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Use of Building Information Modelling in responding to Low Carbon Construction Innovations: An Irish Perspective

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At present the Irish construction industry is facing one of its most uncertain and challenging periods and will see major cuts in all areas of the economy in 2012. Despite this, Ireland pushes forward in sustainability initiatives with the Government ruling that environmentally-friendly policies are to get priority in competing for State contracts worth up to €16 billion a year. This and further initiatives are in place, so as to reduce greenhouse gas emissions by up to 20% by the year 2020. By the end of 2018 the public sector must own or rent only buildings with high energy-saving standards and promote the conversion of existing buildings to "nearly zero" standards. Furthermore, the "retro-fitting" of Ireland's existing building stock will challenge Ireland to meet carbon targets. This paper outlines how Building Information Modelling (BIM) can be utilised on future and present public works projects in Ireland to significantly assist the Irish Government in managing a low carbon energy future. The paper will focus on the application of a sophisticated BIM model in helping to predict the performance of buildings or assess retrofit/upgrade options in managing low carbon construction. The authors' data collation methodology involved the testing and analysis of a BIM model for a public works project, used during a four day workshop in late 2011. The workshop proved a success and provided the platform for the Irish Government to see first-hand, how a collaborative BIM model used on a public works projects could provide a low carbon future for both future and existing building stock.

Keywords: Building Information Modelling, Low Carbon Construction, Public Works Projects, Sustainability,

1.0 Introduction

At present the Irish construction industry is facing one of its most uncertain and challenging periods and will see major cuts in all areas of the economy this year. The Irish construction industry has experienced a severe contraction in construction output since it peaked in 2007 at €38.4 billion, to a return to output volumes of around €10.5 billion by the end of 2011 (DKM, 2011). Despite this Ireland pushes forward in sustainability initiatives with the Government ruling that environmentally-friendly policies are to get priority in competing for State contracts worth up to €16 billion a year (Gormley, 2010). This initiative is to be complemented by the Capital Works Management Framework (CWMF) which was introduced in 2007 (Construction Procurement Reform, 2012). The CWMF is a series of documents which collectively describe the operating environment, procedures and processes to be followed for the delivery of capital works projects. It incorporates contractual provisions, guidance material and technical procedures covering the public works project lifecycle from inception to final project delivery and review. The aim of the CWMF is to ensure that there is an integrated methodology and a consistent approach to the planning, management and delivery of public capital works projects, with the objectives of greater cost certainty, better value for money and more

efficient project delivery. Within the CWMF the Irish government published a new suite of public sector contracts. These new forms aimed to support the certainty of outcome in terms of cost, quality, programme and recognise the development of new procurement methods, such as, design and build. In addition to this there is a plan to bring Ireland in line with the Energy Performance of Buildings Directive (EPBD). The EPBD will ensure that Ireland meets strict EU regulations set by the European Parliament since the 19th May 2010 and avoid crippling fines which could prove detrimental to an already faltering economy. This directive requires that:

- All buildings built after 31 December 2020 must have high energy-saving standards and be powered to a large extent by renewable energy.
- By the end of 2018 the public sector must own or rent only buildings with high energy-saving standards and promote the conversion of existing buildings to "nearly zero" standards.

In order to successfully compete within the public works sector and guarantee that Ireland meets its carbon target deadlines, it is recommended by the authors, that the Irish Government move towards the legal imposition of Building Information Modelling (BIM) on public works projects by following a similar methodology to that adopted in the UK. The Irish Public sector must fall in line with the recent UK IGT Report (2010), where the UK are now based on the IGT Report's recommendation, in the process of ensuring that companies in the wider construction industry are undertaking the following three fold task:

- to de-carbonise their own business
- to provide people with buildings that enable them to lead more energy efficient lives
- to provide the infrastructure which enables the supply of clean energy and sustainable practices in other areas of the economy

This process requires innovation and new ways of working and the acquisition of knowledge and skills that will provide competitive advantage at home and internationally. This innovative new way of working has come through the legal implementation of BIM. There is a plan for a phased five-year development that projects will be required to use Building Information Modelling tools and techniques from 2016. This plan was devised around a hypothesis which defined a scenario in which the Government client would have an estate that was smarter and better equipped to face a low carbon economy, with associated reductions in delivery and carbon emissions.

