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How can BIM Technology assist in optimising the Life Cycle Cost of a Building?

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Abstract

The complexity of a modern construction project, especially in a fast track environment, necessities the use of Building Information Management (BIM) system to manage such a project to provide the necessary probable cost outcomes of alternative designs ahead of actual construction times. The visualization of such alternative designs through 'prototyping' design solutions has the definite advantage of identifying coordination and other construction issues, minimizing delays in construction downtimes and avoiding the cost of reworks. As a communications tool, BIM technology, through modelling techniques such as Ecotect developed by Autodesk's Revit, can additionally be used to assess impacts of alternative energy saving designs on the life cycle of a building.

This paper explores the use of Ecotect in the sustainable design analysis of alternative energy saving designs of a simple residential building. It serves to graphically illustrate the successive steps of the building through its economic life, illustrating the effects of a design decision to the building. It aims at uncovering the feasibility and/or the desirability of using BIM 4D Modelling Technology for life cycle costing in construction projects generally and in residential housing projects in particular.

Key Words: Building Information Modelling, 4D Modelling, Life Cycle Costing Analysis.

Introduction

The property industry has recognised the benefits that decisions basing on life cycle costing can bring to the design and operation of buildings. Many building owners apply the principles of life cycle costing when making decisions regarding construction or improvements to a facility. Life cycle cost analysis is an economic evaluation technique that determines the total cost of owning and operating a building throughout its life time (Emblemsvag 2001; Al-Haji & Horner 1997). According to Mearig 1999, life cycle costing is the "total discounted dollar cost of owning, operating, maintaining, and disposing of a building facility over a period of time". Thus, the life cycle costs of a building include the initial property costs, costs of any building or renovation works, operating costs and the eventual disposal costs (Aye et al. 2000). Life cycle costs provide more comprehensive assessment of the long term cost effectiveness of a building than many alterative building analyses that mainly focus on the initial capital costs or on operating-related costs in the short term. Reduction in costs is significant to company profitability and it is possible through action research that the life cycling costs of buildings can be reduced by design, often at no overall increase in capital cost. Notwithstanding the significance of life cycling costing, practical difficulties have prevented effective use of this technique in making decisions about buildings due to lack of rigorous techniques for life cycle costing and appropriate practical working tools in building design techniques. In the latest research by the Royal Institution of Chartered Surveyors (RICS) on the subject (Kelly & Hunter 2009) the fact that there is still no standard method of measurement of life cycle costs has been emphasized. True, "the life cycle costing texts are rich in mathematical theory, risk and sensitivity analysis, data management and component life assessment" but there is still no "explicit method of measurement for option appraisal or benchmarking." (Ibid p. 6).

With the above literature as the backdrop, this paper explores the use of 'Ecotect Analysis 2010', the 5D Building Information Modelling (BIM) technique of Autodesk Revit for life cycle costing analysis of one single set of specifications for a simple residential building. The 3D drawings of a simple house are entered into the BIM database to form the basic building blocks for study. An attempt is made to apply the full Ecotect analysis to the design to capture the effects to the building over time, simulating visualized outcomes in the form of 3D drawings representing the differing time spans of the life of the building.

The benefits of using BIM in modern construction project management have been well recognized. Eastman et al (2008), for instance, have described the use of BIM for developing models that enable computational based analysis and simulation to be undertaken. Soubra (2008) has discussed the ability of BIM to model "comforts" including thermal, visual, acoustic and air quality. Vaizidou (2007) has highlighted the benefit of BIM's modelling technique in using the x-y-z axes for representations of time line: project tasks: design outputs in projects. The concept of the x-y-z axes, which will be discussed to a fuller detail later in this paper, is of particular relevance as it illustrates the simple idea of representation of the outcomes from Ecotect applications.

The use of BIM techniques has therefore achieved widespread commercial use in building designs. The American General Contractors Association (2006) publishes a 'Guide to BIM' identifying BIM as a tool that enables the construction industry to:

> "more efficiently operate in new and increasingly expeditious ways. Initially, BIM and 3D models have primarily helped eliminate design conflicts with far more efficient coordination. Expanding beyond this premise to some other specific practices, contemplate the future with BIM in regards to … project scheduling and the concept of 4D, in which time considerations are inserted into the modelling process; … estimating and quantification when 5D concepts are incorporated with the BIM process; … envision that shop drawings could be developed simultaneously as the design unfolds; …"

Since 2006, the use of BIM for construction projects has moved swiftly to become a key factor in the development of accurate as-built 3D drawings captured in electronic format in computer disks virtually at the close of construction phase. This will have a tremendous beneficial impact for property owners and property managers in the maintenance field as well as in the renovating or redecorating phases of a building's life. BIM data for a building will definitely be lasting beyond its construction phase and it is the use of the BIM tool (Ecotect as an example) for visualization in the management of facilities to be carried out during the very initial design of the building that is the primary focus of this paper.

