AUTOMATIC SIMULATION AND CARBON ANALYSIS FOR ARCHITECTURE DESIGN

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ABSTRACT

This paper presents computational work in building information management, data interoperability, and data population, to support automatic carbon analysis. The goal is to build an effective design support tool to help maintain a carbon perspective during building design, and as such accuracy and ease of use are pertinent objectives. This entails computational capability to automatically manage information flows between different domains and tools and generate useful operative information for design decisions, including 1) processing incomplete building models into well-formed and complete models, 2) integrating and matching data sets of material properties and emission factors, 3) automatic EnergyPlus simulation, and 4) analysis & visualization (post-processing).

The computational approach in this research attempts to address well-recognized challenges in automating and delivering easy-to-use simulation-based design support tools:

1. Disparate data sources, ontologies and schemas
2. Missing data in early design stages required for energy simulation

By leveraging on existing research in building information modelling, expert systems, and case-based reasoning, this paper presents application findings and developments in computational approaches to enable automatic simulation and carbon analysis in a prototypical design support tool. Specifically, prevalent software and information schemas were adapted to work with a split Shared Object Model (SOM) and Domain Object Model (DOM), case-based reasoning and heuristics were developed to facilitate automatic simulation, and the various computational approaches were integrated to deliver an expert system that is fully automatic, and does not deviate from existing industry practices and processes. While the current implementation utilizes a decision tree, the implementation also supports data analytics in completing building models, suspending the need for a priori ontological models.

INTRODUCTION

This research is interested in developing prototypical automatic carbon analysis software in support of synthesizing high performance building designs. Carbon calculation in this context is more than just using a computer program to predict carbon footprint of buildings; but rather it entails the management of information flows between different domains and tools throughout the entire design stage, defining useful information for design decisions. This research thus falls within the larger research topic of computational design support tools, borrowing on the hypothesis that fast and easy to use tools are beneficial to building design as they help a designer achieve more design iterations within the same design time constraints, given the ability to evaluate design performances much faster than manual processes. The objective of this research is thus to develop such a fast and easy to use tool, and the same premise sets the limitation. Within the same spectrum in providing ease-of-use, the carbon tool is prototyped as a plug-in within prevalent BIM tool - Revit Architecture. Thus eliminating the need for users to learn new software and modelling approaches.

DISPARATE DATA SOURCES, ONTOLOGIES AND SCHEMAS:

Building Information Modelling is a well-established albeit far from ideally implemented concept. To facilitate interoperability, the research utilizes Industry Foundation Class (IFC)(Bazjanac,1997) schema as the main information standard, which quickly and effortlessly supports various data sources and subsequent domain tasks and tools.

It is difficult and not necessary to design a holistic Building Information Model (BIM).By defining some holistic BIM as an externally implemented Shared Object Model (SOM), energy and carbon perspective is domain specific, and would only require a subject view of this holistic model. The Domain Object Model (DOM) is thus defined as a special model in this research, where requirements can conceptually be defined (and linked to SOM via IFC) but not within the scope of this research.

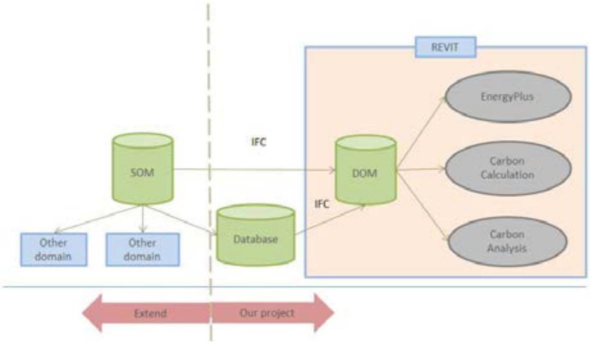

Figure 1 SOM/DOM Diagram

SHARED OBJECT MODEL:

Based on existing industry research, the process of transferring pertinent building information from BIM models to energy simulation is often difficult and incomplete; resulting in the need for extensive time and effort to correct models. This is largely attributed to differing semantics between design models and energy simulation models. As an example, within the domain of architectural design, 3D model construction is often represented as building elements such as rooms, wall, floor, and roof. An energy simulation tool however, is concerned with thermal zones and surface boundaries. Additional effort is also required to include simulation-based parameters such as schedules, building loads, environmental variables, and HVAC systems.