2.0 Methodology

In an attempt to promote BIM within the Irish AEC / FM sector, a recent pilot project was launched by the Royal Institute of Architects in Ireland and the Construction Information Technology Alliance (CITA). This project involved a full professional team working in conjunction with the Department of Education and Science on a generic primary school project. The main goals of the workshop where to:

- Raise awareness and promote a higher level of understanding of BIM.
- Demonstrate a more effective way for teams to collaborate.
- Assess / demonstrate some of the BIM software tools available.

- Validation of design through digital analysis.
- Testing of BIM technologies in responding to Low Carbon Construction

This workshop served as the main primary research tool for this paper and provided data in regards to testing the implementation of BIM on public works projects, as a method for adding cost certainty to contracts and managing low carbon construction. This paper will also review the use of BIM initiatives to procure public sector buildings and manage low carbon construction internationally and relate how those experiences can be applied to Ireland.

3.0 Literature Review

The authors conducted a literature review of journal papers, professional publications and research articles in regards to low carbon construction and BIM. The literature review focused on the three main areas detailed below in order to establish the benefits of using BIM in responding to Low Carbon Construction Innovations in Ireland:

- Construction Carbon Footprint and BIM
- Global Implementation of BIM
- BIM in Managing Low Carbon Construction in Ireland

3.1 Construction Carbon Footprint and BIM

Hallberg and Tarnardi (2011) detailed the construction sector as the largest industrial sector in EU-15 and from an environmental point of view, the construction sector is in a unique position, as it is accountable for 46 % of the total energy usage, 46 % of the CO₂ emissions and generates 40 % of all man-made waste. Okoroh et al (2012) estimated that approximately 80% of carbon emissions caused by buildings are created during the operating phase of existing buildings. This issue is even more concerning in that our neighbours the UK produce 50% of their total CO₂ emissions from energy used in heating, lighting, and cooling buildings, with an initial 25% of CO₂ emissions arising from the energy used in transporting people and goods during the construction and usage of these facilities (Pearce, 2008).

These figures have shifted the construction industry towards a more productive way of doing business, in order to control escalating energy costs and more productive methods of managing low carbon construction. This can be achieved through BIM, which can ensure a thorough life cycle analyses, service life planning and more solid life cycle optimisations of the design and use of the buildings (Hallberg & Tarnardi, 2011). BIM is beginning to change the way we build, the way the buildings look, the way they function and the way buildings are maintained and managed (Godager, 2011). The same author explains that resource consumption and waste production together form a construction trigger for a number of environmental problems. BIM is seen to be a very important tool to handle all these challenges. It is generally reported that the level of analysis required to predict the performance of buildings or assess retrofit/upgrade options, is not feasible without sophisticated BIM models or computational analysis tools. This relatively new technology has allowed a new paradigm within the AEC sector, which has the ability to promote and encourage each stakeholder within the project to play a more prominent role. BIM has helped develop the way designers and contractors look at the entire building process including the initial design brief all the way through the

construction documentation stage, into actual construction management stage, and finally the FM stage (Dzambazova et al, 2009).

3.2 Global Implementation of Building Information Modelling

The revolution of BIM across the global construction world continues to grow, and must result in Ireland adopting a similar methodology or face been left behind and unable to compete in foreign markets. The strong growth of the green building market has seen a greater encouragement in the adoption of BIM in the design and construction Industry. Green BIM is an emerging trend which can enable highly sustainable outcomes through energy simulation and prefabrication (McGraw–Hill Green BIM Report, 2010). In order to participate in this lucrative market, Ireland must follow the example of various countries including the USA, Finland, Norway, Denmark, UK, Germany, Singapore and Korea, who are all currently in the process of developing BIM guidelines.

VTT in Finland, Rambøll in Denmark and SINTEF in Norway are the major research organizations in BIM in these countries, as outlined by Wong et al (2010). The involvement of companies in BIM initiatives within Europe, facilitated by buildingSMART, is increasing with involvement estimated to vary between 20 and 40% of the number of companies implementing BIM (Wong et al, 2009) . Outside of the USA and Europe, Singapore is one of the few countries in Asia who have implemented BIM at the public sector, with Hong Kong in the process of establishing BIM guidelines to help increase productivity and meet established high standards that include tight schedules and high land costs. In a report by McGraw Hill (2010) titled “Getting BIM to the bottom line in France, UK and Germany” outlined that nearly 60% of total respondents are currently frequent users and 74% of Western European BIM users report a positive perceived return on their overall investment in BIM. Perhaps most encouraging to the Irish Public Sector is the move of their neighbour’s the UK, towards the legal implementation of BIM. Ireland needs to adopt a similar hypothesis and begin to mirror our neighbours and move towards the legal imposition of BIM in order to enhance low carbon construction

