AUTOMATIC CARBON TOOL IN SINGAPORE

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ABSTRACT

Growing interest towards carbon neutrality have led to the proliferation of carbon footprint calculators (both online and software) to aid building professionals in quantifying the carbon impact of buildings. While carbon calculators can ease design-carbon quantifications and expedite design decision-making, the use of such carbon calculators is often tedious, time-consuming, and difficult due to the need for extensive input data, lack of dependable localized carbon data, transparency, scalability, and interoperability. This is especially true in Singapore's context where the building industry at large, still new to the concept of carbon impact and computation, lack operative knowledge on carbon computation and local carbon models or standards to refer to. Hence industry players find it difficult to integrate carbon computation in current work processes.

Keeping with Singapore's carbon agenda to achieve carbon reductions by 11% below business-as-usual levels by 2020, the paper presents a new carbon tool that facilitates carbon management and carbon tracking in the planning and design of Singapore industrial developments. The new carbon tool focuses on 4 key innovation:

1) automation of carbon calculation with minimal user intervention,
2) interoperability with prevalent design and simulation tools,
3) a single consistent carbon calculation methodology that is scalable throughout all stages of development, and
4) transparency and usability of carbon tool.

Through literature studies, analytical and empirical studies, embodied and operational energy are identified as key contributors of carbon emission in buildings. Fundamental technologies and methodologies encapsulating the mentioned features forms the basic software framework, allowing the new carbon tool to be used for design-support activities and allowing users to maintain a carbon perspective throughout design.

INTRODUCTION

Given the increasing concern of environmental impact on buildings, many building professionals have begun applying a conscious effort in performing holistic life cycle assessment of buildings (equivalent to carbon footprint), to analyse the carbon emissions effect on climate change and make informed decisions on carbon reduction and mitigation strategies. In Singapore, the government is committed to cut carbon emissions by 7-11% below business-as-usual levels by 2020. On this front, various carbon calculators were developed to help ease the carbon quantification process. These calculators however primarily focus on organizational applications to existing small offices or households, and remain inapplicable to the general building stock. Given that buildings account for 20% of total carbon emission (BCA, 2013) and that decisions made during early planning stages can significantly impact amount of carbon emission, it is imperative that carbon mitigation strategies are already explored and committed during design stages. To perform carbon computation during this process however will require architects to learn and be trained in carbon computation methods, a task which involves investments in manpower and time, or monetary investments in expert consultants to do the job. While the Singapore building industry may refer to overseas-developed carbon calculators, it is imperative to note that none of the them are suited for comprehensive carbon analysis, much less a design support tool that helps maintain a carbon perspective throughout design process. The key challenge in successfully implementing carbon calculation in Singapore's building industry is thus at the operational level for the agencies and building industry at large to have the technology that is dependable, eases carbon computation, and help maintain a carbon perspective throughout design process (Fig 1).

The key contribution of this paper is to elaborate on the development of a new carbon tool that is designed to work seamlessly with existing modelling software without any disruption or deviation from current work processes, supports and facilitates multi-stakeholders decision-making process

