and a *Macrotermes* mound. a-b: The exterior of the Eastgate Centre, showing chimneys along the roof[4]. c: The interior atrium of the Eastgate Centre[5]. d: A mound of *Macrotermes michaelseni* in northern Namibia.

How the Eastgate Centre is like a termite mound

If Eastgate was inspired by termite mounds, what precisely about them was the inspiration? This is not as simple a question as it might seem. Termite mounds are structurally diverse - some are festooned with one or more large vents, others have no obvious openings to the outside, and shapes range from cones to pillars to hemispheres [2-6]. Most biologists believe this structural diversity betokens a diversity of function [7]. As we shall show, this turns out mostly to be incorrect. What makes Eastgate all the more remarkable is that it melds many of these diverse, and in some instances contradictory, design features into a single, functionally coherent, building.

[4] www.archpaper.com/features/2007_14_imitation.htm

[5] http://blog.miragestudio7.com/wpcontent/uploads2/2007/12/eastgate_centre_harare_zimbabwe_interior_mick_pearce.jpg

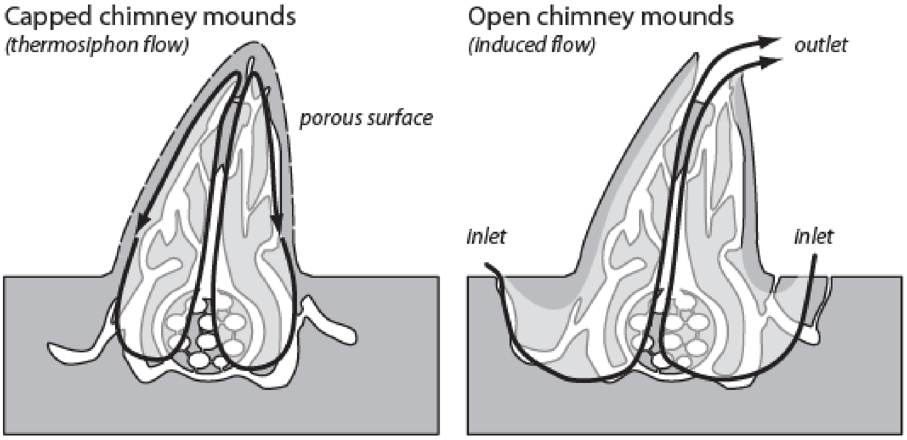

Figure 2. Two early models for mound ventilation. Left. Thermosiphon flow thought to occur in capped chimney mounds. Right. Induced flow thought to occur in open-chimney mounds.

The earliest model for termite mound function was Martin Lüscher's thermosiphon mechanism, in which the mound is a venue for metabolism-driven circulation of air [8]. Here, the colony's production of heat (roughly 100 watts) imparts sufficient buoyancy to the nest air to loft it up into the mound and to drive it eventually to the mound's porous surface. There, the spent air is refreshed, as heat, water vapor and respiratory gases are exchanged with the atmosphere across the mound's porous walls. Gravity acting upon the increased density of the refreshed air then forces it downward into open spaces below the nest and eventually through the nest again. This mechanism was thought to operate in mounds with capped chimneys, those that have no obvious vents.

The second model is known to biologists as induced flow [9-11], but it is probably better known to architects and engineers as the stack effect. This mechanism was thought to occur in open-chimney mounds [12]. Because the mound extends upward through the surface boundary layer, the large chimney vent is exposed to higher wind velocities than are openings closer to the ground. A Venturi flow then draws fresh air into the mound through the ground-level openings, then through the nest and finally out through the chimney. Unlike the thermosiphon model's circulatory flow, induced flow is unidirectional.

The similarities between the Eastgate Centre and termite mounds now become clear. The induced flow principle is implemented in the row of tall stacks that open into voluminous air spaces that permeate through the building (Figure 2). Meanwhile, heat from the building's occupants and machinery, along with stored heat in the building's thermal mass, helps drive a thermosiphon flow from offices and shops upward toward the rooftop stacks. In the climate of Harare, the combination provides for an impressive steadiness of interior temperature, accomplished without resorting to a costly and energy-hungry air-conditioning plant. This is where most of the building's efficiencies accrue.

How the Eastgate Centre is not like a termite mound

The design and function of the Eastgate Centre departs from termite mounds in some significant respects, however, and this makes for some interesting design anomalies.

One of the more interesting involves temperature regulation. In the architectural literature, discussions of the Eastgate Centre are often accompanied by encomia to the impressive thermoregulatory abilities of the mound building termites. A few quotes make the point:

> "The Eastgate building is modeled on the self-cooling mounds of *Macrotermes michaelseni*, termites that maintain the temperature inside their nest to within one degree of 31 °C, day and night … "[6]

[6] http://www.biomimicryinstitute.org/case-studies/case-studies/termite-inspired-air-conditioning.html

"Indeed, termites must live in a constant temperature of exactly 87 degrees (F) to survive."[7]

"Termites farm fungus deep inside their mounds. To do so, the internal temperature must remain at a steady 87 degrees F." [8]

"The fungus must be kept at exactly 87 degrees …"[9]

There is just one problem: at least in the nest of *Macrotermes michaelseni*, there is no evidence that nest temperature is regulated. Indeed, there is good evidence that it is not. In the subterranean nest of *Macrotermes michaelseni*, for example, while temperatures are strongly damped through the day, they also closely track deep soil temperatures through the year (Figure 3). Consequently, the annual march of temperature in the nest ranges from about 14°C in winter to more than 31°C in the summer, a span of nearly 17°C. Nor is there any evidence that mound ventilation affects nest temperature. In the nest of *Odontotermes transvaalensis*, which builds open-chimney mounds, eliminating ventilation altogether (by capping the open chimney) produces no discernible effect on nest temperature [13]. These observations have a straightforward explanation: when a nest is embedded in the capacious thermal sink of the deep soil, the nest energy balance (and hence its temperature) is strongly driven by this large thermal capacity. This produces the nest's strongly damped diurnal temperatures, and the mound infrastructure and nest ventilation has virtually nothing to do with it.