3.3 BIM in Managing Low Carbon Construction in Ireland

The need to reduce CO2 emissions and energy consumption from buildings has never been more immediate. Godager (2011) outlined that there is more and more environmental requirements because of growing environmental challenges and depleting energy resources. This ultimately means that there is a need for focusing on building materials and for performance classification in the energy field. The European Union and its Member States have a large number of on-going policy initiatives directly aimed at supporting of sustainability of the built environment. There are current climate and energy strategies implemented globally to try and ensure that by 2020 renewable energy will represent 20% of energy production; a reduction of greenhouse gas emissions by 20% and the reduction of CO2 emissions by 80-90% by 2050 (Zeiler et al, 2012). There is a growing consensus that we must reduce our dependence on rapidly depleting, carbon intensive fossil fuels, which, amongst other things, will involve overhauling how buildings are designed, constructed and used (Kilip, 2010) To achieve this Kilip (2010) outlined that in Ireland a combination of everything from introducing innovative policy, to enforcement of building regulations, to adapting to more advanced construction methods and technologies must be undertaken. It is critical that Irelands return to economic growth is not matched by a corresponding growth in energy demand, where Ireland’s future economic successes are not

undermined by deteriorating environmental patterns and unsustainable energy usage (Lewis, 2009). The managing of low carbon construction in Ireland can be achieved through an innovative policy by the Government to implement BIM. This will provide a unique access to a combination of energy analysis tools that complement the BIM process.

Energy profiling, in the built environment, involves an analysis of the actual or predicted energy performance of buildings and/or an analysis of the embodied energy within the materials and methods used to construct buildings (Crosbie et al., 2009). Energy profiling is explained as involving comparisons between actual or predicted energy use and some type of benchmark or model intended to indicate regulatory requirements, average energy consumption or best practice. In a report issued in November 2010 for low carbon emission which is heavily referenced by the UK's Government's Construction Client Group BIM Working Party Strategy Paper, found that BIM to have the greatest potential to transform the habits and eventually the structure of the industry. This is further recommended by Gould (2008) who believes that BIM's has the ability to model and predict carbon outputs through its environmental analysis packages. In regards to house construction Mah et al (2010) outlines how the BIM approach allows for rapid computations of CO₂ emissions from various house sizes, designs and materials. The use of BIM and the integration of an intelligent database permit end-users to calculate CO₂ emissions for different styles of houses with different types of construction methodology. The McGraw – Hill Green BIM Report (2010) details that robust tools exist within BIM to help in reducing significant carbon emissions though performing analysis on energy performance, lighting and HVAC systems.

The European AEC/FM Sector is also researching the use of BIM for sustainability designing, with a section of this research being funded by the European Commission through the EU FP7 funded project entitled 'Intelligent Use of Buildings' Energy Information (IntUBE). This project is detailed by Crosbie et al (2009) who describe it as a scheme created to increase life-cycle energy efficiency of buildings by integrating the latest developments in the ICT-field into Intelligent Building and Neighbourhood Management Systems. The authors warn us that BIMs and energy simulation tools can also hinder each other and that up to 50 % of the project team's time can be dedicated to performing energy simulation.

Other opportunities to mitigate high CO₂ emissions within the Construction process range from scheduling changes to newer construction practices, such as, pre-fabrication (Mah et al. 2010). Typical wastage rates within the industry are as high as 10-15% (McGrath and Anderson, 2000). A study conducted by the National Audit Office (NAO) showed that highly prefabricated systems can reduce construction periods by 60% and require 75% fewer operatives on site, with consequential benefits for the client, contractor and the local community. BIM is in the unique position to play a major part in the reduction of waste and, therefore, CO₂ emissions through the fostering of better off site fabrication techniques. Detailing BIM software, such as, Tekla Structures can output data from the BIM model directly to machines for fabrication saving significant time on the construction of a project, as the steel structure of a building is known to have a heavy lead time to site (Gavin, 2008). The BIM model can also allow most elements of the building, such as, precast concrete elements or sheet metal and ducting systems to be fabricated from the BIM model off-site. This all leads onto as outlined by Mah et al (2010) to the BIM model resulting in having a positive impact on the environment due to reductions of CO₂ emissions and material waste disposal to landfills. Ireland also faces significant problems in the near future through the "retro-fitting" of Ireland's existing building stock to meet carbon targets. The McGraw–Hill Green BIM Report (2010) states that Green BIM PR actioners find BIM to be particularly useful when it comes to green retro – fitting. Over 27% of the

survey sees BIM as highly applicable for use in green retrofits with 49% believing it to be of medium applicability. The convergence of BIM and Green Building could prove to be the catalyst of ensuring the adoption of BIM within Ireland for long term gains for clients.