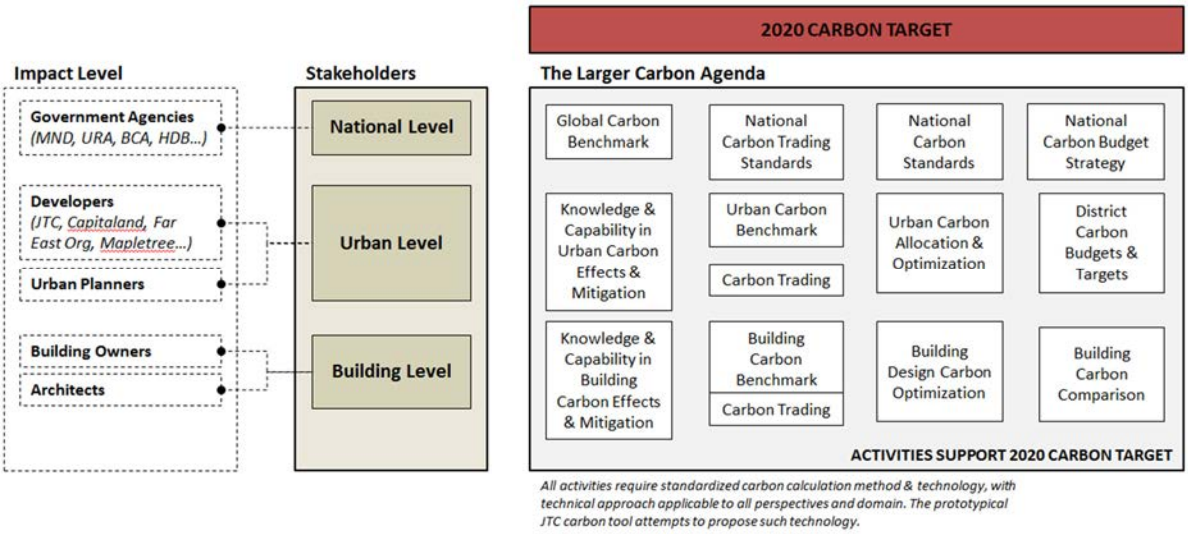

Figure 1 Activities that support multi-stakeholder carbon perspectives toward 2020 Carbon Target

throughout project stages. The new carbon tool builds up a supporting technology with locally-adapted databases, calculation methodologies, and computational techniques (focusing on automation, case-based reasoning, applied heuristics) to satisfy carbon quantification needs and ease previously difficult carbon computation processes, thereby enhancing carbon decision-making capabilities of stakeholders without enforcing the need to invest in time and effort to learn carbon computation methods and software technicalities.

LIMITATIONS IN CONTEMPORARY CARBON TOOLS

Unable to support comprehensive carbon perspective

Research (UNEP, 2010 & WRI, 2004) have classified carbon emissions of buildings into 3 types 1) embodied carbon from building material, process and manufacturing of materials, 2) operational carbon from operational and maintenance of buildings, and 3) organizational carbon from demolition, recycling and processing of waste. The need to provide holistic assessment of these 3 carbon types is imperative, yet most contemporary carbon calculators only tries to vaguely address one or two aspects of carbon emissions in buildings and not holistically account for all 3 influencing categories of carbon emission. These calculators are found to require varying levels of input information, ranging from as little as 5 input fields to as many as 20 input fields. The accuracy of carbon results generated from each calculator is thus dubious and the implicit calculation method highly questionable.

Existing carbon calculators also lack the ability to encompass the carbon perspectives of multi-disciplinary stakeholders (government agencies, planners, developers, architects) and facilitate their decision-making needs. They typically support carbon quantification for individual habits and at best individual buildings, not accounting for district or urban level analysis of which activities at these levels have greater impact on the larger carbon agenda.

	Calculators from Padgett's paper										Singapore Carbon Calculators		
	American Forests	Be Green	BEF	Carbon Counter.org	Chuck Wright	Clear Water	The Conservation Fund	EPA	Safe Climate	TeraPass	NUS-OES	SEC Climate	Hemispheres Foundation
Type of Analysis													
Embodied Carbon						√							
Operational Carbon	√	√		√	√	√	√	√	√	√	√	√	√
Organizational Carbon	√	√		√	√		√	√	√	√	√	√	√
Input Level													
Household	√	√		√	√	√	√	√	√	√	√	√	√
Small organization												√	
Large office								√					
Planners & developers													
Government													
Number of input field													
5 - 10				√	√		√						
10 - 20		√						√		√			
> 20	√					√			√		√	√	√
Does the calculator work in CAD													
Are the Assumptions known	√					√	√	√		√	√		
Are the Methods known						√	√			√			

Figure 2 Comparison of existing carbon tools

Limitation in computation capabilities

Apart from the lack of support in multidisciplinary carbon computation needs, the technical limitations embedded in contemporary carbon calculators likewise result in a process that is tedious, difficult, time-consuming, and filled with ambiguity. Technical limitations include high inconsistencies, lack of transparency, scalability, and interoperability, and consequentially significant inaccuracies (Padgett, 2008, Bottrill, 2007, Pablo, 2009). The lack of transparency in assumed parameters, calculation methods, and carbon conversion factors leads to results that are difficult to ascertain as accurate or reasonable; and thus results seldom provide meaningful and applicable knowledge to users.

Research (Bottrill, 2007) has also highlighted the lack of localized empirical data that is applicable and usable for carbon calculation in specific context. Most carbon conversion factors readily found and accessible from online databases and in research projects are adapted for the larger European and North American context with limited information for ASEAN countries. To use these figures within

Singapore's context will result in a less dependable carbon evaluation.

