Using BIM Technologies to Calculate and Visualise the Global Warming Potential of Building Materials

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Abstract−The built environment has a significant potential to reduce carbon emissions and raw material consumption. Digitisation processes such as Building Information Modelling (BIM) and Life Cycle Assessment (LCA) can offer solutions to improve sustainability throughout the building's life cycle for the decarbonisation of the industry. In Ireland, the Royal Institute of Architects Ireland (RIAI) launched the 2030 Climate Challenge in response to the climate emergency. This sets out a list of targets to meet before 2030 for carbon emissions within the built environment. This research aims to investigate if the application of BIM tools can be leveraged to automate Global Warming Potential (GWP) to support design decision-making in meeting the RIAI 2030 Climate Challenge. This research focuses on the development of a validated database for building materials using the growing register of Environmental Product Data certificates (EPD) necessary for the correct calculation of GWP of building materials. This study has developed a series of workflows that can be used to automate and monitor Global Warming Potential (GWP) to assist professionals in meeting the RIAI 2025/2030 embodied carbon targets. The results demonstrated a proof of concept for automating GWP calculation via the digital building model database and in doing so giving the design team visual feedback empowering them in their design decision-making.

Keywords−Building Information Modelling (BIM), Decarbonisation, Global Warming Potential (GWP), Life Cycle Analysis (LCA), Automation, Embodied Carbon

I INTRODUCTION

In 2021, the Royal Institute of Architects Ireland (RIAI) launched the 2030 Climate Challenge in response to the climate emergency. Adopted from the Royal Institute of Architects Britain (RIBA), this document presents four key challenges with specific targets before the end of the decade. These include a reduction in operational energy demand, a reduction in embodied carbon by at least 40%, a reduction of potable water use by at least 40%, and achieving all core health and well-being targets (RIAI, 2021). The building sector generates roughly 33% of CO_2 in the atmosphere and is responsible for 40% of total global energy through the construction and operation of buildings (McAuley et al., 2019). In Ireland, the built environment is directly responsible for 37% of Ireland's emissions, with 14% consisting of embodied carbon emissions from the production of construction materials, transport, construction, maintenance, repair and disposal of buildings and infrastructure (IGBC, 2022a). To achieve the targets set in the EU Directive on Energy Performance of Buildings

(EPBD), sustainability must become a core focus for educators and firms in our industry. Investments and research in energy efficiency from governments are a necessity for meeting 2050 targets (European Commission, 2018). In addition to this, significant measures are required for the built environment to reach the United Nations – Sustainability Development Goals.

Since the EU launched 'Net-Zero 2050' in 2011, the focus on decarbonisation has been at the forefront of the built environment. In 2021, the Global Alliance for Buildings and Construction (Global ABC) published *'Decarbonising the Building Sector – 10 Key Measures'*- a report containing 10 essential steps to decarbonise the construction industry. From the recommendations, the seventh focuses on building materials that "*enable easy access to information on the carbon footprint of materials*" (Global, 2021). In the same vein, the Irish Green Building Council (IGBC) launched a draft roadmap to decarbonise Ireland's built environment across the entire life cycle. A key recommendation from the draft includes *"publishing a clear timeline on the introduction of*

regulations on embodied carbon to provide certainty to the industry" (IGBC, 2022b). Both reports highlight the crucial role of materials in the decarbonisation of the construction sector.

A major consumer of raw materials (Buildings, 2022), the built environment has a huge role in mitigating climate change. For environmental impacts to be significantly decreased to achieve net zero by 2050, innovative solutions to how the built environment designs, constructs and operates need to be implemented in new construction as well as the existing building stock. Processes such as Life Cycle Assessment (LCA) and Building Information Modelling (BIM) have been widely adopted in the industry as a means of analysing and improving the performance of buildings while allowing decisions to be made at the early stages (Hollberg et al., 2020). LCA is a method for assessing environmental impacts associated with all stages of a product's life cycle (Muralikrishna & Manickam, 2017). Building Information Modelling (BIM) is a process of information management underpinned by collaborative working and digital technologies (BSI, 2023).

This study will develop an automated workflow using BIM tools for monitoring Global Warming Potential (GWP) values to support design decision-making in meeting RIAI Climate Challenge targets, with an overall contribution to decarbonising the construction sector. To achieve this aim, the following objectives were developed in response to the research question.

1) To critically review the synergy of BIM and LCA in the construction sector.
2) To hypothesise a solution with the capacity to incentivise stakeholders to decarbonise the built environment.
3) To progress the hypothesis from theory to application using rigorous testing.
4) To analyse and present findings of the application for the potential implementation in the built environment.

II LITERATURE REVIEW

In response to the first objective, the literature reviewed subject areas in BIM, Life Cycle Assessment, BIM & LCA Synergy, Material Libraries, and Data Management for Environmental Performance. It is imperative to the research that these key topics were extensively reviewed before establishing the hypothesis of the study. The overview presented in this chapter has been resourced using academic papers, national guidelines, recent reports and publications, books, internationally recognized standards, websites from experts in this field, and software providers.

a) BIM
As stated in the introduction of this paper, Building Information Modelling is a process (BSI, 2023). During this process, coordinated digital construction information representing built assets across a project's life cycle is developed using industry-recognized technology and software. Examples of BIM software currently adopted in the construction industry include Autodesk Construction Cloud, Autodesk Revit, Autodesk Formit, Dynamo, Navisworks, Solibri, and ArchiCAD.

BIM has been shown to offer many benefits across various stages of the life cycle. Firstly, in pre-construction, BIM can facilitate better concept and feasibility and enhance energy efficiency design (Eastman et al., 2011), resolve design clashes earlier through visualisation (Latiffi et al., 2016), and enable faster and more accurate cost estimation (Kjartansdottir et al., 2017). During construction, BIM leads to better site utilisation and planning (Deshpande & Whitman, 2014), efficient off-site fabrication using design models (Enshassi et al., 2018), and allows for effective management of the storage and procurement of project resources (Eastman et al., 2011). Lastly, in post-construction, BIM is a strategic enabler for improving decision-making about operations, maintenance, repair, and replacement of a facility (Kjartansdottir et al., 2017).