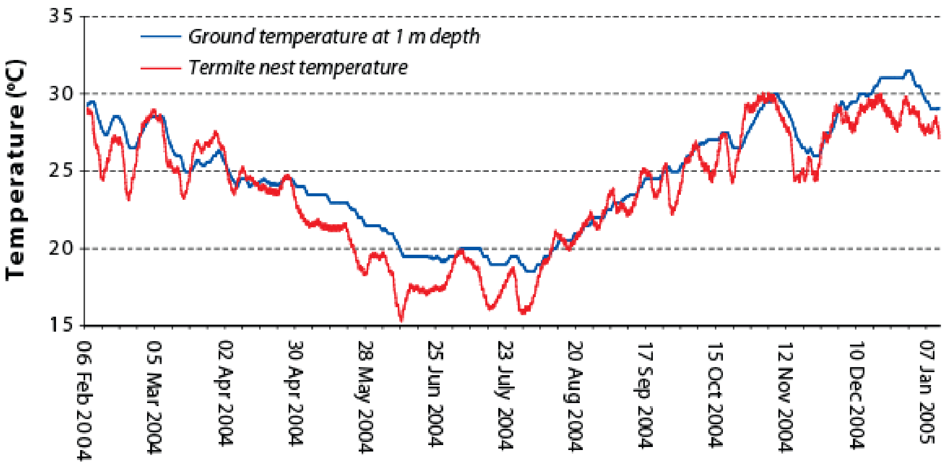

Figure 3. The annual march of temperature in the nest of a *Macrotermes michaelseni* colony in northern Namibia. For comparison, ground temperature 15 m away and at 1 m depth (about the depth of the nest) is also plotted.

Another surprising feature involves the relationship between nest temperature and mound temperature. A core assumption of Martin Lüscher's thermosiphon model is that buoyancy is imparted to nest air by waste heat from nest metabolism. There is, in fact, a considerable production of waste heat, estimated to range from about 80 watts, to as high as 250 watts, and this can elevate nest temperature by a few degrees above soil temperature [14]. However, for the thermosiphon to work, nest temperature must be warmer than *mound* temperature. Extensive measurements over the year of mound vs nest temperature for *Macrotermes michaelseni* reveal that nest temperature is most frequently *cooler* than mound temperature (Figure 4). In short, the nest air is most commonly stably stratified with respect to mound air, which means no thermosiphon flow is possible. Where the nest is warmer than the mound, the buoyant forces that result will be weak and unlikely to drive much flow [15].

[7] http://www.aia.org/aiarchitect/thisweek03/tw0131/0131tw5bestpract_termite.htm

[8] http://database.biomimicry.org/item.php?table=product&id=1007

[9] http://www.zpluspartners.com/zblog/archive/2004_01_24_zblogarchive.html

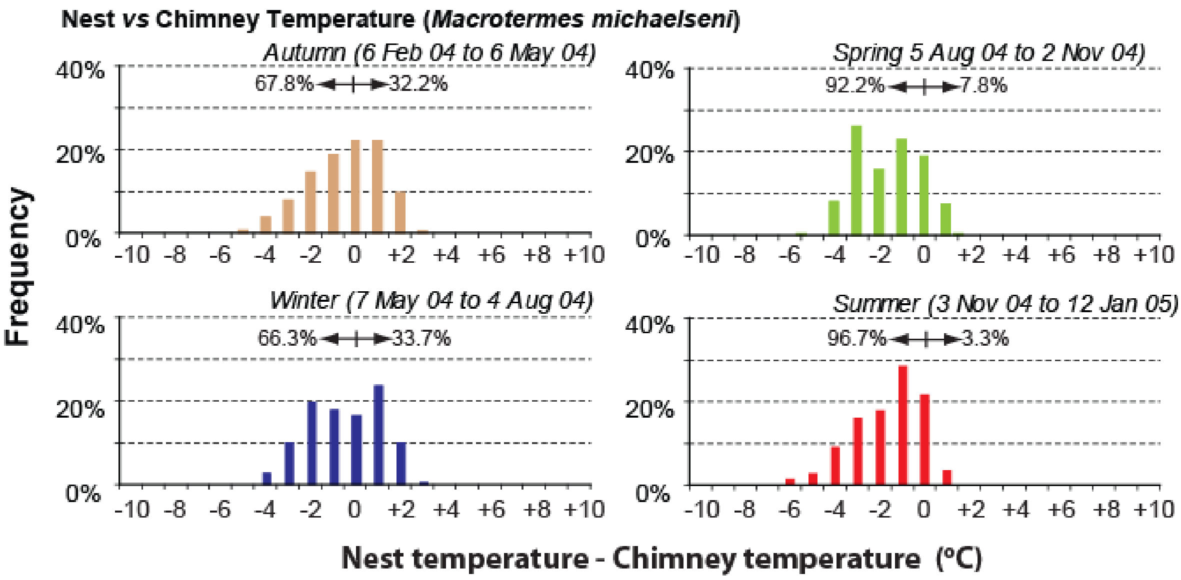

Figure 4. Seasonal distribution of nest vs mound chimney temperature (about 1 metre above the nest) for a *Macrotermes michaelseni* colony in northern Namibia. Cumulative incidence of a temperature difference above and below *nil* are indicated by the double-headed arrows.