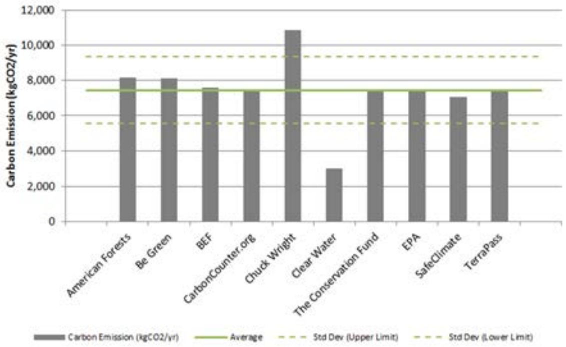

Figure 3 Inconsistencies in carbon results due to differing carbon data & methods

Confounding the meaningful use of carbon calculators is lack of scalability across design stages due to varying information level-of-detail (LOD) across stages of development. With varying LOD at different stages, the availability of information invariably determines the technical approaches used to calculate carbon. It is however difficult for a single carbon calculator to be consistently used across stages of development. Most contemporary carbon calculators often require detailed information which is only available after detailed design stages, and cannot account for the varying LOD that is observed across stages of design. Contemporary carbon calculators are therefore not scalable and post-evaluative.

Most existing modelling software does not support the sharing of building information with other performance evaluation tools (Wong et al, 2000, Bazjanac, 1997, Papamichael, 1997). In other words, software-based carbon calculators that are developed for specific software may not be interoperable with the other diverse set of modelling software used in industry practices. The semantic and syntactical differences between modelling and simulation tools often result in conflicting and missing information. To perform carbon calculation, users are required to manually transfer and translate geometrical models into different software platform and repopulate missing information; a process that has been noted by researches to be inconsistent and incomplete, resulting in high redundancies, time and effort required to manually rectify errors.

THE NEW CARBON TOOL

Retrospective to motivation by Singapore government to reduce carbon by 2020, the new carbon tool is developed with close examination of local industry practices and policy processes, and focuses on building up quantification capabilities of building industry, providing ease of computation, and supporting multi-stakeholder decision making across project stages through the effective management of carbon perspective in planning and design of Singapore industrial developments. The tool focuses on several technical innovations to achieve an immediately implementable, highly integrative tool that facilitates carbon analysis, benchmarking, budgeting, and optimization. The proposed technology will radically alter currently disruptive and post-evaluative carbon computation processes that generate minimal value impact on overall carbon reduction. The technical innovations are listed as such:

- Localized carbon & energy database
  (maintain relevance of results to Singapore's context, database can be further enhanced as more local data comes in)
- Automation of information transfer & carbon-related logistical tasks
  (minimal user input, zero disruption to current work processes)
- Scalable information model
  (calculation method and results remain applicable and comparable across project stages, maintains carbon perspectives)
- Interoperability with prevalent design and simulation tools
  (eliminate need for expert user, no time or cost investments required to learn software technicalities, no manual effort required to perform daunting tasks)
- All assumptions & calculations made explicit – "transparency"
  (instils high level of confidence in carbon result)

CARBON METHODOLOGY

All carbon computation methods used for the new carbon tool are founded upon research done on identifying the level of impact of the different carbon activities. Research (UNEP, 2010, IEA, 2010 & Huang et al., 2012) rightly identifies operational (~ 80%) and embodied (~ 20%) carbon phases to have significant impact on buildings' total carbon emission. These findings are largely consistent and apply to Singapore's context. The same research showed organizational carbon to only account for a minimal portion of carbon emission and is thus not impactful enough to influence decision-making. This is due to the lack of well-established datasets, which impedes meaningful implementation, and accurate quantification of activities within the after-use phase. The new carbon tool focuses squarely on first providing the fundamental technology that addresses the 2 main carbon phases, before further enhancements in later years to achieve a holistic carbon assessment. While organizational carbon is difficult to quantify and computation is currently not supported in the new carbon tool, the team nonetheless recognizes the significance of HVAC in carbon and thus supports carbon calculation for the use of HVAC refrigerants and equipment across its lifespan including the installation, operation, and disposal stage (after-use phase).

Localised carbon database

Part of this research emphasizes on formulating a dependable and localized carbon database. Operational carbon draws upon 2 main sources: 1) local case studies, and 2) local government and industry standards. Empirical data collected from a diverse set of audited local case studies, comprising of general offices, R&D laboratories, flatted factories, and ramp-up factories, are used as default load assumptions for energy calculation. Where information is unobtainable from these audits, Singapore standards and building codes were used as reference.