In an attempt to promote BIM within the Irish AEC / FM sector and test its application in regards to low carbon management, a recent pilot project was launched. The purpose of this workshop was to showcase BIM to the relevant Government heads and provide valuable primary data towards the implementing of BIM on Public Works Projects

4.0 BIM Pilot Workshop

The RIAI /CITA BIM workshop was held over four days with a number of subsequent presentations given to industry leaders. This workshop was used by the authors to test the research topic for this paper by conducting a number of interviews and through the collection of data from the results of the four day pilot. Semi-structured open interviews were used as the main tool of analysis.

4.1 Pilot Overview

The client for the BIM project was the Department of Education and official observer for the event was the Office of Public Works (OPW). The workshop involved the deconstruction of an existing primary school building and rebuilding it using BIM technologies as outlined in figure 1. This involved a whole project team working in collaboration to maximise low carbon construction and sustainability potential, through the harnessing of BIM technologies.

Build the Base BIM Model ▶ **“Explode” to Standard Components** ▶ **Prepare a New Design**

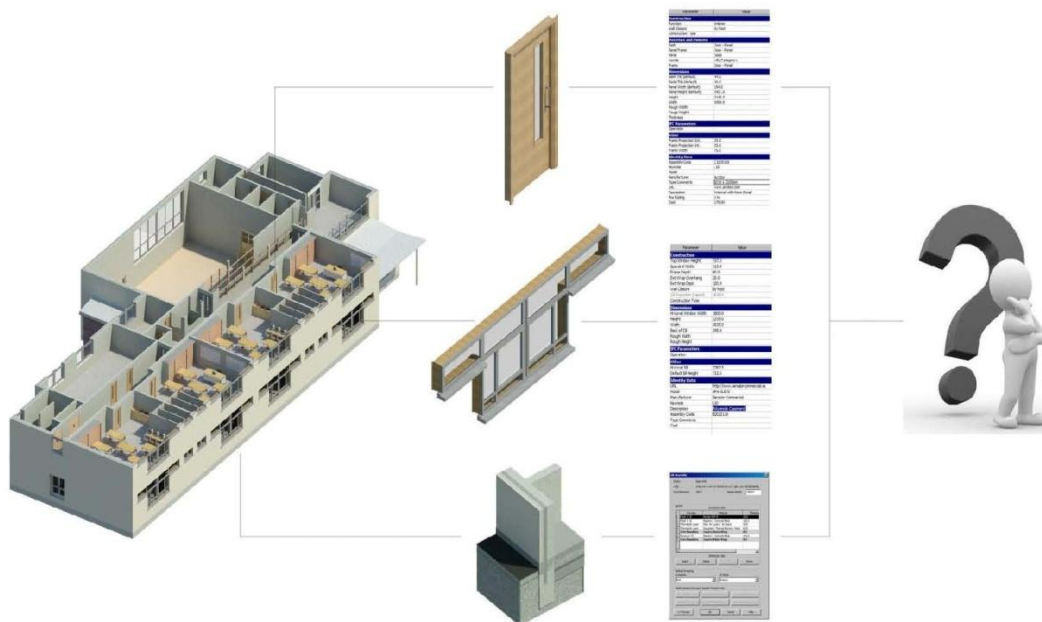


Figure 1: Workshop Overview

4.2 Pilot Team

The pilot team consisted of a number of leading design professionals from selected firms within the AEC/FM sector, integrated into the design team in order to foster the best method of collaboration, as illustrated in figure 2. The pilot team was primarily made up of Consulting Engineers, Services Engineers, Architects, and Consultants as illustrated in figure 3. This team model also consisted of additional support from Contractors, Quantity Surveyors, Technical Support, Facilities Management support for handover documentation and BIM Energy specialists.