This points to some of Eastgate's interesting design anomalies. Like termite mounds, Eastgate uses thermal capacity to damp temperature excursions through the day. Over the long term, however, damping is less effective, as is demonstrably the case in termite nests (Figure 3). To counter this, Eastgate makes clever use of a daily fan-driven ventilation cycle: low-capacity fans operate during the day, while high capacity fans operate at night. During Harare's typically warm days, the low volume turnover of air in the building facilitates heat storage in the building's fabric, keeping internal temperatures cool. During the typically cool nights, the high volume fans are deployed to extract stored heat from the building's high-thermal-capacity walls, essentially "emptying" them to receive a new load of heat the next day. Thus, even though Eastgate can dispense with an air conditioning plant, it still requires a forced-air plant to drive the required daily ventilation cycle. No termite colony does this.

Interaction with wind presents another interesting divergence between termite mounds and buildings like Eastgate. Wind has practical value as an energy source only if it is predictable and reliable. Yet wind, by its very nature, is variable and unpredictable [16]. A building design that seeks to harness wind must therefore seek those aspects of the wind resource that maximizes reliability and energy content. This is why it is common for buildings that tap wind energy to be designed around some variation on the induced flow principle: one of the most predictable features of natural winds is the vertical gradient in wind speed (and hence wind-borne kinetic energy) that comprises the surface boundary layer.

Termite mounds also exploit boundary layer winds, of course, but with some important differences. Natural winds are nearly always turbulent winds, so that at a particular location, there is a high probability that the wind velocity vector will vary significantly over time, in both the speed and direction components of the vector. Thus, any scheme that aims to tap wind energy as a point source will be inherently unreliable. In designing passive ventilation schemes into buildings, architects gravitate toward induced flow mechanisms, in part because it has a reliability advantage: the likelihood of a boundary layer *gradient* between two locations is very high compared to the likelihood of a particular wind velocity at one location. This reliability advantage is increased by height difference between the wind capture points, so for a building to be reliably ventilated by induced flow, it must therefore be tall. Termite mounds, in contrast, are comparatively short, usually only a metre or two in height, and this reduces the reliability advantage commensurably. As a result, induced flow rarely operates in termite mounds, even in open-chimney mounds where the structure would seem to strongly favour it [13, 15, 17].

Finally, there is the assumption that mound ventilation also means nest ventilation. This has long been the prevailing assumption in termite biology (and in building designs inspired by termites). Surprisingly, there is little evidence that supports this claim, for whether ventilation is purportedly driven by wind (induced flow) or by waste metabolic heat (thermosiphon flow). Indeed, measurements of actual flows of air in termite nests and mounds (using tracer gases) indicate that air in the mound is almost never driven in bulk into the nest [15]. This signifies, among other things, that other mechanisms beside ventilation must be involved in mediating the mound's function: the colony's respiratory gas exchange.

Termite-inspired building designs thus depart in some significant ways from the conventional view of how termite mounds work. How, then, do termite mounds actually work?

How a termite mound is like a lung

The termite mound is but one part of a larger integrated system that includes the subterranean nest and the complex reticulum of termite-excavated tunnels that permeate the mound. These both extend upward into the mound and downward to envelop the nest (Figure 5).[10] This system is the functional analogue of a lung, and like the lung, multiple layers of subsidiary function are involved in the global function of colony gas exchange. Previous models for mound function have fallen short because they have not accounted for these functional complexities.

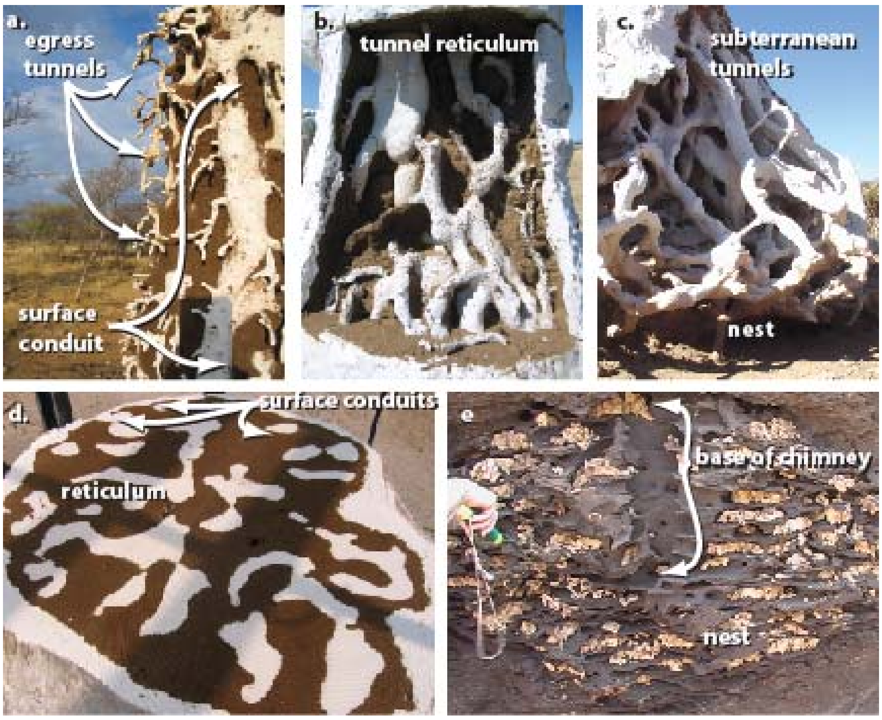

Figure 5. The internal structure of a *Macrotermes michaelseni* mound. a. Plaster cast of a portion of the superficial tunnel network showing egress tunnels and surface conduits. The mound surface has been partially washed away. b. Plaster cast of the deep tunnel reticulum in a mound of *Macrotermes michaelseni.* c. Plaster cast of the subterranean reticulum that envelops the nest. The nest is just visible behind the reticulum. d. A horizontal slice at roughly 1 m above ground level through a plaster filled mound. The reticulum and surface conduits are indicated. e. Cross section through the subterranean nest, showing the galleries (the fungus combs are the yellowish masses inside the galleries) and the base of the chimney opening into the nest.