While operational figures are very much straightforward and can be obtained from government building codes, sourcing for appropriate embodied carbon emission suited for Singapore's context can be an arduous task. Given that the research primarily focuses on computational techniques entailed in carbon computation and to ensure a working prototype, international databases for embodied carbon are used, with reasonable accuracy, in the new carbon tool. Detailed life-cycle analysis accounting for material embodied carbon in Singapore will be done by our counterpart in another research project (Teo et al., 2013), and subsequently updated into the current database in future.

To reasonably use international emission factors for Singapore's context, the embodied calculation appends the estimated carbon required to ship the materials from the various source location to Singapore. A constant shipping emission factor, obtained from DEFRA is used to multiply with distance required to transport materials from each country to obtain total transportation carbon emission. The summation of material emission factor and transport emission factor will give the total embodied carbon emission. The eventual embodied calculation equation will be as such:

Mass x [Material emission factor + (Distance X Cargo Emission Factor)] = Embodied Carbon

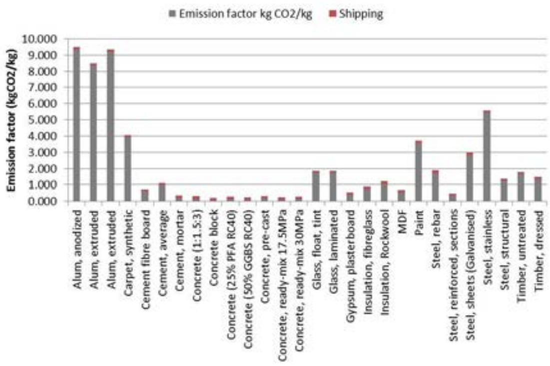

Figure 4 Embodied carbon with transport

AUTOMATION

The use of current carbon calculators is counter-intuitive and disruptive to conventional work processes, often requiring users to work beyond the boundaries of their CAD modelling platform and learn new software and modelling approaches. Semantic and syntactical differences between modelling and simulation platforms make the transferring building information between domains difficult and error-prone. To overcome this limitation, the new carbon tool focuses on automation, with applied heuristic approaches, of carbon calculation with zero (or minimal) user intervention and integrates well with local widely used design modelling platform. The innovation can be presented on two fronts: 1) seamless and automatic transfer of information between tools, and 2) automatic population of missing data based on smart assumptions.

Automation of information transfer

The new carbon tool is prototyped as a plug-in within Revit Architecture, a BIM platform that is endorsed by the Singapore building regulators and nationally adopted by the building industry as part of the local building submission requirements. Without deviating from standard drawing conventions, users only need draw design models of varying levels of abstraction (according to stages of design), and preliminary carbon analysis will be instantaneously calculated at a click of a button. The enabling technology behind such automation is the creation of a complete and well-formed Shared Object Model (SOM) whereby a general BIM, removed of domain-specific semantics, is maintained. The SOM functions like a mapper, facilitating information transfer between domain models (EnergyPlus, Revit, XML database), where the domain models being subsets of the SOM, can be derived from the SOM.

An example of such application is the translation of user-defined materials within Revit to the equivalent material entities to be specified in EnergyPlus, and carbon database. For every material specified within the Revit BIM model, a support module within the SOM formulates association, automatically translates, and performs necessary syntax translations into EnergyPlus material entities and XML database containing respective material carbon emission factor. Assuming a complete and well-formed SOM, the domain model is thus also complete and well-formed at all times.

This approach brings multiple benefits. In achieving full automation, users will not be required to deviate from their conventional work processes and will be able to instantaneously obtain carbon results based on any modifications made within the Revit model. Given the generality of the SOM, any type of domain model can be derived, achieving extensibility to other