In the context of sustainability, BIM offers solutions for rapidly producing energy outputs enabling design teams to analyse and compare the most cost-effective, energy-efficient options (Lewis Anderson M. et al., 2015). Another widely adopted method for evaluating and improving sustainability is life cycle assessment (LCA).

b) Life Cycle Assessment
By definition, LCA measures the environmental impacts on products or services across the entire life cycle of buildings (Quist, 2023). Within a life-cycle assessment, four phases are carried out as per ISO 14040: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation (ISO, 2006). A critical element of the LCA process is using environmental impact factor information on products and materials that are found in Environmental Product Declarations (EPDs). EPDs developed through EN 15804:2012 present a standardised way of providing environmental impact data on products

across their life cycle (Ireland, 2022). In an EPD that conforms to EN 15804:2012, the environmental impact indicators report the following:

- Global Warming Potential (GWP)
- Acidification (AP)
- Eutrophication (EP)
- Stratospheric Ozone Depletion Potential (ODP)
- Photochemical Ozone Creation Potential (POCP)
- Abiotic Depletion (Elements) (ADPF)
- Abiotic Depletion (Fossil Fuels) (ADPF)

By adopting this standard, EPDs can be integrated into building assessments through a common methodology for reporting environmental impacts that support decision-making. Construction products and their environmental impact are modelled over five life cycle stages as set out in EN 15978:2011 (ISO, 2011):

- Product Stage (A1-A3) – covers 'cradle to gate' processes for materials and services used in construction.
- Construction Stage (A4-A5) – the construction stage starts from the factory gate of the different construction products to the practical completion of construction work.
- Use Stage (B1-B7) – the use stage covers the period from the practical completion of construction work to the point of time when the building is deconstructed/demolished.
- End-of-Life Stage (C1-C4) – the end-of-life stage starts when the building is decommissioned and is not intended to have any further use.
- Beyond the Life Cycle (D) – this covers reuse, recovery, and recycling potential. To note this is outside of the scope of this research.
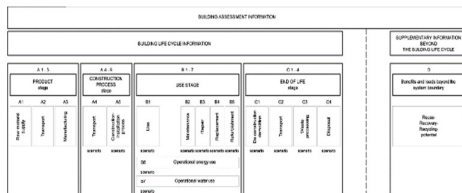

Figure 1- Life Cycle Assessment Stages as set out in ISO 15978 (ISO, 2011)

An EPD Ireland programme was developed by the Irish Green Building Council (IGBC), allowing Irish producers the opportunity to create EPD for their produce in line with EN 15804:2012 and CEN TR 16970:2016. Using Product Category Rules

(PCR), products can be verified and published onto the EPD database that has been digitised, facilitating EPD data to be integrated into BIM tools through a plugin from the LCA tool One Click LCA.

In this research, a 'cradle to grave' approach will be adopted with the inclusion of all life cycle stages for EPD, with a focus on one aspect of an environmental impact indicator – global warming potential (GWP). The next section will focus on the integration of BIM and LCA used to promote the calculation of GWP values.

c) BIM & LCA Synergy

This area has been explored through numerous scientific papers found in the literature. Each study has explored several approaches in the coupling of BIM and LCA as a means of creating a more sustainable industry (Dalla Mora et al., 2020). One of the most common findings across these studies is the adoption of both methodologies for supporting decision-making in the early stages of design (Röck et al., 2018). Palumbo et al., (2020) experiment on achieving accurate LCA results that assist decision-making in the selection of building products and materials. Through analysis, the results highlighted a possible reduction in errors and inconsistencies in LCA results through the integration of BIM and EPDs.

To evaluate a BIM-based LCA workflow in the early design phase of buildings, Nilsen & Bohne (2019) adopt the use of OneClick LCA for design analysis. In a case study approach, a building model is developed and evolved through different levels of development (LOD). It is proposed for frameworks to demonstrate the definition of LOD information evolving through a project life cycle, a consistent combination of LCA databases, and providing a link between LOD levels and LCA databases. Bridging a link between databases through the framework will improve GWP values by emphasizing decision-making processes during design (Nilsen & Bohne, 2019).

In the context of BIM, the LOD set out specifications that give professionals the ability to describe, communicate, and specify information delivery requirements for a project. The term level of development has been replaced by level of information need in the ISO 19650 suite of standards. Moreover, ISO/ DIS 7817 sets out the concepts and principles for the level of information need in BIM.

Assessing environmental impacts from building materials through the application of BIM using EPDs may facilitate environmentally friendly decisions to occur (Shadram et al., 2014). In their

study, a model was produced of a roof structure using Revit, with a material database of EPDs being supplied in Microsoft Excel. Materials that were quantified in the BIM authoring tool were exported to Excel for the final calculation of GWP. It is noted that the workflow requires manual input from users.

A similar key finding was found in a research project for product resource and climate footprint analysis during architectural design in BIM (Sameer et al., 2020). A cradle-to-gate approach was investigated within the LCA boundaries for building elements and construction materials using GWP values. The LCA calculation was integrated into Revit for monitoring changes in footprint results, which were accessible to project design teams. It was found that significant reductions can be made to overall footprint results when alternative design decisions are applied. Due to the task of manually inputting LCA data into BIM objects, real-time footprint analysis is not achievable without an additional tool. This is where adopting a visual programming tool can offer a solution.

Dynamo which comes in the Revit default package offers many automated benefits allowing users to gain insight into designs, improve design evaluation, eliminate repetitive tasks, and prove efficiency in projects (Cadd, 2022). What Dynamo does significantly well, is that it provides a user-friendly interface and built-in functions to assist users without a background in programming.