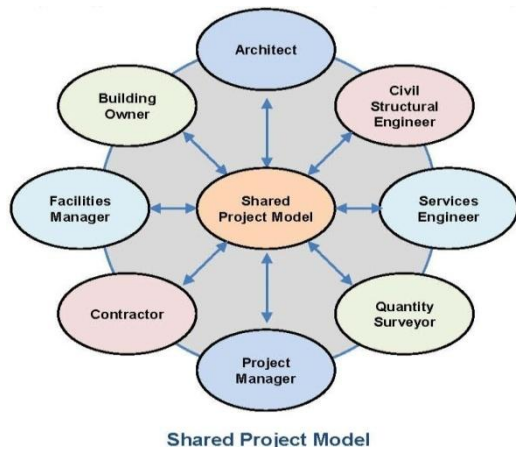


Figure 2: Shared Project Model

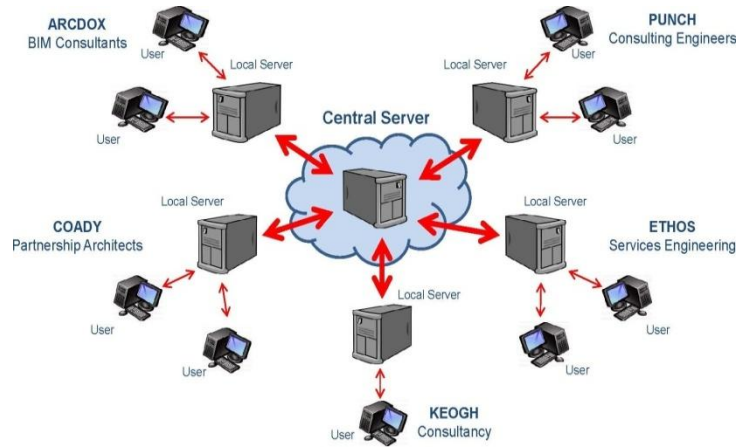


Figure 3: Pilot Team

4.3 Pilot Activities

The BIM model was developed to respond to client specific requirements using a visual communication tool to meet their expectations. The design team was provided with a digital brief with the overall goal to design a BIM model of a standard generic Department of Education school. This model was exploded down to its components and then given to the design team to work on specific components. The various professionals involved all worked on their own model which was synched with a central server allowing all participants of the workshop to monitor each other's work and therefore promoting collaboration. The outline of the workflow for the BIM Workshop is detailed in figure 4 and a section of the model is illustrated in figure 5.



Figure 4: Workflow

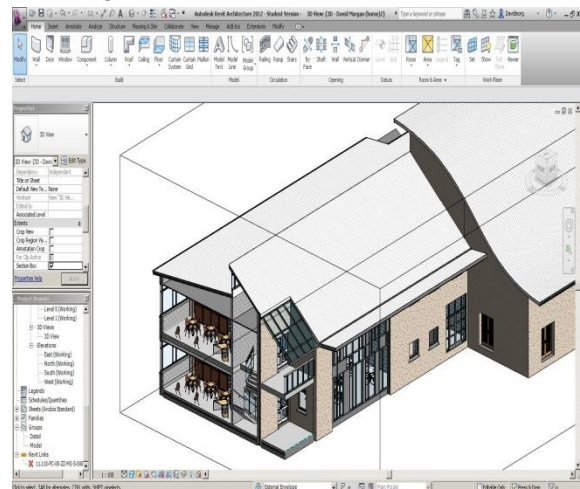


Figure 5: Primary School Section

4.4 Pilot Feedback

The workshop derived results across all sectors and disciplines and strongly advocated the application of BIM to become mandatory in future Public Works Projects. The BIM model was effectively virtually built before having to be physically built, which allowed foresight on a number of key areas and helped identify eventualities that may occur on site. The design team could identify areas of possible clash detection and could instantly confront them before they went to site. The BIM process added a greater cost certainty and reduced a significant amount of the design risk associated with contractors cost. Through the collaborative process of everyone working on the same model enabled the design team to see what the other disciplines were doing and fostered a greater team ethic throughout the design process.

Energy efficiency according to one of the workshop participants is not a priority at the design stage and decisions on materials selection amongst other things are purely driven on cost. The BIM process permitted a different and more sustainable method of construction to be undertaken which helped concentrate on energy efficiency and improved carbon construction. The BIM workshop allowed the designers to create four mass models at different orientations and to perform exercises in concept energy analysis, so as to, choose the most economical and sustainable building possible. The energy model was inputted with weather predictions to aid in orientation data, internal floor areas, the number of people who will use the structure, cost of electricity and fuel, average lightning power, exterior wall area, window area, etc. to enable an accurate analysis to be performed. The energy analysis armed with this data was used to calculate the energy usage for the year and so therefore assuming discounts rates, a life cycle energy usage / cost could be generated. The analysis also provided the user with the predicted renewable energy potential that could be harnessed from the roof PV potential (solar electric) and the wind turbine potential for the mass model, based on its climate and geometry. These figures were subsequently used to generate the net annual CO² emission, which is basically the CO² emissions from electricity and fuel consumption for the analysed model, minus the renewable energy potential. This in turn permitted the BIM energy specialist to provide the Architect with the knowledge to suggest the most carbon friendly building to the Client. The results from this energy analysis are illustrated in figure 6 – 9, where mass model 4 shows the least carbon emissions on yearly basis.