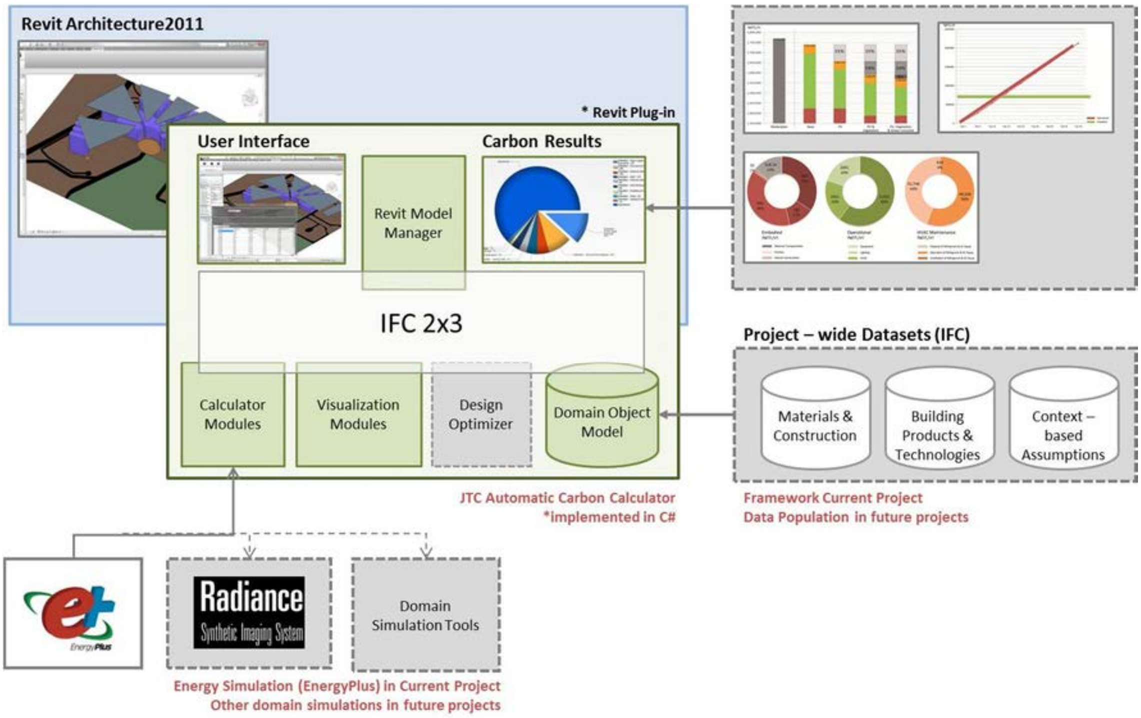

Figure 5 Software Framework

domain simulations in future. This ensures that the new carbon tool, even with the need for future extensibility, can be readily adopted and deployed by the building industry without any changes to current resources, manpower, capabilities, or work processes.

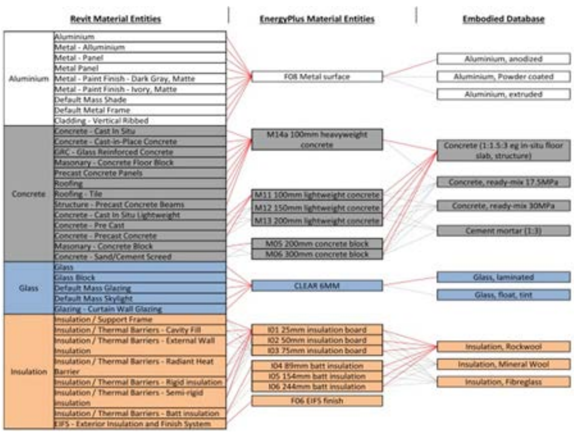

Figure 6 Material association for automatic translation

Automatic population of missing data

All carbon models (data libraries, interface controllers) are likewise formulated as computable. In early design phases, the design model is incomplete. Information (material thermal properties, operational schedules, internal gains, HVAC systems) required for simulation is unavailable and remains missing for most parts of the design process, until later detailed stages. To ensure a consistent carbon calculation, through the use of first-principles based calculation such as state-of-the-art EnergyPlus energy simulation tools, a database of context-based assumption is necessary to supplement the SOM and complete missing information.

The database, implemented as an XML-based dataset, is formulated based on 6 empirical surveys covering building types: general offices, R&D lab, flatted factory, ramp-up factory; of which the measured data is considered minimally sufficient for the demonstration of the new carbon tool. A case-based reasoning approach is implemented to hierarchically organize the data according to real-world building characteristics, with identified metrics and indicators that the context rule-sets can query on. To support automation needs, proper codifying of tacit knowledge is required, where the quality of context-based analysis and assumptions is highly dependent on 1) the breadth and quality of memory and experiences that is being drawn upon, and 2) the correct identification of metrics or indicators that would accurately categorize and predict the missing attributes or information.