In the New Zealand context, most major architectural practices are using BIM or at least 3D tools to various extents in the design of buildings. These practices are expected to increase their usage significantly in the future. Boon (2009), in his paper presented at a Quantity Surveying conference in Malaysia, promotes the better understanding of BIM by the quantity surveying fraternity. However, BIM has been demonstrated as more than just an electronic drawing tool. It can be used as a communications tool as reported by Snijders (2009), in the re-design of the $60 million fast-track Plaza Shopping Centre in Palmerston North. BIM brings the project to life as owner, planners, main contractor, subcontractors can see the building (through the models over the time series of representations) before its construction and can discuss the best possible way to bring any possible conflict into an amicable and practical solution by all concerned.

In a similar manner, because BIM is not just a collection of diagrams but a realistic collection of intelligent elements, with each element being a part of an overall database of construction components, the visualization of a building design over time is a valuable exercise for many players to the building team. With the use of the 5D BIM Ecotect program, the owner or developer and the design team of architect, engineers, quantity surveyor and even the property manager can run through the visualised results of varying alternative designs (differing building materials for the main components of the building, differing orientation of the building to the sun, differing internal layouts of the building) long before the first digging of the top soil for construction work.

Methodology

The aim of this study is to find out how BIM can be used to assist us in optimising the Life Cycle Cost of a simple residential building. The study proposes to do this by way of developing a basic 3D house model design and place this model house on to a hypothetical plot of vacant land without any nearby structure that can restrict the entry of solar energy to the house. The model house is then provided with the specifications for the external walls, the roof, the windows and the external doors entering these into Autodesk Revit's Ecotect program. The program should then be able to produce meaningful output data for the period of the building's life in use. A variation in the orientation of the house can be made to see the effects of this change in orientation has on thermal insulation, sun shading and other qualities of human comfort. More details of analysis concepts have been advocated by Autodesk in its website. The aim of Ecotect is stated therein as satisfying the "increasing client and regulatory pressures to produce *higher performing* and *more energy efficient* buildings.” [See website http://squ1.org/wiki/Concepts].

Once the simple 3D house model has been placed under the microscope of Autodesk Revit’s Ecotect program, an opinion as to whether the BIM Ecotect program can assist in optimising the Life Cycle Cost of a Building can be formed.

The Simple 3D House Model

The floor plan is shown in figure # 1 below. The house has a simple rectangular shape measuring overall 16.06m by 7.20m with a living floor area of 113.61 square meters. The accommodation includes an open plan living area that houses the lounge, dining and kitchen and three bedrooms, ensuite, separate bathroom and toilet and a laundry area. There is also a space for computer desk, just off the main lounge. There is no garaging provided.