Through the energy simulation for different options, results could be analysed, to see what changes have the biggest impact on the proposed site both positively and negatively. These changes if the Architect felt were beneficial could be incorporated into the design in order to take advantage of this without impeding on the architect's design goals. In the workshop the form and orientation chosen for the school was not the best performance wise. The reason for this was that the information gained from the analysis allowed the design team to understand that there were minimal energy performance gains to be achieved, with opting for a form that was more energy efficient, but performed less well, as a space for the occupants for their required usage. BIM allows an excellent opportunity to perform this sort of energy analysis which can be done extremely quickly and should be used at each stage of design. The energy analysis can also be done when deciding on room and glazing layouts along with daylight analysis. The Department of Education have a set natural lighting for each classroom. BIM enables designers to pick windows that will be in line with Department of Education's standards and give best lighting design. This exercise was carried out in the BIM workshop to inform window sizes based on the required daylight factor for each classroom. The Designs from the model were also imported into studio Max in which enabled the surface of the road to be created. This also allowed traffic to be

seen through animation and could help predict traffic flow and therefore manage future carbon emissions through better traffic management and design.

The use of BIM enabled the designer to have the option to choose a carbon friendly design for the primary school. The energy analysis enabled a relatively easy calculation to be performed in regards to whole-life energy usage for all four design iterations. Energy efficiency lies at the heart of improved carbon management and the designers then have this information early in the design process, which can only have a positive impact on the buildings carbon footprint. To really investigate the carbon footprint then the embodied energy of all the building material must be carefully examined, in which was not performed in great detail due to time constraints.