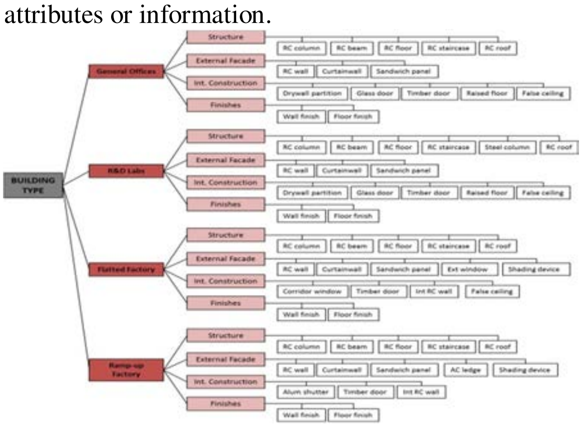

Figure 7 Decision-tree algorithm in database

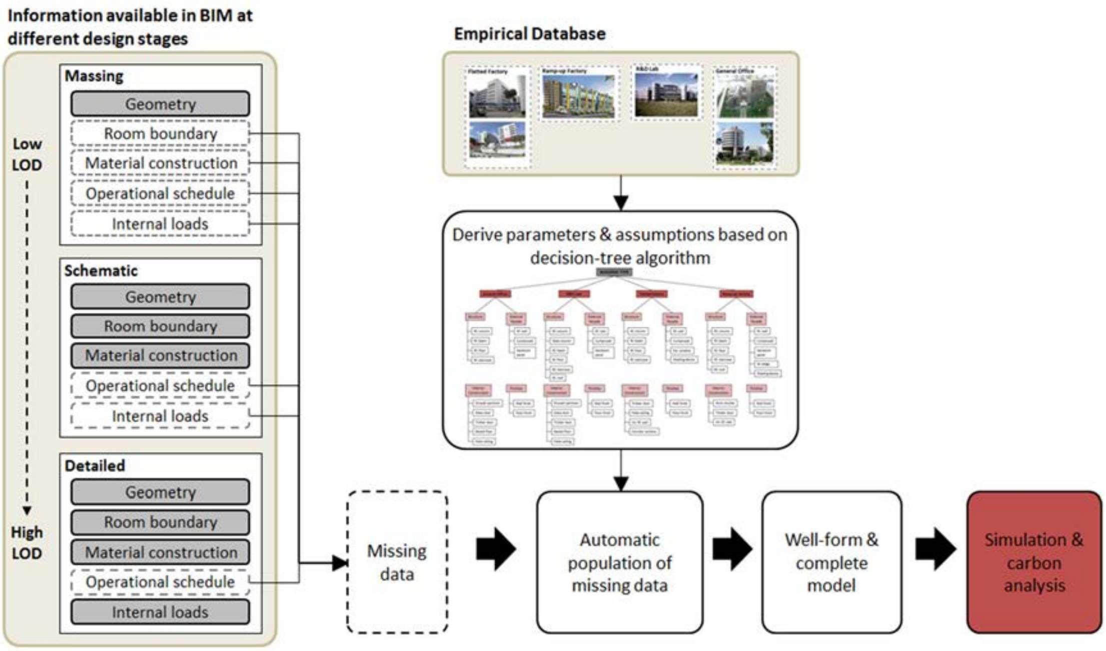

Figure 8 Automatic population of missing data

A support module which is part of the SOM is then developed to derive parameters and assumptions from the XML-database, automatically populate any missing information that cannot be obtained from the BIM model, and use these assumptions as placeholders for carbon calculation. Using the decision-tree algorithm, this extraction of assumptions from database highly mimics human experts' analyses (information processing) and considers a variety of information, including building type and various building geometric attributes, in much the same way a human expert would examine building design and drawings to make reasonable assumptions and estimates for missing information. The assumption value to be extracted from the database is based on probabilistic analysis of the relative frequency of known values in the dataset (Huang & Liu, 2013). In doing so, ensures a complete model that is always ready for carbon calculation. Previously technically challenging tasks such as digital modelling and parameter definitions for energy simulations are now automated, drastically reducing expert-time in model preparation from a few weeks to a few minutes.

SCALABILITY

Addressing the need to appeal to a wide audience of industry players and ensuring maximum relevance to national needs, the new carbon tool directly addresses the issue of scalability by means of automation technology described in earlier section. The new carbon tool is designed to function from physical scales of estate planning to parcel developments and individual buildings, and is capable of analysing models of varying levels-of-detail (LOD).