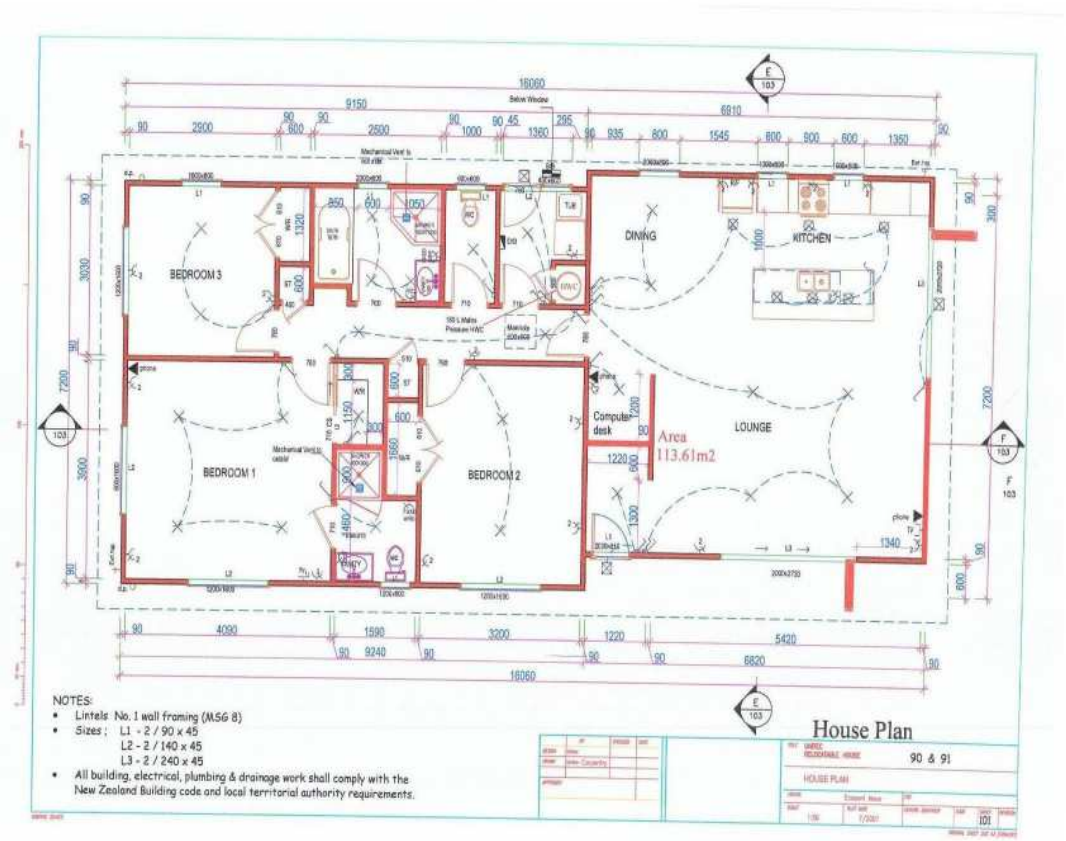

Figure # 1: The simple house model – Floor Plan.

The basic specifications are:

External Walls: 200x25 Cedar multisplay weather boards on 90x45 timber framings at 600mm centers over breather type building paper and pink batt insulation.

Roof: 0.4mm coloursteel longrun corrugated roofing over breather type self supporting building paper supported by timber gangnail trusses at 900mm centers.

Floor: 20mm particle boards supported by 190x45 joists at 400mm centers.

Windows: 35mm residential suite aluminium joinery throughout.

External Doors: 35mm sliding doors of aluminium joinery to match windows; main entrance door – solid Cedar door with timber frames.

Foundations: Timber piles on concrete footings.

The x-y-z Axes Concept of Representation

The idea of a cube as an information cell has been developed by Lotteaz et al (1999) in the Architecture Department at the University of ETH in Zurich. The spatial relations of the cubical structure are defined in an orthogonal coordinate system where:

The x-axis represents the time line;
The y-axis represents the task line; and
The z-axis represents the design information data outputs.

This ‘x-y-z axes concept of data representation’ envisaging a cube as representing a unit that bears every kind of information of a building in that space in time has been relied upon in on-going researches in the topic of virtual building life cycle analysis. The ‘Virtual Building Life Cycle’ (VBLC) project carried out at the University of Karlsruhe and described in Linnert et al (2000) bears testimony to its use in connecting 3D geometrical information to research data such as life expectancy, carbon emissions, the behavioural patterns of building materials, and such like items to produce meaningful life cycle cost analysis of alternative designs.

The concept can best be illustrated graphically in a diagram thus:

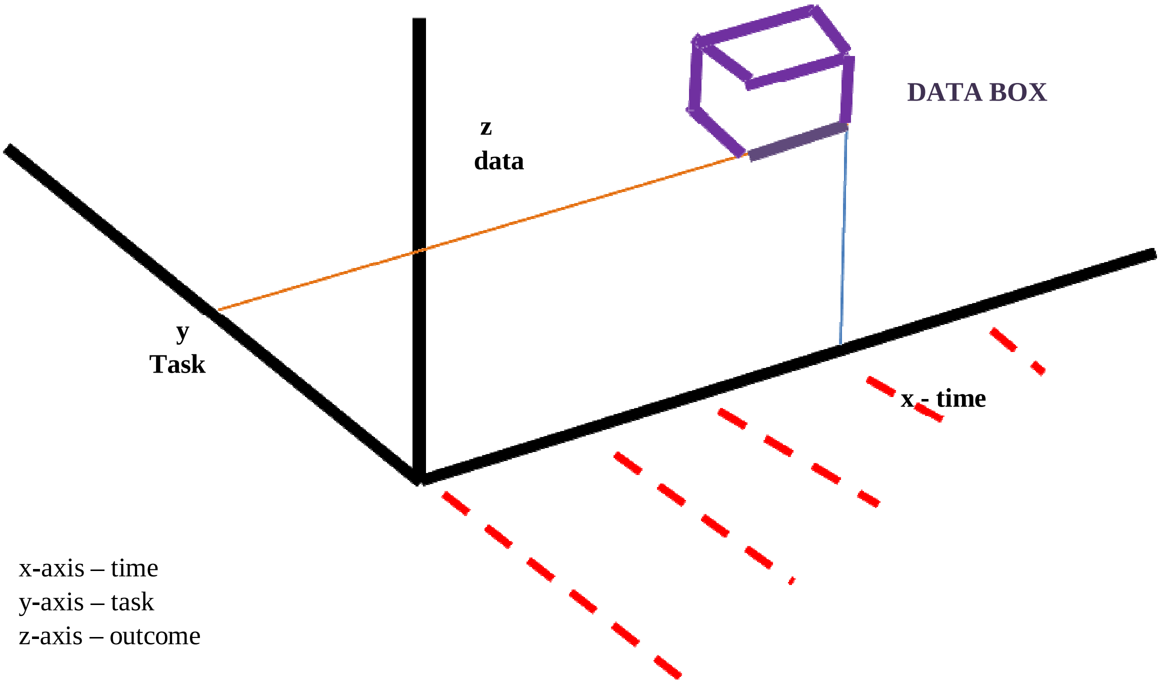

Figure # 2 - The x-y-z axes concept

In the context of this paper, the main concern is the period where the building is in active use as shown in period 5 in Figure # 3 below:

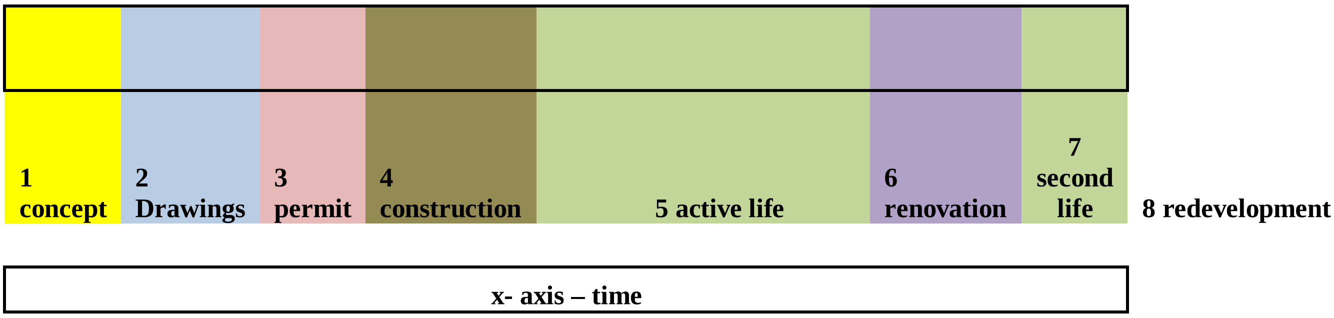

Figure # 3 – The x-axis time line

Use of BIM for Life Cycle Costing

The slogan for Autodesk Ecotect Analysis 2010 Green Building Studio Web Service is "Simulate Early. Analyze Often. Create More Sustainable Designs." The claim as stated in Autodesk Ecotect Analysis 2010 brochure is a "comprehensive analysis capabilities … to analyze and simulate conceptual designs" and to "study alternatives and make decisions early to deliver achievable, resource-efficient building designs."

The logical steps in which this study of the life cycle costing proceeds are thus as follows:

- A simple 3D house model as described above is adopted as the Base Line Model, transferring the data into Autodesk Ecotect Analysis 2010 Green Building Studio Web Service.

- The options for the building envelop to match the basic specifications as described earlier are to be selected and a simple click at the Autodesk Green Building Studio Run Status window gives us the DOE-2.2 analysis. DOE-2.2 is the widely used and accepted industry standard for building energy analysis that predicts the energy use and cost of all types of buildings. DOE-2.2 uses the description of the building layout, construction specifications, usage, conditioning systems (lighting, HVAC, etc) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills.