Using Revit and Dynamo to access GWP totals through an open-source tool called Buildings and Habitats object Model (BHoM) was developed by BuroHappold. By housing this information in the 3D objects, the results can be visualised using some of the Revit functionalities such as filtered views (Houde, 2022). Several other studies have explored adopting Dynamo to connect material databases to Revit to reduce the effort required in carrying out LCA (Cavalliere et al., 2020). To simplify the efforts even further, Naneva et al., (2020) adopt the Dynamo Player in executing analysis through visual programming. This presents a more user-friendly approach for running scripts without opening Dynamo.

The importance of automating material mapping to reduce human error was suggested by Abu-Ghaida & Kamari, (2021) in their proposal of a practical approach to automating LCA using BIM software. The proposed tool from the study introduced a bottom-up material mapping approach to mitigate the errors in material names in a BIM model. By combining EPD data in Excel and Revit, the tool delivers rapid early design-stage feedback on material choices and their environmental impact.

Charts are produced in a pop-up window, as well as custom filters in Revit views indicating where GWP limits have been exceeded. The research team situated in Denmark compared this tool on a case study building using the national LCA tool LCAbyg. Differences that arose in the results of both tools were shown to be caused by four main factors:

-Difference in the plugin's material quantity extraction and the automatic bill of materials obtained by Revit.
-Element areas/volumes with corners are quantified properly.
-Differences in database values in EPDs from sources.
-Differences in results due to end-of-life scenarios.

Abu-Ghaida & Kamari (2021) conclude that the tool is not considered to be a replacement for what already exists on the market, but rather a solution for quick feedback on environmental impacts at early design stages to be used in tandem with other tools such as LCAbyg.

d) Material Libraries
Several of the previous studies discussed to show how environmental data can be applied to Revit materials for calculating GWP totals. For this to happen, a selection of shared parameters is required to host the information. To avoid this process for every new project, utilising a project template containing a material library can give users a starting point.

The adoption of a 'green template' was introduced by Lee et al., (2015) to evaluate GWP impact for BIM-based LCA through a library of building elements using established databases. A similar template was developed by Hawkins Brown with their open-source tool containing a material template library built using ICE databases and per EN 15978:2011 (Bowles et al., 2021). Adopting this workflow enables designers to quickly review and visualise GWP impacts throughout the design process (Schwartz et al., 2016). Providing a Revit template file containing a baseline of materials has also shown benefits in establishing consistency and efficiency in streamlining decarbonisation using digital tools (Collier, 2022).

Outside of the Revit environment, ARUP has invested in a carbon insight typology library of commonly used elements and systems in buildings and infrastructure. It is anticipated that this will guide designers in decision-making by providing GWP totals at the A1-A5 lifecycle stages (ARUP,

2021). Although not currently available, the build-ups and systems could include native files for downloading into projects.

While these examples provide an excellent starting point for designers, it is important to note that manual inputs are required in the development of additional materials outside of the generic suite supplied with the template. Consequently, if external BIM objects from manufacturers' websites are imported, they will also require to abide by the standards set in the template. Hollberg et al., (2020) suggest that adopting predesigned components may limit freedom of design, and architects may not want to use this approach. They continue that perhaps it is best suited for projects that contain standard components such as modular and prefabrication.

e) Data Management for Environmental Performance

These studies show different innovative ways that EPD data can be married with BIM technologies to support decision-making during design stages. Nevertheless, it is clear from recent literature that there is no standardised approach to how construction product EPDs are digitised to support BIM. Recognising the necessity to eradicate the environmental impact of the building sector, ISO 22057 was developed to standardise the digitisation of EPD providing data templates for the use of EPDs for construction products in BIM (ISO, 2022).

Research carried out by Anderson & Rønning (2022) investigated the use of standards to maximise the benefit of digitisation of construction product EPD to reduce Building Life Cycle Impacts. Through adopting ISO 22057, it is envisioned that digitised EPD results are accompanied by machine-readable and machine-interpretable data in a common format that can be used alongside BIM. The authors note there is a huge potential for a rapid digital transition of building LCA could be achieved through ISO 22057. In the early design stages, where the information available on EPD data is absent, a generic LCA data template is available by adopting this standard. This may overcome the barrier pointed out by (Röck et al., 2018) of the wide application of LCA at early design stages due to uncertainty in the design and materials.

Schulze, (2022) discusses how the standard provides a common language amongst stakeholders, information can be captured and shared that is traced to a credible source. This is supported by Lavagna (2020) who acknowledges digitised EPDs

in machine-readable formats – Extensible Markup Language (XML) as being an important first step in the integration of data in BIM and LCA software. Further work, however, is needed for Revit-compatible LCA tools to include an importing feature for XML files (Lavagna, 2020).

In application, empowering BIM software with construction object data templates and EPD properties has led to GWP evaluation using IFC models integrated with carbon assessment algorithms (Cerny et al., 2023). In Estonia, a similar development was presented by Raitviir (2022), where an automated digital building permitting system was introduced. Although not currently a requirement, the system has the functionality to automate GWP totals based on an uploaded BIM model that has been developed using a default national GWP database for typical materials (Raitviir, 2022).

There have been several concepts explored in the literature review that introduce examples of BIM & LCA synergy, BIM & EPDs, leveraging BIM for GWP calculations, material libraries, and data management for environmental performance. From a design perspective, several studies have implemented the use of Dynamo for automating Revit tasks and giving rapid GWP results to support decision-making. More recent developments demonstrated methods in how BIM models can become verification tools through the automation of GWP totals. The next section will discuss the importance of both workflows to the research methodology and present the hypothesis that has been influenced by the findings of the literature review.

III RESEARCH METHODOLOGY

This chapter will describe the research methodology and methods that were selected following an exploration of several forms of research. A study was undertaken to establish the most suitable approach. Taking an already existing process such as BIM to extend its functionalities to solve real-world problems has led to the adoption of Design Science Research (DSR). In its simplest form, DSR is a problem-solving paradigm that seeks to enhance human knowledge via innovative solutions to real-world problems (Hevner et al., 2004).