The tool facilitates the perspectives of different stakeholders and deals with varying levels of abstraction without compromising accuracy of carbon results. With reliance on a single consistent carbon calculation method and applied heuristics to reasonably populate missing data based on building types, carbon results during sketch design phases can be presented to users with a level of confidence. With only one user-defined input: building type, values and parameters pertinent to this building type (through decision-tree algorithm and automation) along with building parameters derived from BIM model, will be used for carbon calculation. The applied heuristics are progressively replaced by EnergyPlus simulation, and context-based datasets replaced by information retrieved from detailed BIM model as LOD increases, thereby achieving scalability and ensuring consistent performance assessments across all stages of development. This oppose to previous processes where planning and policy agencies only have access to grossly generalised statistical projections of carbon impact that possibly underestimate or overestimate carbon figures.

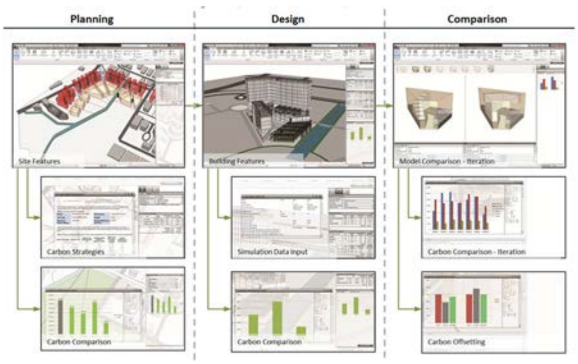

Figure 9 Scalability across design stages

INTEROPERABILITY

The development and implementation of the software technology was planned with Industry Foundation Class (IFC) schema in mind. Motivation to use IFC schema in the new carbon tool is the need to streamline processes to coincide with national standards, ensuring that the tool is always applicable to industry efforts. IFC is recognized as an adopted national standard in Singapore, and is widely used to allow overall modularization and interoperability vis-à-vis industry research efforts. The new tool utilizes Industry Foundation Class (IFC) schema as the main information standard.

Databases and calculation methods are designed to be well-encapsulated in IFC-ready modules, and each software module (including data libraries, DOM manager, and controllers) are likewise IFC-ready. This allows for extensibility for future implementation where technologies developed in this project can be easily deployed and implemented in IFC supported design modelling tools such as Sketchup, Microstation, and ArchiCad. Databases developed as part of this project can also be shared and extended across project teams, eliminating the need for replication of similar information. Enhanced interoperability technologies will potentially eliminate previously intermediary processes that are considered tedious, time consuming, and high-expertise tasks. Different industry players are likewise no longer compelled to learn new software approaches and technicalities in order to work different information schema.

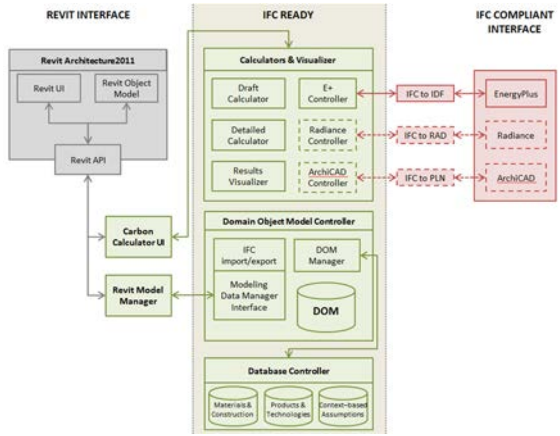

Figure 10 IFC ready modules & interfaces

TRANSPARENCY

The new carbon tool supports transparency of all pertinent assumptions, parameters, calculation methods, and databases through the form of look-up tables, reference charts and diagrams, and analytical graphs. The tool maintains a simple and interactive graphical user interface (GUI) with adoption of a "drill down" approach to allow progressive detail-oriented inspection of values and parameters used in carbon computation, thus ensuring a high level of confidence in the carbon results generated. A general workflow illustrating the "drill down" approach is as such.

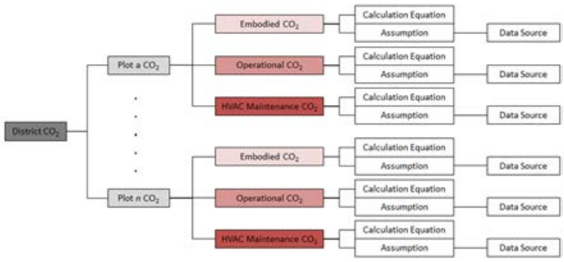

Figure 11 Workflow of "drill down" approach

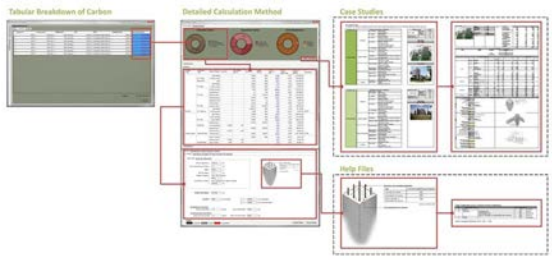

Figure 12 Drill down of information sources

Within the Masterplan carbon model, the main GUI presents total carbon emission of all building plots in the district, with a function equipped to further inspect carbon figures (embodied, operational, HVAC maintenance) for each building plot. Each component listed is appended with detailed explanation on assumptions and calculations.