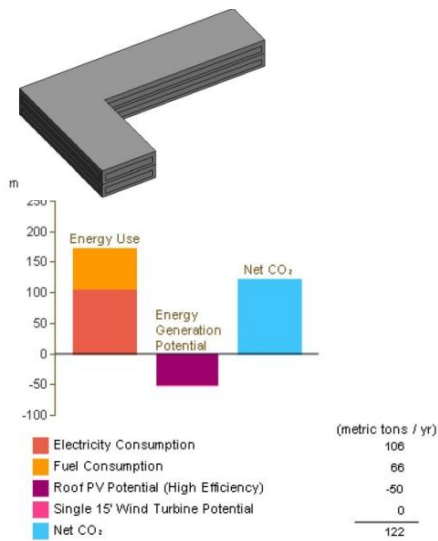


Figure 6: Mass Model 1

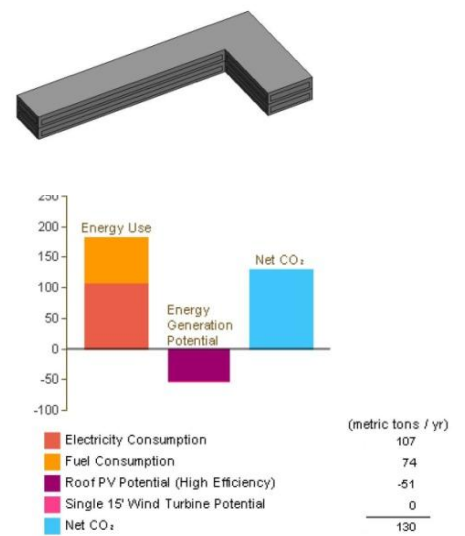


Figure 7: Mass Model 2

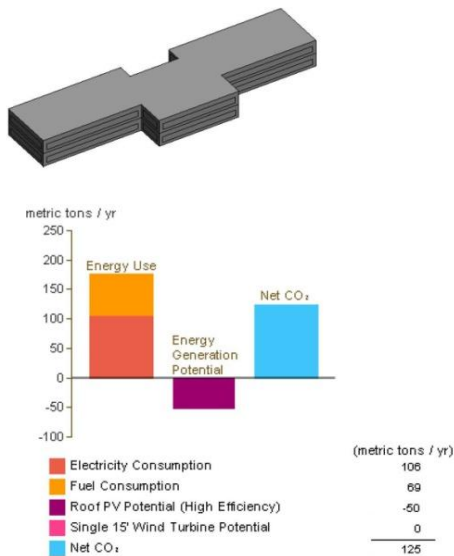


Figure 8: Mass Model 3

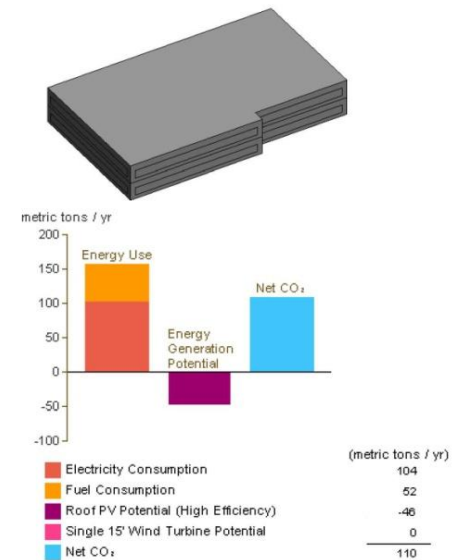


Figure 8: Mass Model 4

5.0 Conclusion

The lack of compatible systems, standards and protocols, and the differing requirements of clients and lead designers, has inhibited widespread adoption of a technology on public sector projects in Ireland. These technologies have the capacity to ensure that all team members are working from the same data, and that the implications of alternative design proposals can be evaluated with comparative ease. The UK government's move to demand by 2015 that projects are modelled in three dimensions will lead to eliminating coordination errors and subsequent expensive changes, which was at the foundation of historical public sector project delivery in the past.

The CITA BIM workshop has offered the opportunity for a whole design team to break a constructed primary school down to its core elements, and re-build it using a BIM platform, which would focus on best construction practice in regards to its overall life cycle. The BIM Model allowed a data rich model, allowing testing of design solutions to provide a more responsive building design to the client brief, and, better coordination of all project information. The workshop proved a success and provided the platform for the Irish Government to see first-hand, how a collaborative BIM model used on a public works projects could provide the cost certainty they so urgently seek. This model showed how through a relatively simple energy analysis undertaken at the beginning of the project permitted the designer to view the life cycle costs of that structure. This analysis can only have a positive impact on the buildings carbon footprint and help the client and his design team choose the most beneficial carbon based construction solution. The embodied energy of all the building material must be carefully examined, which will then along with further energy analysis provide the financial and environmental tools for the Client to choose their building.

There is a need for a more innovative approach in regards to better carbon construction within Ireland, so as to, ensure crippling fines are not enforced and carbon targets are met. Despite the success of the workshop, Ireland is still a long way from embracing BIM on public works projects. Representatives of the OPW noted that despite the benefits that BIM would have on a number of Departments within the Government, it would still require "an act of faith" for the Irish Government to fully embrace it. There is a notable lack of incentive from the Government and reluctance to incorporate more change, due to the, recent introduction of the GCCC forms of contract within the CWMF. This fact, coupled with the fear of legal implications, such as who owns the BIM model and which profession will carry most liability for the model, have left the Irish AEC/FM sector in an uncertain stance towards the implementation of BIM on public works.

The next step in the process for Ireland in promoting the legal adoption of BIM for Public Works Projects has come through the commissioning of ten BIM workshops in 2012. These workshops will be primarily hosted by CITA and are to be sponsored by leading professional institutes throughout Ireland, so as to, promote BIM within the Irish AEC/FM industry. These workshops will address a number of key areas such as the social, cultural, process change management, required for BIM implementation. These further workshops will serve as the consensus for the central role that BIM can play to ensure the practice of design, construction and facilities management for a long term sustainable solution for the build environment.

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- Keogh Consultancy Stewart Construction Moore DFM
- Datech Diatec

References

CITA / RIAI (2011) *CITA RIAI BIM Workshop*, RIAI 8 Merrion Square Dublin 2, 1st – 4th November.