[10] These tunnels ultimately connect to the extensive array of foraging tunnels that radiate several tens of metres from the nest, and which gives the colony's workers access to their food (dried grass, dead wood and dung).

Commonly, physiologists describe the lung as a multi-phase gas exchanger (Figure 6, [18, 19]). Ventilation is only one phase, and it operates in the lung's upper airways (the trachea and several branches of the bronchial tree). There, gas exchange is dominated strongly by forced convection driven by the respiratory muscles. In the lung's terminal passages—the alveoli and alveolar ducts—gas exchange is dominated by diffusion, and there is virtually no bulk flow of air there. Sandwiched between these phases is an extensive region of the lung, which includes the fine bronchi and bronchioles, where neither forced convection nor diffusion dominates flux. This mixed-regime region is the site of the overall control of lung function. This is dramatically evident in asthma, which is a constriction disorder of the mixed-regime airways. Small constrictions of these airways during an asthma attack disproportionately compromises lung gas exchange in a way that similar constriction of the upper airways do not.

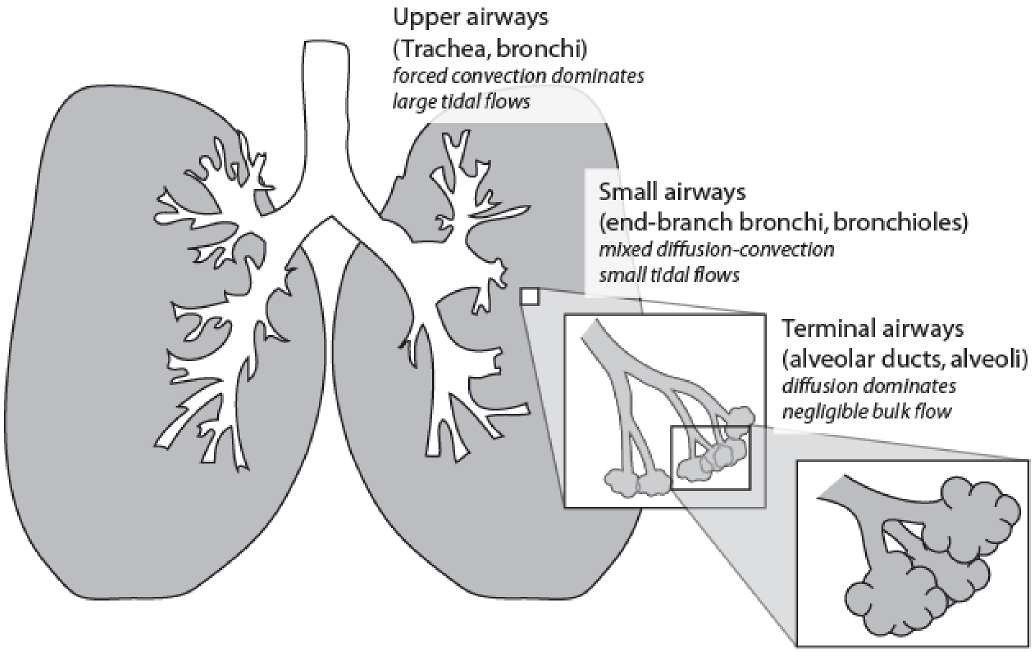

Figure 6. Functional organization of the lung

This casts lung ventilation into a somewhat different perspective from how we normally view it. For example, when respiratory exchange is elevated, as it might be during exercise, increased ventilation (heavier breathing) does not *by itself* enhance respiratory flux, as most might think. Rather, increased ventilation works its effect secondarily by enhancing gas exchange through the limiting mixed-regime phase.

Termite colonies have a structural organization similar to the lung's (Figure 7). The analogue to the alveolus is the termite itself (which can be thought of as a mobile alveolus). These, in turn, are embedded in the nest, which is organized into about a hundred *galleries*, each containing a fungus comb, and each connecting to its neighbours through one or two small passageways, roughly 2-3 mm in diameter. Altogether, the structure of the nest makes for a comparatively isolated air mass, similar to the alveoli and alveolar ducts of the lungs. The mound air space, meanwhile, consists of a large vertical chimney centrally, and the extensive airways of the mound reticulum, which envelop the nest and terminates at the mound surface in innumerable small-diameter egress tunnels. These are the sites of mound porosity, opening inward to the large vertically-oriented surface conduits on one end, and outward through a thin porous layer of soil grains at the surface. Air movements in the mound are strongly driven by wind. Mixing of the mound air and nest air is impeded in two ways. First, there is the frequent stable thermal stratification that occurs when the nest is cooler than the mound (Figure 4). Second, the nest and mound air spaces communicate only through very small channels: at the nest's lateral surfaces to the reticulum enveloping the nest below ground, and at the chimney from the central part of the nest.

The structural similarities between the lung and termite colony betoken functional similarities as well. In the lung, the alveolar and bronchial air masses are poorly mixed, and ultimate gas exchange depends upon the degree of mixing that can occur across the mixed regime zone between alveolar air and bronchial air. In termite colonies, nest air and mound air are poorly mixed, and ultimate gas exchange between the nest and environment depends upon the degree of mixing between the air masses in the mound and nest. By our best estimates, the mixing zone occupies the lower parts of the chimney and the deeper parts of the mound reticulum [15]. In both the lung and termite colony, understanding gas exchange boils down ultimately to understanding what drives the mixing between two air masses.