To overcome the mentioned limitation, the carbon tool emphasizes on the creation of a complete and well-formed Shared Object Model (SOM) to manage information transfer; whereby a general BIM, removed of domain-specific semantics, is maintained (Figure 2), and domain models, being subsets of the SOM, are derived from the SOM. Support modules in the new tool automatically translate building information, and perform necessary syntax adjustments. Assuming a complete and well-formed SOM, the domain model is thus also complete and well-formed at all times. This approach has the benefit of extensibility, where the generality of the SOM would allow any type of domain model to be derived; thus facilitating the future integration of other domain simulations with the tool.

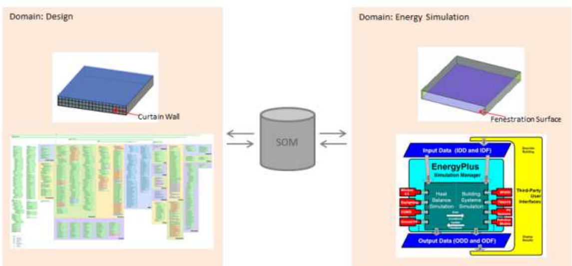

Figure 2 Building Information Exchange through SOM(Drury,1999)

The SOM functions like a mapper, facilitating information transfer between modelling tool (Revit Architecture), simulation tool (Energyplus), and the XML database containing all assumptions.

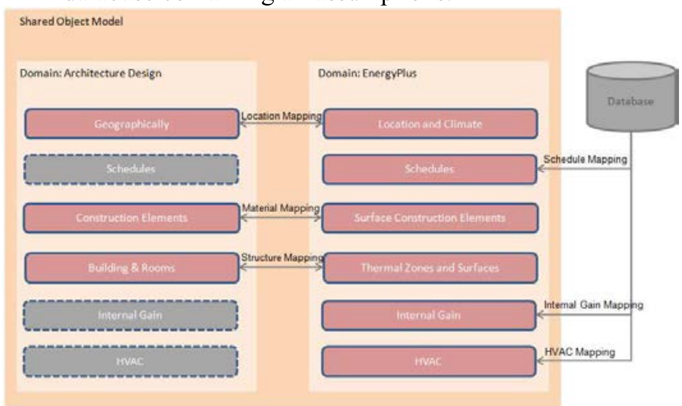

Figure 3 SOM Essential Hierarchy Diagram

As an example of a mapping scenario, within Revit Architecture, users select various pre-defined materials to formulate wall, floor, ceiling construction. For the same material type, Energyplus on the other hand utilizes a different set of naming. In order to facilitate semantic translation between material types used in modelling software and simulation software, the mapper is used to formulate association between materials. The association and links between Revit and Energyplus materials are documented and formulated as a lookup table (Figure 4).

	REVIT		ENERGYPLUS	
	Revit Material	Revit Thickness	EnergyPlus Material	EnergyPlus Category
Air Barrier	Air Infiltration Barrier		F04 Wall air space resistance	Material:AirGap
	Air Layers - Air Film - Inside Surface			
	Air Layers - Air Film - Outside Surface			
	Air Layers - Air Film - Air Space			
	Default Mass Opening			
Aluminium	Aluminium		F08 Metal surface	Material
	Metal - Alluminium			
	Metal - Panel			
	Metal Panel			
	Metal - Paint Finish - Dark Gray, Matte			
	Metal - Paint Finish - Ivory, Matte			
	Default Mass Shade			
	Default Metal Frame			
	Cladding - Vertical Ribbed			
Asphalt	Site - Tarmacadam		Tile: asphalt - linoleum - vinyl - rubber	Material:NoMass
	Roofing - Asphalt		Asphalt roll roofing	Material:NoMass
Brick	Masonary - Brick		M01 100mm brick	Material
	Masonary - Brick - Horizontal Pattern			
	Masonary - Brick Engineering			
	Masonary - Brick Engineering Soldier Course			
	Masonary - Brick Engineering, Grey			
	Masonary - Brick Soldier Course			
	Masonary - Brick Soldier Course, Buff			
Carpet	Carpet		F17 Carpet	Material
Concrete	Concrete - Cast In Situ	100-150mm	M14a 100mm heavyweight concrete	Material
	Concrete - Cast-in-Place Concrete			
	Default			
	Default Floor			
	Default Form	150-200mm	M14 150mm heavyweight concrete	
	Default Mass Exterior Wall			
	Default Mass Floor			
	Default Mass Interior Wall			
	Default Mass Roof	200-300mm	M15 200mm heavyweight concrete	
	Default Roof			
	Default Wall			
	GRC - Glass Reinforced Concrete			
	Masonary - Concrete Floor Block	>300mm	M16 300mm heavyweight concrete	
	Precast Concrete Panels			
	Roofing			
	Roofing - Tile			
	Structure - Precast Concrete Beams			
	Concrete - Cast In Situ Lightweight	100-150mm	M11 100mm lightweight concrete	
	Concrete - Pre Cast	150-200mm	M12 150mm lightweight concrete	
	Concrete - Precast Concrete	200-300mm	M13 200mm lightweight concrete	
	Masonary - Concrete Block	200-300mm	M05 200mm concrete block	
		>300mm	M06 300mm concrete block	
	Concrete - Sand/Cement Screed		Concrete: sand and gravel or stone aggregate concretes - 2400kg/m3 - 51mm	
Glass	Glass		CLEAR 6MM	WindowMaterial:Glazing
	Glass Block			
	Default Mass Glazing			
	Default Mass Skylight			
	Glazing - Curtain Wall Glazing			