- The results from the selection, available within just a few minutes show not only a series of numerical data covering items like estimated energy cost per annum, life cycle cost, annual CO_2 emissions in tons, SUV (Sports Utility Vehicles) equivalent, annual electric energy in kWh, fuel energy in Therms, etc. In short the whole building's carbon footprint, but also a series of simulated diagrams over a selected period of time to illustrate the effects of solar energy changes.

- The specifications of the external envelope can then be varied. This can be easily done as the software allows the user to simply click at the elements of a building, change the specifications and assuming that the needed data for the selected materials are in the system, another series of data concerning the alternative design's carbon footprint are produced. The more important analyzed outputs are the items concerning the carbon neutrality potentials. By changing the specifications and perhaps using solar energy in the form of roof solar heating, for instance, the output can show us the possible savings in CO_2 emissions in tons.

- A repetition of the previous steps by varying the orientations of the building can result in another series of output data that are useful in terms of life cycle costing and of

Leadership in Energy and Environmental Design (LEED) Green Building Rating System as advocated by the United States Green Building Council in its website http://www.usgbc.org.

However, the results of the experiment in this simple 3D house model have not been completed due to the fact that there are insufficient external data to make the entire comparison possible. To illustrate how the rest of the Ecotect Program can work in the life cycle analysis of a building, the basic data for the San Francisco Convention Centre Building as relayed by Autodesk, are given below:

Baseline Model: General Information	Baseline Model: Location Information
Project: SF Convention Center	San Francisco CA 94199
Floor Area: 170,448 sf	Electricity cost: \$0.131 / kWh
Seven Office Floors;	Fuel Cost: \$1.000 / Therm
Three Basement Car Parking Floors	Weather: CA TMY2

Other relevant data concerning initial costs and sun lighting sensors and building envelope specifications can be entered into the system. The system can then be asked to run the DOE-2.2 simulation and the resulting carbon footprint of the building can be represented by the following output data:

Estimated Energy and Cost Summary	Carbon Neutral Potential: CO_2 emissions p.a.
Annual Energy cost: \$268,679	Base Run: 993.9 tons
Life Cycle Cost: \$3,659.405	If maximising the natural resources and relying on onsite potentials, the possible savings are:
Annual CO_2 emissions:	
Electric – 813.2 tons	
Onsite Fuel – 180.7 therms	Onsite Renewal Potential: -577.5 tons
Large SUV equivalent – 90.4 large SUVs driving 15,000 miles a year	Natural Ventilation Potential: -214.6 tons
	Onsite Fuel/Offset Biofuel Use: -180.7 tons
Annual Energy: electric – 1,813,109 kWh	Possible savings reduce the:
Fuel – 31,162 therm	Net CO_2 emissions to: 21.1 tons
Annual Peak Electric Demand – 546.8 kWh	Large SUV equivalent – 1.9 large SUVs

Lifecycle Energy: Electric – 54,393,270 tons Onsite Fuel – 934846 therms Annual Electric End Use: Lights 29.0 % HVAC 33.9 % Other 37.1 %	Electric Power Plant Source: Fossil 61% Nuclear 14% Hydroelectric 15% Renewable 10%

There are also additional output data generated. The water usage and water cost summary is given showing the water usage and cost per annum thus:

Water Usage and Cost:	Total:	10,533,521 gal/year	$36,817/year
	Indoor:	10,507,421 gal/year	$36,778/year
	Outdoor	26,100 gal/year	$ 39/year

The Photovoltaic Potential shown below provides the information of how much power can be generated if the option is to install solar panels to all the best performing solar exterior surfaces of the building.

Annual Energy Savings	780,252 kWh
Total installed Panel Cost	$ 4,158,439
Nominal Rated Power	520 kW
Total Panel Area	40,429 sf
Maximum Payback Period	30 years at $ 0.13 kWh

There is also a Yes/No decision point for the LEED Daylighting glazing Factor. The area with glazing factor less than 2% in this case is 36.6% and thus there is no LEED Credit.

The next section of the results is the Wind Energy Potential to be gained from a wind micro turbine based upon the data of one of fifty five thousand locations used by Green Building Studio. For this case, the potential annual electric generation is 3,990 kWh.

The last section of the results gives the Natural Ventilation Potential of the building to see if natural ventilation can come from the opening of windows within the building.

After the results above are studied, the Ecotect software produces various tables where selected alternatives to the external envelope specifications – roof, walls, double-glazing windows, floors – and also to the orientation of the building towards the sun can be inputted, and within seconds of a selection, all the results of that alternative set of designs can be seen on the computer screen.