In the termite colony, mixing is driven by energy in wind, and the mound is the principal interface with environmental winds. Most thinking about termite mounds (or termite-inspired buildings) has idealized the mound as a flow-through system driven by idealized gradients in wind energy. It is common, for example, to see diagrams of mounds (or buildings) with winds depicted as a vector with implicitly predictable and well-behaved velocity and direction. To render a useful analogy, there is a tendency to idealize wind as a DC energy source, and to characterize the mound (or building) as essentially a resistance load that spans a DC gradient in potential energy (such as the surface boundary layer). Function is then defined by the DC work done, that is, bulk movement of air through the building's occupied space, as in induced flow.

However, neither lungs nor termite mounds are DC systems and it is inapt to treat them that way. Rather, they are more properly thought of as AC systems, driven by dynamic transients in the energy that powers their function [20]. Lung ventilation, for example, is driven by an AC "motor", namely the tidal movement of air driven by the cyclically active respiratory muscles. What determines lung *function* is the depth to which this AC energy can penetrate and influence exchange across the mixed-regime phase. Similarly, termite mounds capture energy in the chaotic transients that are the defining features of "badly-behaved" turbulent winds. The mound's *function*, however, depends upon how deeply this AC energy can penetrate into and do work in the mound. In both instances, function is essentially AC work, driven by the capture of AC energy across an *impedance*, not a resistance.

Many peculiar aspects of lung (and mound) function can only be understood in this context. One has already been mentioned: how both the lung and the colony-mound complex mediate respiratory gas exchange when ventilation does not extend to the entire structure. This is not necessary in an impedance-driven system: the AC energy need only penetrate deeply enough to affect the mixed-phase region that limits global function: gas exchange. There are other interesting aspects of AC systems, however, that not only uncover novel mechanisms for how termite mounds work, but that can inspire entirely new kinds of biomimetic designs.

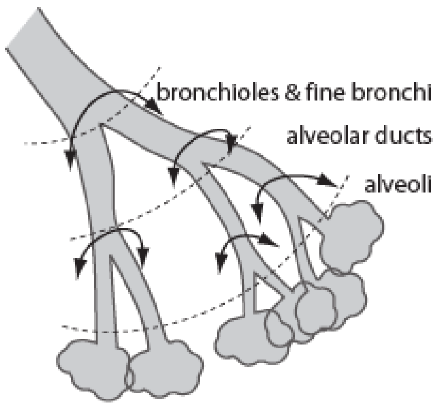

Figure 8. Pendelluft flow in the terminal and small airways of the lung

For example so-called *pendelluft* ventilation (literally, air pendulum) enhances gas exchange across the mixed-regime region of lungs through weakly-driven bulk flows of air between alveolar ducts and between the fine bronchi (Figure 8, [18, 19]). We believe there is a pendelluft operating in termite mounds as well, driven by an interaction between slow transients in turbulent wind energy that penetrate to the lower chimney and subterranean tunnels, and the rapid transients that drive flows in the superficial tunnels (Figure 9). These disparities in *frequency* of AC wind energy, along with variations in wind speed, wind direction and the distribution of surface porosity on the mound, can set up a slow back-and-forth “sloshing” of the boundary between nest and mound air, enhancing the mixing of the two air masses there [15].

Another interesting impedance-based mechanism involves so-called high-frequency ventilation, or HFV [21]. This is a respiratory therapy that is used to sustain gas exchange in lungs that have suffered mechanical damage and cannot sustain the large volume changes that normally accompany respiration. High frequency ventilation imposes minuscule volume changes on the lung, but at a much higher frequency, 10-20 Hz as opposed to the normal ventilation frequency of 0.2 Hz. According to one theory, HFV works by driving the lung at the resonant frequency of the airways, enhancing diffusion and promoting pendelluft ventilation [20, 22].

A form of high-frequency ventilation may also occur in termite mounds, but here driven by particular bandwidths of the frequency spectrum of turbulent winds. The extensive array of long, large-calibre tunnels in termite mounds can extend for more than 2 metres in length. These resonate strongly at frequencies of about 20-30 Hz, which sits comfortably within the frequency bandwidth of turbulent winds, typically 1-100 Hz. If the mound’s tunnels are “tuned” to capture the AC wind energy in this narrow frequency band, it may set air in the tunnels resonating, driving a kind of HFV that could promote gas exchange without large bulk flows of air through the nest. More likely, however, is a structural distribution of wind capture that matches a distribution of resonant frequencies. For example, the air spaces in the mound offer a variety of path lengths for transient wind energy to follow, ranging from a few centimetres in the superficial egress tunnels, to metres in some of the deeper and larger calibre tunnels. Thus, transient winds at the upper end of the frequency spectrum could do work in the shorter superficial tunnels, while lower frequency transients do work in the deeper and longer tunnels.

This opens the possibility for discriminatory mass transfer mechanisms in termite mounds (and termite-inspired buildings) similar to those that operate routinely in lungs. Evaporative cooling through panting works this way, for example. Panting cools a dog by elevating the rate of evaporative mass loss from the mouth and lungs, driven by an increased lung ventilation [23-26]. This poses a physiological quandary: how to increase water vapour flux without simultaneously increasing carbon dioxide flux, which could cause severe upsets of the body’s acid-base balance. The quandary is resolved by the lung’s impedance. Driving the lungs at the resonant frequency of the thoracic cage increases the lung’s impedance. The higher-frequency ventilation preferentially enhances evaporation from the upper respiratory passages. The lung’s high impedance to these high frequencies leaves CO_2 flux at the deeper, mixed regime level unchanged.