The main objective of DSR involves the creation of new and innovative "artefacts" in the form of constructs, models, methods, and instantiations (Gregor & Hevner, 2013). In the context of DSR, an "artefact" can be a new development, adding to

an already existing process to expand its capabilities (vom Brocke et al., 2020). Approaching this research to join existing processes (BIM with IGBC database of materials) to automate GWP values (innovative solution is the reason for choosing this methodology.

This methodology as outlined by (Peffers et al., 2007) involves six activities to be integrated into the overall research project. Below lists the six activities and how the structure of this research paper will follow the DSR methodology.

1) *Problem identification and motivation – define the specific research problem and propose a solution.*

- Through a literature review, the problem, and motivation for this research were identified. It is clear from the literature significant steps are required to support the decarbonisation of the built environment. Global ABC recommends providing accessible and easily attainable information on the carbon footprint of materials. This is echoed by (S. McGuinness, 2022) who states that there is a need to record data on GWP values to verify designs. In addition to verification requirements, McGuinness (2022) continues that the proposal needs to *"de-skill"* and *"de-risk"* current GWP workflows.

  Furthermore, the recent publication of the RIAI 2030 Climate Challenge presents targets encouraging their members and the wider construction industry to act with urgency to reduce the environmental impact of the construction sector in Ireland. The targets established by the RIAI – in line with the EU Level(s) Sustainable Buildings Framework – sets out clear thresholds to be achieved in domestic, non-domestic, and school project settings. In response to this initiative, the research will work to the thresholds set out by the RIAI and demonstrate if the proposal can be used to support professionals to make better decisions throughout a project's lifecycle. Moreover, with the correct information, tools, and processes in place, it is hoped that the construction industry can achieve a net zero whole-life carbon for new builds and retrofits by 2030.

2) *Definition of the objectives for a solution – create objectives for a solution from the problem definition.*

- The objectives for a solution expand upon the objectives already stated in the introduction of this paper. The overarching aim of this paper is to incentivise stakeholders to decarbonise the built environment using BIM technologies. Elaborating on the aim, the paper hypothesises two possible solutions in response to the research question:

H1 - The proposed tool/workflow will have the potential to deliver real-time lifecycle GWP calculation that will incentivise better decision-making in decarbonising the construction sector.

Throughout the literature review, several existing LCA tools were explored and reviewed for their functionalities, usability, and interoperability with BIM tools. While LCA tools have a user-friendly interface, these tend to be technical and appear daunting to those who do not have sufficient training. Moreover, the extra costs of training, licences, and plug-ins to an already expensive suite of BIM software may prove to be a barrier in practices adopting LCA tools. For that reason, the application of this theory will de-skill this process by producing a cost-effective solution embedded in Revit, offering rapid feedback on GWP calculation. Design decisions will be influenced by this workflow in the attempt to de-risking and decarbonising the built environment.

Therefore, the first proposal is built on the theory presented in papers by Palumbo et al. (2020) and Röck et al. (2018) who focus on the early-design stage GWP calculation. For this research, the tool will focus on all project stages rather than the early-design stage. This will transform design, as every decision a designer makes as they develop the design will have a lifecycle carbon footprint which gets added to the building's GWP total. In addition to this, Abu-Ghaida & Kamari, (2021) stress the importance of automating material mapping to reduce manual errors. Taking this into consideration, to prevent human error, an automated approach will use digital EPDs in machine-readable formats (XML) as suggested by Lavagna (2020). To make the workflows easily accessible, the visual programming aspect will introduce Dynamo Player for running scripts for a more user-friendly approach Naneva et al., (2020). This experiment will be in a Revit template file encapsulating a generic

material library based on the IGBC database. Like studies from Lee et al., (2015) and Bowles et al., (2021), the "green template" will provide a starting point for monitoring designs.

H2 – The model will be used as a verification tool to record and monitor the GWP totals of a building.

Secondly, the model will then become the verification tool at various project milestones where the verified GWP will be confirmed by the model. This will enable a declaration of GWP per m^2 of floor area for regulatory purposes. As well as this a timestamp and signature will be supplied providing evidence of declaration. In a BIM process, GWP targets may be included in the client brief and information requirements as part of the plan of work (LETI, 2020).

Additionally, to monitor progress in a BIM project, information exchanges/data drops present the opportunity to confirm the status of a project in line with the brief. Models that are required in these information exchanges can host the GWP declaration that can be used to verify the established targets and make comparisons with previous versions.

3) ***Design and Development – create the artefactual solution.***

In preparation for creating an artefact, the following strategy has been developed using the tools and data sources identified in the above section.

Conceptually, the artefact will be designed using a visual programming script (Dynamo) used to map EPDs into a BIM design software (Revit). Within Revit, a series of information containers (parameters) will be created that contain information on the GWP values of selected material from the IGBC database following the standard EN 15804. Using a selection of schedules and formulas based on the standard EN 15978, the total GWP values will report and evaluated based on the targets set out by the RIAI 2030 Climate Challenge. Rapid feedback on GWP totals will be presented in schedules and using visualisations (Revit & Dynamo).

4) ***Demonstration – show the efficacy of the artefact.***

- The proposed artefact developed to support the hypothesis of this research will involve experimentation. The developed workflow will be broken down into a series of steps and demonstrated through images that can be found in the research testing section of this paper. In addition, the supplementary ePortfolio of this research will contain a walkthrough demonstration video of the process.

5) ***Evaluation – measure the efficacy of the artefact for addressing the problem.***

- The evaluation of this proposed workflow will be presented through the findings from the demonstration stage. These will be used to evaluate the workflow and discuss the potential application in the built environment.

6) ***Communication – conclude and communicate the importance of the artefact for the problem.***

- In collaboration with stakeholders of the Department of Housing, Local Government & Heritage of Ireland, the designed artefact will be presented to discuss its future potential.

IV RESEARCH TESTING

To thoroughly investigate the proposed theories presented in the second activity of DSR, the path for experimental research will be organised into key stages as presented below:

1) Preparation of data sources to be used in the study.