Ideally, all the outputs can be illustrated diagrammatically and thus returning to the x-y-z axes concept of representation stated earlier, each of the stated result can be captured and archived into data boxes stored within the x (representing time), y (representing task, such as a specific specification) and z (representing output) area for ease of referencing so that meaningful conferencing type discussions can be carried out by various parties at the same time in different locations accessing the same matrix of the project file.

Findings and Conclusions

Unitec's experiment in Autodesk Ecotect Analysis 2010 using the 3D simple house model cannot be considered successful for the following key reasons:

1. There are insufficient basic alternative costing and life expectancy data of every component of the building in the system. Not only that, in order for life cycle costs to be properly assessed there is a need to have in the system the costs and life expectancy data of every alternative set of specifications. To have these data entered properly would take at least a further six months before the paper can be finalized. For some components such as heat pumps, solar panels, under floor heating, lightings, acoustic panels and the like, there is also the need to update with the latest upgrades before meaningful output data can be drawn from the system.

2. Although there is mention of the fact that the transfer of data from the Autodesk 3D model to the 5D Ecotect software in the form of gbXML files is an easy one, the Unitec's experiment suggests that the exercise is more complicated than originally envisages. In fact at the time of writing this paper, Unitec's research team has not been able to move the entire 3D files into the Ecotect compatible configuration.

3. A considerable amount of added reliable external information is needed in order for the Autodesk Ecotect Analysis 2010 system to succeed in producing worthwhile output data in terms of the thermal quality of a building. Such external information includes, inter alia, the weather pattern in the particular area in which the building is located, the natural heat sources in the building components, and the sun’s radiation at various times of the year.

4. Whilst the Autodesk Ecotect Analysis 2010 system is able to provide the life cycle cost of the entire building when the data as described in # 1 above are in the system, Unitec’s research team is unsure how to quantify the output when minor alterations in detailing occurs, an example being a building with overhangs of the eaves of the roof projecting out versus one without such projections. Another example in this category is the comparison of open fire heating versus the use of heat pump for thermal insulation of a room within the building.

5. There are other existing simpler computer software programs dealing with life cycle costing analysis, but none of these programs have the capacity to illustrate outputs diagrammatically.

6. The Unitec’s research team had hoped to be able to demonstrate the effect of life cycle cost analysis in the form of a continuous time line boxes of graphic illustrations in the x-y-z axes presentation format more or less in the following order:

y-axis representing one aspect of our tasks, say Sun Shading Effects	**z- data box graphic representation at Year 2**	**z- data box graphic representation at Year 15**	**z- data box graphic representation at Year 15**
	Year 2 completion	Year 15 after 13 years' use	Year 35 after 33 years' use

x- axis representing time line

This series of illustrations would have given a better picture of the effects of one aspect of the tasks on other components of the building. Whilst this theoretical concept can be seen to be possible, it would probably consume more time and computer storage to be practical.

To conclude therefore, the answer to the research question:

"How can BIM Technology assist in optimising the Life Cycle Cost of a Building?"

is a qualified yes. BIM Technology can assist in providing an optimized life cycle cost if only the following conditions are met:

a. The entire industry is committed to BIM technology in the sense that for a single project, every player involved is committed to place all the relevant data into one common computer BIM data file within the x-y-z format as stated above. This may sound like a long way off but with the increasing trend towards a paperless society and with the local authorities demanding proper compliance to building regulations from conception of building plan, the use of BIM technology for all players in the construction industry may well be coming sooner.

b. The push for reductions in greenhouse gas emissions from buildings by government agencies is gaining momentum and everyone involved in the building industry will soon have to use known computerised technology such as Autodesk Ecotect Analysis 2010 to demonstrate carbon neutral buildings long before the construction process can be allowed to proceed.

Perhaps it is fitting then to close by quoting from Bates and Kane (2009) in their research paper 'Building The Future' written for BRANZ (Building Research Advisory Council of New Zealand) thus:

> "The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment report recognized that buildings represent the best opportunity to make significant reductions in greenhouse gas emissions while maintaining economic growth. The IPCC estimates

that by 2022 CO_2 emissions from building energy use can be reduced by 29% at no extra cost."

Given this target of working towards 2022 reduction in CO_2 emissions, it would be in the best interest of all parties to perfect the necessary technique(s) of analysis to ensure buildings of the future are carbon neutral at least. Any study in computer software that can help achieve energy savings in the future such as the present study of Autodesk Ecotect Analysis 2010 should be considered worthwhile.

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