Similar discriminatory schemes may operate in termite mounds too. For example, termites tightly regulate the nest’s water balance, which is often undermined by percolation of ground water into the nest following rains [27, 28]. At the same time, termites also tightly regulate the concentrations of oxygen and carbon dioxide within the nest [15]. Termites are thus faced with a physiological quandary similar to the one panting dogs must face: how to evaporate water faster from the nest without simultaneously disrupting the balance of respiratory gases. Termites accomplish this by actively transporting water to the superficial parts of the mound in wet soil, where it is deposited around the egress tunnels. Because it is precisely these regions that should be ventilated most strongly by rapid wind transients, evaporation can be enhanced without also increasing respiratory gas flux that depends strongly upon low-frequency transients.

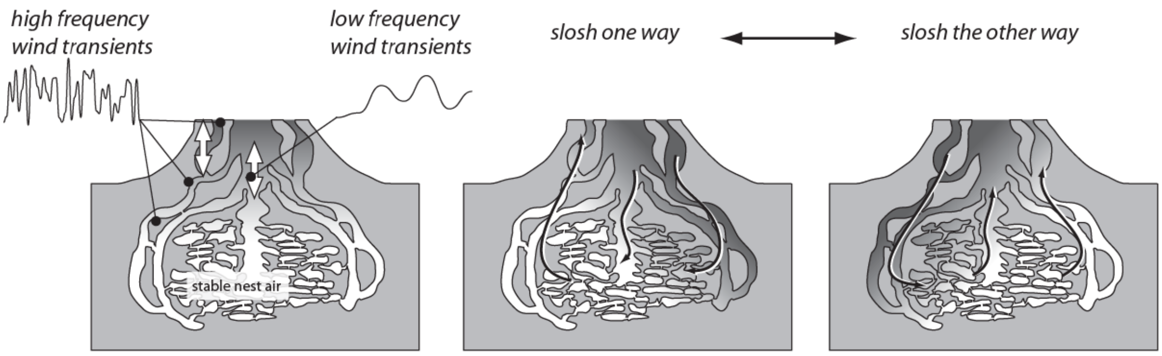

Figure 9. Hypothetical pendelluft ventilation in the termite mound and nest. Top. Array of forces acting on the deep air masses in the mound and nest. Middle and bottom. Pendelluft flow that arises in response to variation in wind speed and direction.

How buildings can be like lungs

This enhanced conception of how termite mounds work is immensely liberating because it opens a veritable new universe of termite-inspired building designs. No longer need such designs be constrained by the long-prevailing models of induced-flow and thermosiphon flow: a good thing, since these mechanisms rarely operate in natural mounds anyway. In contrast, a clear vision of how termite mounds actually work literally opens a whole new spectrum of wind energy to explore and exploit.

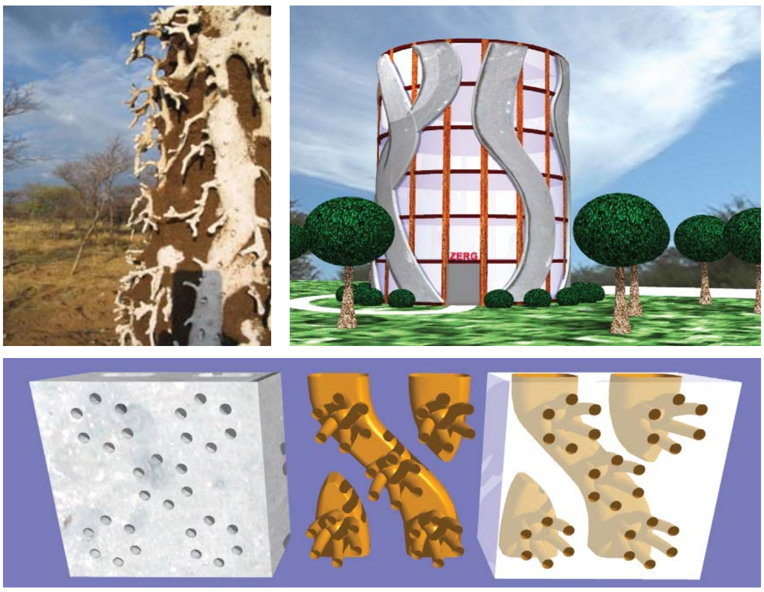

Figure 10. Some imagined biomimetic designs. Top left. The surface conduit-egress tunnel complex. Top right. A rendering of a building enveloped by porous "surface conduits." Bottom. The block elements for an artificial surface conduit.

Consider, for example, the traditional conception of the wall. In most building designs, walls are erected as barriers to isolate spaces: internal spaces from the outside world, internal spaces from one another and so forth. Yet spaces, if they are to be occupied and used, cannot be isolated. Resolving this paradox is what forces building designs to include infrastructure - windows, fans, ducts, air conditioning, heating etc - all essentially to undo what the erection of the walls did in the first place. In short, the paradox forces building design toward what we might call the "building-as-machine" paradigm (BAM).

Living systems, which also are avid space-creators, resolve the paradox in a different way: by erecting walls that are not barriers but adaptive interfaces, where fluxes of matter and energy across the wall are not blocked but are managed by the wall itself [29, 30]. This is illustrated dramatically in the complex architecture of the interface that termites build - the mound - to manage the environment in their collectively constructed space – the nest [31].