VALIDATION

As proof of concept and validation, two carbon computational approaches including conventional carbon calculation methods, and the proposed automatic carbon tool, are used as comparison (Fig 12). To maintain consistency and relevance of comparison, geometrical model and its associative parameters (room boundary, thermal zones, and material thermal properties) are kept the same. An abstract representation of an existing Singapore building is used as the basis for comparison. Operational schedules and internal loads are kept different to demonstrate the reasonableness of adopted assumptions derived from database. Work processes to model and calculate carbon for each computational approach is documented in Figure 13 (black solid lines – requires manual input, red dotted lines – automated).

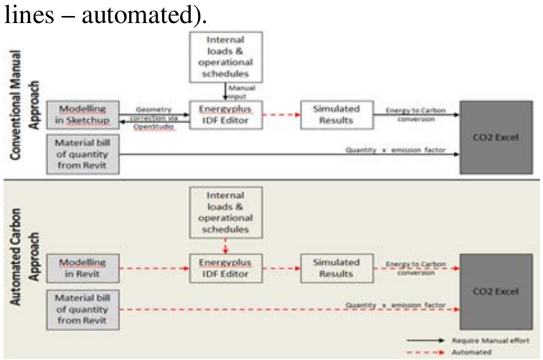

Figure 13 Comparison of 2 approaches

All else being equal for embodied and HVAC maintenance carbon emission, preliminary operational carbon comparison (using default assumptions) between the 2 computational approaches showed 81% differences. Upon investigation, it was shown that 69% of that 81% was attributed to extremely high equipment loads. This is due to the nature of the building being a high power intensive industrial building, of which has yet to be included in our datasets. The actual load was 10 times higher than default assumption used in the new carbon tool. The equipment load in the new carbon tool was thereafter adjusted to reflect actual load, and carbon calculation was repeated. The difference between the 2 approaches then stood at 12%. Minimal difference is attributed to varying operational schedules, and slight differences in occupancy and lighting loads. This validation thus supports the feasibility and applicability of such automated computational approach in calculating carbon emissions of buildings.

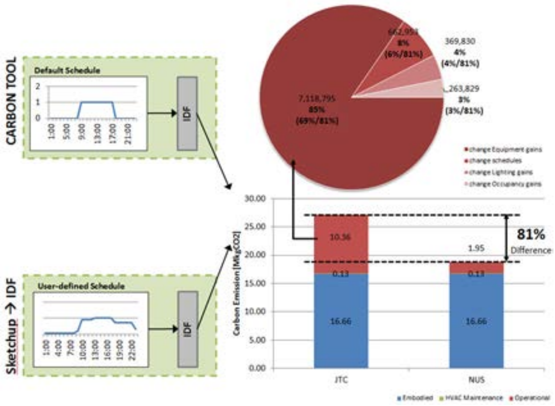

Figure 14 1st Carbon results

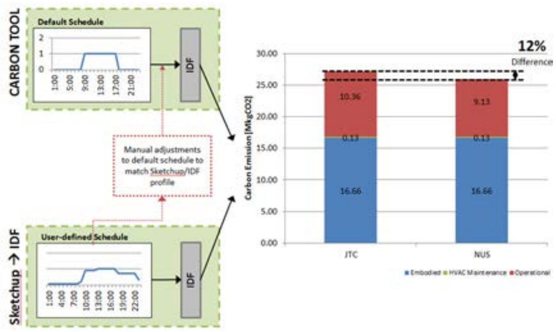

Figure 15 Carbon results after calibration

CONCLUSION

The new carbon tool is an effort in the ground research thrust to build simulation tools that facilitate ease-of-use, and design support tools that may bring computation support such as carbon calculation upstream in design processes. At the heart of this carbon software is the automatic preparation of a full EnergyPlus simulation from design model (Revit Architecture) with minimal user intervention.

The key effort of this project is to build the technological framework; additional work is required at a later part to build better datasets, investigate into software validation and user testing.

ACKNOWLEDGEMENT

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