Conseil Européen des Professions Immobilières (2010) *Recast Energy Performance of Buildings Directive*, European Parliament

Construction Procurement Reform (2012) *Capital Works Management Framework, Contracts for Public Works*, available at <http://constructionprocurement.gov.ie/> accessed (06/03/12)

Crosbie, T., Dawood, N. & Dean, J. (2010) Energy profiling in the life-cycle assessment of Buildings, *Management of Environmental Quality: An International Journal*, Vol. 21 No. 1, pp. 20-31

DKM Economic Consultants Ltd (2009) *Report for the review of construction in 2009 and outlook for 2011-2012*, Department of the Environment Heritage and Local Government, <<http://www.environ.ie/en/Publications/StatisticsandRegularPublications/ConstructionIndustryStatistics/FileDownload,24473.en.pdf>> [accessed 07/10/11]

Dzambazova, T., Krygiel, E. & Demchak, G. (2009) Introducing Revit® Architecture 2010: BIM for Beginners, *Understanding BIM*, Chapter 1, pg1, Sybe

Gavin, J. (2008), Advances in MEP software will help foster collaboration, *Focus Magazine*, January, p.70.

Godager, B. (2011) Analysis of the Information Needs for Existing Buildings for Integration in Modern BIM-Based Building Information Management, *Proceedings of the 8th International Conference May 19–20, 2011*, Vilnius, Lithuania

Gould, L. (2008) CRI Analysis - What is BIM and should we Care?, *Construction Research and Innovation*, Vol 1, Iss 2, pg 26-31

Government Construction Client Group (2011) *A report for the Government Construction Client Group Building Information Modelling (BIM) Working Party Strategy Paper – March 2011*, UK Government

Hallberg, D. & Tarandi, V. (2011) On the use of open BIM and 4d visualisation in a predictive life cycle management system for construction works, *ITcon*, Vol. 16, pg. 445

Irish Times (2010) *Green firms to get priority in contracts says Gormley*, Irish Times, Available at <<http://www.irishtimes.com/newspaper/ireland/2010/0522/1224270894108.html>> accessed [06/03/2012].

Kilip, G. (2010) Building a Low Carb Future - The Challenge of Making Low Carbon Buildings a Reality, *Construct Ireland*, Iss 16, <<http://www.constructireland.ie/articles/0215lowcarb.php>> [accessed 06/02/12]

Low Carbon Construction IGT (2010) *Final Report*, available at <<http://www.bis.gov.uk/assets/biscore/business-sectors/docs/1/10-1266es-low-carbon-construction-igt-executive-summary>> accessed [12/02/12]

Lewis, O (2009) *Energy in Ireland 1990-2008*, Energy policy Statically Support Unit, SEI, pp 3-4.

Mah, D., Manrique, J.D, Yu. , Huessein, M.A. and Nasser, R. (2010) House construction CO2 footprint quantification: a BIM approach, *Construction Innovation*, Vol. 11, No. 2, pp. 161-178

McGrath, C. and Anderson, M. (2000), Waste minimisation on a construction site, *Building Research Establishment Digest*, no.447.

McGrath – Hill Construction (2010) *Green BIM: How Building Information Modelling is Contributing to Green Design and Construction*, Smart Market Report

McGrath – Hill Construction (2010) *The Business Value of BIM in Europe – Getting BIM to the bottom line in the UK, France and Germany*, Smart Market Report

National Audit Office, (2005) *Using modern methods of construction to build more homes quickly and efficiently*, Report By The National Audit Office | November 2005, available at <www.nao.org.uk/sector/idoc.ashx?docid=56fa1566-a4fd...1. > accessed [06/03/2012]

Okoroh, M., Dean, A. & Tracadi, E. (2012) *Strategic Framework for Building Environmental Performance, Proceedings of the Joint CIB W070, W092 & Tg72 International Conference On Facilities Management, Procurement Systems And Public Private Partnership*, University of Cape Town, 23-25 January 2012.

Pearce, O., (2008) Holistic Assessment of Sustainability and its application at Halcrow, *JCC*, Vol. 30, pp.37-65.

Wong, A.K.D, Wong, F.K.W. & Nadeem, A. (2011) Government roles in implementing building information modelling systems Comparison between Hong Kong and the United States, *Construction Innovation*, Vol. 11 No. 1, pp. 61-76

Wong, A.K.D, Wong, F.K.W. & Nadeem, A. (2009) Comparative Roles of Major Stakeholders for the Implementation of BIM in Various Countries, *Integration And Collaboration 3, Changing Roles*

Zeiler, W., Maaijen, R. and Masse, W. (2012) Decision Support for Facilities Management of the Future: Sustainability Accelerator, *Proceedings of the Joint CIB W070, W092 & Tg72 International Conference On Facilities Management, Procurement Systems And Public Private Partnership*, University of Cape Town, 23-25 January 2012