2) Creation of a material library and shared parameters based on GWP data.

3) Designing and modelling an example to be utilised for research testing and experimentation for this study.

4) Creation of a visual programming script to map EPD data to building materials inside the model.

5) Creation of additional visual programming scripts used to visualise the GWP data of the model and compare thresholds.

Stage 1 – Preparation

To begin the experimental part of this research, the first step involved identifying the data resources to be used in this study. This was necessary to establish the parameters of the research. The following data sources have been identified that the research will be working to:

Benchmark: Target set out in the RIAI 2030 Climate Challenge (Table 1)
Standards: EN 15804, EN 15978, and ISO 22057
Database: IGBC National Inventory of Generic Construction Materials Data / The Inventory of Carbon and Energy (ICE) database
Environmental Impact Factor: Global Warming Potential (GWP)
BIM Tools: Revit, Dynamo
LCA Tools: OneClick LCA
IFC Viewer: BIMcollab ZOOM

RIAI-Embodied Carbon Threshold	Dwellings	Offices	Schools
2025 Target	800 kgCO$_2$e/m^2	970 kgCO$_2$e/m^2	675 kgCO$_2$e/
2030 Target	625 kgCO$_2$e/m^2	750 kgCO$_2$e/m^2	540 kgCO$_2$e/

Table 1- Embodied Carbon Thresholds (RIAI,2021)

Stage 2 – Material Library and Shared Parameter Creation

The second stage of research testing involved the creation of a geometric Project Information Model (PIM) using Revit 2023. Information embedded in elements within a model use 'parameters' for hosting specific characteristics to identify that object. The standard Revit template comes with a suite of parameters; however, this functionality can be expanded upon using shared parameters. Several shared parameters were created based on EN 15804 and using the information for formulas in a schedule per EN 15978. In Figure 2, the list of parameters shown divides the various stages of a product's life cycle. To note, the parameter 'Density (ton/m3)' was created separately from the one supplied through the standard Revit template for scheduling purposes. For filtering materials in the schedule, a 'yes/no' parameter was created to control what information is captured. Lastly, a 'UUID' parameter will provide a link to the XML file that contains an EPD dataset. In the example below, this is set to N/A as the current material library contains generic data.

Figure 2- GWP Shared Parameters

The library itself is built on the National Inventory of Generic Construction Materials Data from the IGBC website. This list contains a dataset for the GWP impact indicator of 15 different material types (28 in total) in the Irish construction industry - covering the Product Stage (A1-A3). Where gaps were found on certain products like 'gypsum', 'concrete block', or 'mineral wool', the ICE database was adopted. A summary of the materials found in the database can be found below.

- Average Cement for Ireland
- CEM I produced in Ireland.
- CEM II/A-V (<20% PFA)
- CEM II/A-L (<20% Limestone)
- CEM II/A-S (<20% GGBS)
- CEM II A-D (<10% silica fume)
- CEM II/B-S (<35% GGBS)
- Average CEM II
- CEM III/A (35-60% GGBS)
- CEM III/B (66-80% GGBS)
- Average Aggregate for Ireland
- Average hot rolled steel coil used in Ireland.
- Average cold rolled coil used in Ireland.
- Average galvanised steel value used in Ireland.
- Average organic coated steel used in Ireland.
- Average steel section and steel rail value for Ireland
- Average reinforcing steel used in Ireland.
- Average aluminium sheet used in Ireland.
- average aluminium foil used in Ireland.
- Average aluminium extrusion used in Ireland.
- Average float or coated glass used in Ireland.
- Average facing brick imported from the UK (excl transport)
- Average Irish C16 timber
- Irish-produced OSB
- Irish-produced MDF
- Imported MDF (737 kg/m3)
- Average imported Chipboard Particleboard (640 kg/m3)
- Average imported plywood

As the database is supplied in Excel, this provided the perfect opportunity to use Dynamo to create the materials and map the generic GWP value for the Product Stage. Through a visual programming script, the list of materials in Excel can be developed into Revit materials within seconds. This will remain in the template as a starting point for authors at the early stages of design (Figure 3).

Figure 3 - Revit Materials Based on IGBC Generic Database

Stage 3 – Schedule Design and Modelling
Within Revit, parameters of building elements can be selected to create lists of schedules and material take-offs in a tabular display of information. To avail of this functionality, a material-take-off schedule was created listing out all materials in use within the model highlighting their GWP totals using formulas per EN 15978. To differentiate the elements in the model, design options were created for generic materials versus EPD materials.

To establish the weight of each material, a multiplication of 'Material: Volume' by 'Material: Density (ton/m3)' is required. This is followed by a calculation of all 'GWP Stage' parameters as listed in the previous stage. The GWP of all stages is then multiped by the 'Weight of Material (ton)' to confirm the 'Total Material GWP (ton CO₂e)' for each element. To establish the 'Building Footprint' impact per element, the 'Total Material GWP (kg CO₂e) is divided by the 'Building Gross Area (m^2)'

For demonstration purposes, four different materials are shown in the schedule to show the overall GWP within the model (Figure 4). A total sum is then calculated through the schedule. The formula is based on the following:

GWPbuilding = Σ (GWPproduct 1, GWPproduct 2 … GWPproduct n)

Where:

GWPproduct = GWP Product Stage(A1−A3) + GWP Construction Stage(A4−A5) + GWP Use Stage(B1−B7) + GWP End of Life Stage(C1−C4)

As projects are developed further, the schedule will automatically fill out the based material selection and add through the 'yes/no' parameter.

Figure 4a - Calculation of GWP Total and Building Footprint

Figure 4b- Calculation of GWP Total and Building Footprint

Stage 4 – Mapping EPDs to Materials
In the preliminary stages of design, specific materials may not be known. This is why the IGBC / ICE material library template presents a selection of generic figures to allow calculations to begin at the earliest possible stage. When products and suppliers are established, designers can begin to implement specific data from EPDs to obtain accurate GWP totals. EPDs can be supplied in either PDF format or through structured datasets using XML - a machine-readable data format. Upon comparing both formats for an EPD of the product 'Kingscourt Clay Brick', several observations were made that influenced this stage.