New rapid manufacturing and free-form fabrication techniques make it now feasible to build walls that incorporate some of these design principles (Figure 10). Imagine, for example, porous walls that are permeated with a complex reticulum that, like in the termite mound, acts as a low-pass filter for turbulent winds. In this instance, an interior space of a building could be wind-ventilated without having to resort to tall chimneys, and without subjecting the inhabitants to the inconvenient gustiness that attends to the usual means of local wind capture, namely opening a window. Now, it is the windows that are the barriers and the walls that connect the inhabitants to the world outside. Or, imagine a cladding system that mimics the mound's complex interface at the surface conduits and egress tunnels (Figure 10). One could employ such claddings as whole-building wind-capture devices, which greatly expands a building's capacity for wind capture. Or, imagine a wall that is tuned for differential mass exchange where the high-frequency components of turbulent winds can evaporatively cool a porous wall's surface layers and provide natural cooling for air forced through the walls by wind's lower-frequency components. The possibilities, we hope you will agree, are large.

Beyond biomimicry

Indeed, the possibilities may be more than large: they may be vast. This is because the termite mound is not simply a structural arena for interesting function. It is itself a function, sustained by an ongoing construction process that reflects the physiological predilections of the myriad agents that build and maintain it. The mound, in short, is the embodiment of the termites' "extended physiology" [29, 32, 33]. This raises the intriguing idea that building design can go "beyond biomimicry", to design buildings that do not simply imitate life but are themselves "alive" in the sense that termite mounds are.

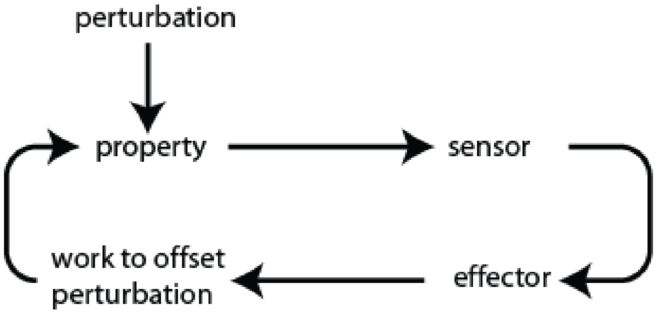

Figure 11. The standard negative feedback model for regulating the built environment

Realizing the living building is predicated upon there being a clear idea of what distinguishes living systems from non-living ones. Unfortunately, most of the criteria that are commonly put forth by biologists - cellular organization, replication, heredity, reproduction, self-organization, low entropy - are not very informative for building designers. Remarkably, they are not even particularly helpful in the life sciences. Reproduction, for example, is not a useful criterion for recognizing living systems, such as the biosphere, that do not reproduce. Nor is a concept like self-organization much help: many complex non-living systems, like clouds, are self-organizing, so how are these to be distinguished as not-life? Fortunately, there is one feature that reliably distinguishes life in a variety of contexts and scales. That is homeostasis, the tendency of living systems to gravitate toward a particular adaptive state in the face of disruptive perturbations. Realizing the living building therefore means realizing the *homeostatic* building.

The idea of homeostasis is nothing new to architects and engineers, of course: it is standard practice to outfit buildings with systems to regulate particular properties of the built environment: temperature, humidity, air quality and so forth. The focus here is on machines that do work to manipulate a property through negative feedback control (Figure 11). Thus, a property is sensed, its deviation from some desired value is assessed, and a machine is activated that does work to offset the deviation. Such systems range in complexity from simple house thermostats to sophisticated Building Energy

Management Systems, but all have in common that they are firmly rooted in the building-as-machine design tradition.

Homeostasis is more than simply self-regulation, however. It is a fundamental property of life that, among other things, confers upon living systems an impressive capability for emergent self-design [30]. Thus, regulation of an environmental property - the essence of the building-as-machine - is but one of many outcomes of a larger systemic homeostasis that engages every aspect of the system's architecture and function.

The termite "extended organism" is a remarkable example of this capability. A termite colony's oxygen demand varies considerably with colony size: small colonies may comprise a few thousand individuals, while the largest colonies may have populations upwards of two million [34]. Despite this large variation in demand, oxygen concentrations do not differ appreciably with colony size: oxygen concentrations in very large colonies are similar to those in much smaller colonies (Figure 12, [15]). Yet, there is no machine in the termite mound that does the work to offset the perturbation that a negative feedback system might demand. Nor is there any evidence of an "oxygen-stat": termites are not particularly sensitive to quite large oxygen perturbations. How, then, is oxygen concentration regulated?

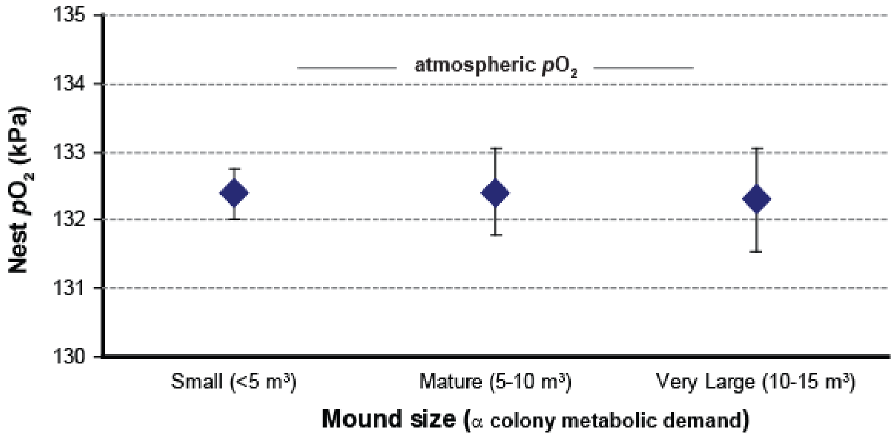

Figure 12. Oxygen concentration in several nests of *Macrotermes michaelseni*. Symbols represent means +/- 1 standard deviation. Mound size is a surrogate for colony metabolic demand.