First, with PDFs, there is the task of downloading the document and then proceeding to manually input figures into parameters within Revit. This

can be a tedious task and opens the possibility of human error when inputting. Moreover, the units shown in the documents require conversion to comply with units within the Revit model. For example, the GWP of the A1 module in the PDF value is 1.42E+01, whereas the dataset provides a value of 14.2, the latter of which suits a Revit workflow. To avoid errors and adopt a common language, the use of XML datasets was selected as a method for mapping EPD data to materials in Revit using Dynamo.

To expand upon the standard package of Dynamo nodes, the LunchBox for Dynamo (2018.7.6) package was downloaded for reading XML data. Figure 5 illustrates the Dynamo script that has been organised under their function. Section 1 (Pink) pulls information from the XML file that has been downloaded from EPD Ireland and creates a list. Section 2 (Blue) searches for any data that includes GWP information and organises them into separate lists according to their stage. Before pushing this data into Revit, these are divided by 1000 for using the unit for tonnes. When this is complete, the data is mapped to a corresponding material within the Revit model. For providing a link between the EPD dataset and the Revit element, the Universally Unique Identifier (UUID) has also been mapped.
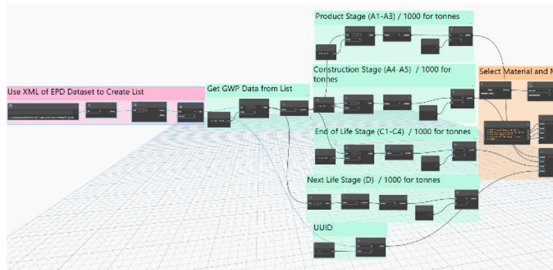

Figure 5- Dynamo Script for Mapping XML Data to Revit Parameters

Stage 5a – Second Visual Programming Script

Whether users are adopting generic or detailed information (Generic vs EPD Design Options), the second Dynamo script has been developed to assist users in their decision-making based on the calculated totals of the schedule in Stage 3. The graph sets out to a) Collect GWP total values from the schedule, b) Find the material with the highest GWP value, c) Pull all elements in the model that corresponds with the material with the highest GWP value, and d) Create graphics to illustrate the GWP contents of the model in a pie chart, as well as highlighting in the active view any element containing the material with the highest GWP value by overriding the graphics. For creating charts and user-friendly interfaces, the Data-Shapes

(2022.2.105) package was deployed. Additional custom packages downloaded in this script include bimorphNodes (4.2.4), Clockwork for Dynamo 2.x 2.4.0, Crumple (2022.5.57) and Rhythm (2023.2.2).
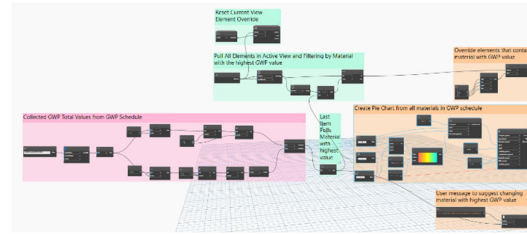

Figure 6- GWP Visualisation Tool through Dynamo

Stage 5b – Third Visual Programming Script

While Stage 5a focuses on GWP totals of specific materials, a variation of this script was developed to capture the GWP footprint of the project building. The reason for this is to allow users to visualise where the building total can be compared against threshold targets at any stage throughout any given project. In place of a pie chart, a bar chart was selected comparing three different values: a) Total GWP Building $kgCO_2e/m^2$), b) RIAI 2025 Threshold ($kgCO_2e/m^2$), and c) RIAI 2030 Threshold ($kgCO_2e/m^2$). To calculate the 'GWP Building Total ($kgCO_2e/m^2$)' this is divided by the building area that has been extracted from the model. Custom packages deployed for this script include Data-Shapes, Crumple and bimorphNodes.

Where the RIAI Targets for dwellings were used for this example, the values can be customised for commercial and school projects, as well as other specific benchmarks. In addition, a link is provided to the RIAI 2030 Climate Challenge document that can be accessed by clicking the 'Help' button on the user interface that is generated when executing this script. For declaring the GWP value and the time of calculation, the total for the building is pushed into parameters hosted in 'Project Information' with a timestamp and who is responsible for the declaration.
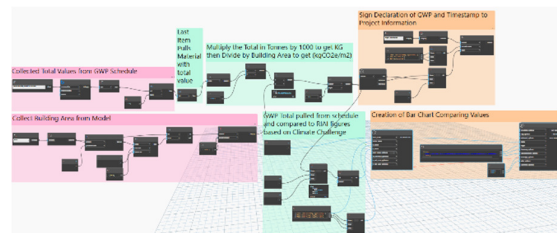

Figure 7- Compare RIAI Thresholds and Declare GWP Totals

V FINDINGS & DISCUSSION

In the previous chapter, the workflows for this research were proposed for implementing GWP analysis within a Revit/Dynamo environment. The following section discusses the findings found through research testing.

a) Material Library and Schedule

A material library template was generated hosting a generic selection of materials based on the IGBC database. Within the materials, a series of GWP parameters have been integrated for purpose of analysing designs. To evaluate the functions of the schedule, a selection of materials was shown in a multi-category material takeoff created to calculate GWP totals. A benefit of the relationship between elements, materials and schedules in Revit is shown when changes are made to the model. For example, if a wall is added or deleted, this will automatically pick up in the scheduled grand totals. Elements that were modelled in the testing phase were applied to design options for comparing generic and EPD data. To import data from the digital EPD (Kingscourt Brick), a dynamo script was prepared for transferring GWP values, as well as the UUID (Figure 8). Unfortunately, not all data could be retrieved from the XML file as the 'Density' was not included. To overcome this, the density was identified through a technical data sheet from the manufacturer.

Figure 8- EPD UUID embedded into the material in the model.

b) Visualisation Tool

As a visualisation tool, the results of the GWP schedule within the 'Generic' design option were published through charts, prompts, and graphical displays. When executing the scripts in Stage 5a, three outputs occurred. First, a message prompt identified the material with the highest GWP value. From the materials listed in the schedule, the material 'ICE_Concrete_Block_215mm' had the highest GWP value and was highlighted in Figure 9. Followed by this, a user interface appeared that contains a pie chart of all materials extracted from the schedule, and their total GWP value (Figure 12). By hovering over the chart, the percentage of

material out of the total was identified. These charts can be published to a drafting view within Revit and can be kept for a record. Finally, to locate any element within the model that contains 'ICE_Concrete_Block_215mm', a red graphic override was set within the active view of the Revit model (Figure 13).
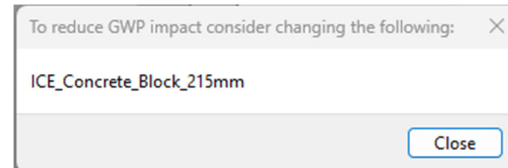

Figure 9- User Message indicating the material with the highest GWP value.
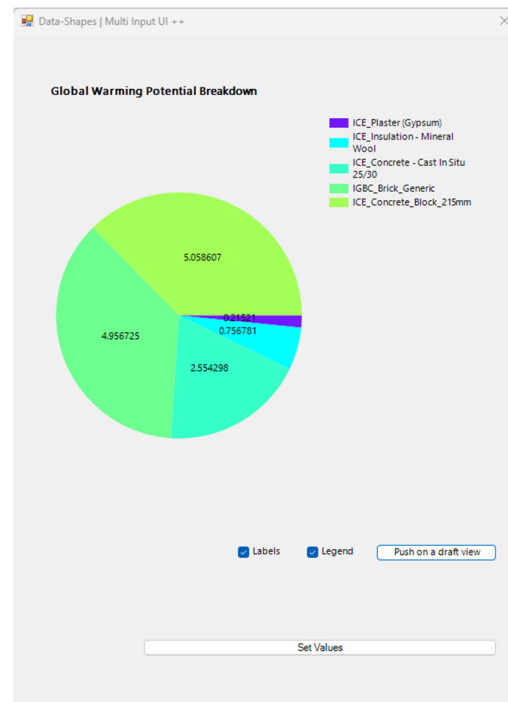

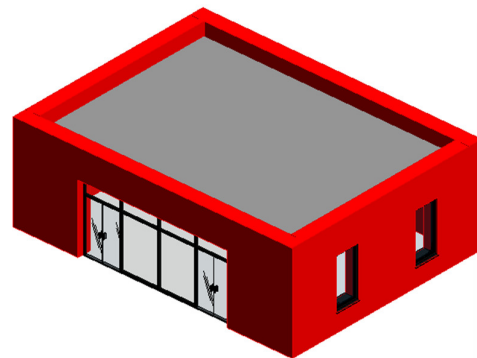*Figure 10 - Pie Chart Containing GWP Breakdown of Model*

Figure 11 - Graphic Override in Active View of Elements containing highest GWP content.

Like Figure 10, by running the script from Stage 5b, a bar chart was presented that illustrates the total GWP extracted from the schedule that can be compared to thresholds. In this instance, the RIAI targets for 2025 and 2030 were shown, however, any threshold can be inputted for use in comparing totals. Further to this, the 'Total GWP Building ($kgCO_2e/m^2$)' was mapped from the schedule into a parameter in 'Project Information'. To note, as this is a proof of concept, a small section was modelled to test the workflows. Therefore, the total GWP was considerably low in comparison to the RIAI Targets (Figure 14).
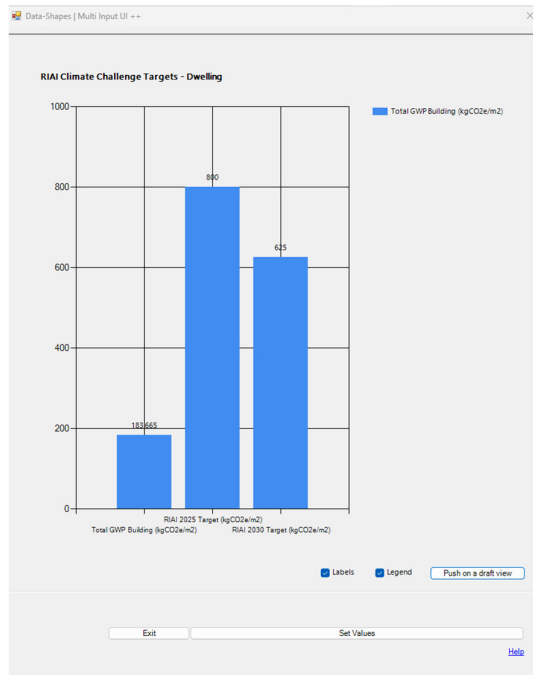

Figure 12- Threshold comparison to building total and declaration of GWP.

c) Verification of GWP

For verification of the GWP value, the mapping of 'Total GWP Building ($kgCO_2e/m^2$)' was inserted into the project information section of the model. Additionally, to keep a record of when the calculation took place, and by whom, a timestamp has been applied to 'GWP Declared On' along with initials for 'GWP Declared By' (Figure 13).

As this testing was primarily carried out in Revit, the model was exported to IFC to review if this information would transfer into an IFC file. Using a free viewer (BIMcollab Zoom), the project information appeared in the IFC file under 'Energy Analysis' (Figure 14). Exporting IFC files presents

an opportunity for stakeholders to review models without access to authoring software (Revit).