Part of the answer is that it is not simply the *property* of oxygen concentration that is regulated. What is regulated, rather, is multiphasic processes of which one outcome is a steady oxygen concentration. Because the mound is an extended organism, this process extends to the mound, which is itself a process. Thus, mound structure is as impressively regulated as oxygen concentration.

How termite colonies manage this seamless integration of structure and function remains largely obscure, but some interesting features are starting to emerge. There is a common link, for example, in the termite-mediated movement of soil that makes the mound both process and structure: this is why it is possible for the mound's structure to reflect the termites' collective physiology. Understanding the termite colony as an extended organism therefore involves understanding what guides this ongoing termite-driven stream of soil through the mound.

Surprisingly, negative feedback, so essential to the building-as-machine paradigm, appears to play only a minor role in the termite extended organism. Rather, there is a kind of swarm intelligence at work. Soil translocation is organized into discrete foci of intense activity that is driven by a multiplicity of positive and negative feedback loops involving termites, the structures they build and the intensity of local AC perturbations of the environment (Figure 13). To complicate matters, the multiple foci compete with one another for workers, with more intensely active foci drawing workers away from less intense foci, the outcome of the competition both determining and being determined by the structures that result. To complicate things further, the entire process is modulated by the availability of liquid water.

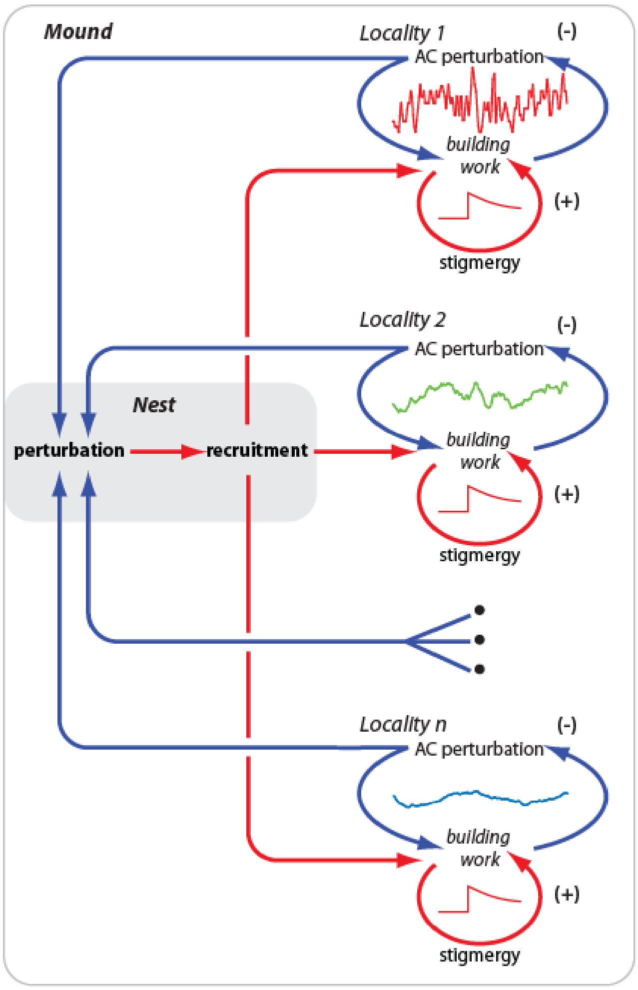

Figure 13. Model for swarm regulation of the nest environment. Building is driven by multiple foci of intense soil movement that can drive soil transport autonomously. The various foci also compete with one another for building agents (i.e. termites). A focus is initiated by an AC perturbation, and is sustained by a positive feedback loop called stigmergy. AC perturbations also sustain the focus of building. As building proceeds, the level of AC perturbation abates. Building will continue being driven by stigmergy, but this has a natural decay time.

The building-as-machine paradigm cannot quite capture this kind of seamless integration, largely because it regards structure as something distinct from function. It is therefore unlikely that the living building can emerge from this design tradition. In living systems, however, no such distinction is possible: structure is function and function is structure. At present, simply stating this offers little practical help in telling us how to realize a living building, but it at least points us the right way: toward buildings that are extended organisms, where function and structure meld, and are controlled by the over-riding demands of homeostasis.

Conclusions

Architects and engineers have lately been looking to building designs inspired by the remarkable termite mounds of southern Africa. The structure and function of termite mounds turns out to be far more complex, novel and interesting than has heretofore been imagined, and this has opened the door to a wide range of new potential "termite-inspired" designs for passive climate control in buildings. Among the most interesting is a unique mode of capture of the "AC energy" transients that are inherent in turbulent wind. This is, by far, the most common and energy capacious source of wind energy on Earth, but it is also a form of wind energy that has been largely ignored in current wind-power engineering, largely because capturing it for useful work has proven to be elusive. Termites have learned how to do precisely this. They do so through using complex structures to tune the broad spectrum of turbulent wind energy. New fabrication methods make it now possible to envision incorporating these complex turbulence-capturing mechanisms in our own built structures.

Another interesting aspect is the entire concept of the “living mound”, which lifts the lid on architecture’s holy grail, the “living building”, a dynamic habitation that adapts seamlessly to the demands of the occupants, and that can engage in a kind of emergent self-design. Details of how termites do this very thing with their “living mounds” are beginning to emerge. What we can presently glimpse points to homeostasis as the fundamental feature of all living structures.

We believe these new discoveries, and others, point to a bright future for termite-inspired biomimetic architecture and beyond.

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