To note on the exporting stage, this information remains static, and trust is needed amongst stakeholders to confirm that the provided values have been validated within Revit before exporting. This does, however, provide a record of declaration that can be used at project milestones to confirm carbon targets, while being fully accessible through a free viewer.
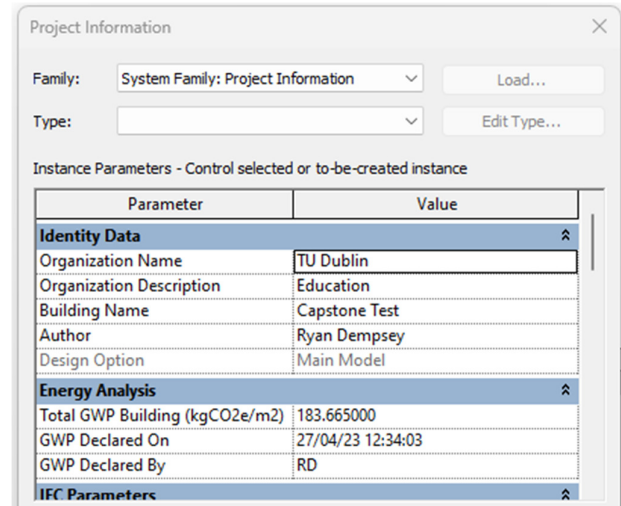

Figure 13 – Project Information of Test Model

Figure 14 – Verification Information Visible in IFC Viewer

VI CONCLUSION & FUTURE WORK

The purpose of this study was to investigate if BIM technologies can be leveraged to automate GWP to support decision-making in meeting the RIAI 2030 Climate Challenge, contributing to the decarbonisation of the built environment. Engagement with the Department of Housing, Local Government & Heritage of Ireland provided the starting point for this research. Therefore, the results of this study will be communicated with stakeholders to establish if the research proposal has been met, as well as discussions on the potential application, issues with the study, and next steps.

In response to the research proposal, four objectives

were identified, first to comprehend the subject matter and then to conduct an application of theory based on the outcome of the literature review. Research into the integration of workflows for BIM and LCA is paired with previous studies (Dalla Mora et al., 2020). In supporting the BIM and LCA workflow, the use of material library templates has been introduced in different studies (Bowles et al., 2021; Lee et al., 2015). As a visualisation tool, different techniques were identified for supporting decision-making in Revit (Houde, 2022; Kamari et al., 2022; Naneva et al., 2020). These studies provided the building blocks for the conceptual framework and method for this research study thereafter. Two theories were proposed based on the findings from the literature review and through engagement with stakeholders from the Department of Housing, Local Government & Heritage of Ireland.

H1 - The proposed tool/workflow will have the potential to deliver real-time lifecycle GWP *calculation that will incentivise better decision-making in decarbonising the construction sector.*

H2 – The model will be used as a verification tool to record and monitor the GWP totals of a building.

For both theories, the research study approach was selected based on the DSR methodology. It was demonstrated that several workflows could be adopted to influence the decision-making process of professionals in the built environment. By marrying GWP data with objects within BIM authoring tools, it is possible to create workflows for rapid GWP calculation that could incentivise users in their choice of materials to meet the targets set out in the RIAI 2030 Climate Challenge.

Firstly, creating a material library template provides users with a starting point when commencing the modelling of a design. If users properly maintain standards set in developing materials, GWP totals can be easily calculated. However, there are limitations that users need to be made aware of before adopting this workflow. When duplicating materials in the library, this will reset all parameters to the default figure and will require additional input. Moreover, as data is manually inputted, the values will need to be verified by a custodian.

Secondly, to overcome the process of manual inputs, an approach of automatically mapping datasets containing EPD information was investigated. For keeping this study within an Irish context, the datasets hosted on EPD Ireland were chosen for testing. It was found through reviewing the content on the platform that there are currently 102 EPDs available to download, compare this to the German platform ÖKOBAUDAT with 1153 total entries. Building a Zero Carbon Ireland aims to improve on this figure for the coming years with milestones set for EPDs of main products in 2024, followed by all products before 2030. An example XML file of an EPD was downloaded to evaluate extracting information related to GWP and UUID values of a product and mapping them to elements in a Revit model with Dynamo. This requires some knowledge of visual programming to understand where and how the information is being mapped across. Nevertheless, the workflow can be achieved through Dynamo to prevent any human error in the manual inputting of information. To ensure the script can work seamlessly using any EPD dataset, it is recommended that they are structured in a standardized way to allow ease of data extraction. Further to this, the density of the chosen EPD was not included in the downloaded dataset and was sought from the technical specifications of the manufacturer. This proved that one element of the automated mapping process required manual input.

Thirdly, in support of the material takeoff schedule, various visual aids were explored to be utilized when making decisions during design. These included charts, graphic overrides, and message prompts. When running these scripts, users are provided with instant feedback on GWP values through a pie chart that highlights all the materials that were extracted from the schedule. All elements in an active view associated with the highest GWP value are presented in a red graphic override, as well as a prompted message noting what the material is. It is recommended to a keep view dedicated to reviewing elements to avoid any unwanted overriding of other views.

Revit can be daunting for novice users and those without experience in LCA and EPD terminology. Furthermore, the testing was conducted with a student license. Without adding to the current costs of software, the workflow in this research aimed to present a free solution that can be adopted where resources do not allow for additional tools. Additionally, the workflow presented aimed to offer a simple and quick solution for providing GWP totals that could support users in decision-making. By conducting a comparative study, the results showed a slight difference of 0.0432526% in the figure for tonCO$_2$/e. However, when rounded to the nearest number the value of 53 kgCO$_2$e/m^2 matches. It was never envisioned that the workflow presented in this research should replace any industry tools for LCA calculations. The tool offers an alternative method of calculating GWP values in a simple and free way before any official reporting is required. of materials.

While Ireland does not have a regulated GWP threshold, in the coming years, the Building a Zero Carbon Ireland plan will introduce requirements for disclosing embodied carbon values, followed by a mandatory set of embodied carbon limits (IGBC, 2022a). For this study, GWP was selected as one aspect of the RIAI 2030 Climate Challenge for testing. Further research into the application of BIM for the remaining targets such as operational carbon and potable water should be explored by industry professionals and academic specialists.

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