Figure 4Material Mapping Table

DOMAIN OBJECT MODEL:

DOM(Domain Object Model) is the main model which store all essential information which is ready to translate into other domain. Before exchanging the information between Revit and EnergyPlus, the data of design model will be accessed from Revit and directly saved in DOM. In other words,
DOM is ready for carbon calculation and also energy simulation. Because IFC is more complex and difficult to use. Using DOM is good solution for this research. The DOM organizes information according

the following hierarchy: Location, Mass & Building, Space, Surfaces and Openings.

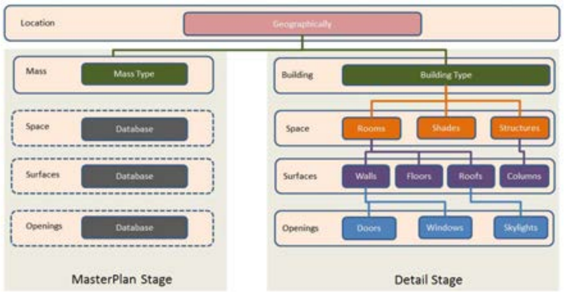

Figure 5 DOM Essential Hierarchy Diagram

For scalable carbon analysis, the carbon result from masterplan and detail stage should be made comparable. Consequently the DOM should be developed under same class schema. For the structure of DOM entities also follow this hierarchy (Figure 6).

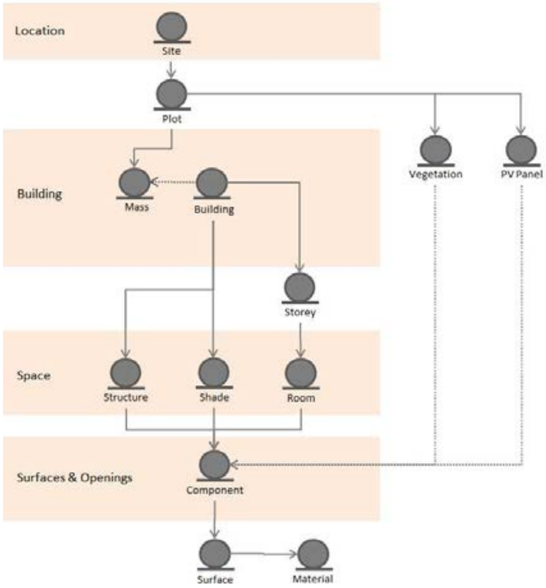

Figure 6 Detailed Expanded Class Diagram for DOM Module

DATABASE:

During design phases, the design model is usually incomplete. Information required for simulation such as schedules, internal gains, thermal properties, and HVAC types, are typically not available for large parts of the design process, until late into detailed design stages. To perform energy simulation however, EnergyPlus is largely dependent on such missing information. A database of context-based assumption is therefore necessary to supplement the DOM in order to create a complete and well-formed model.

Structuring and classification of information in the database relies upon case-based reasoning, where the quality of context-based analysis and assumptions depends upon 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.

Empirical studies were performed for a few existing building types (Figure 7), where data collected from these buildings are used to formulate a dataset which is minimally sufficient for the demonstration of the new tool. The database structure is defined in three distinct domains: Embodied Carbon, Operational Carbon and HVAC Maintenance (Figure 8). The database is then implemented as a XML-based dataset of real-world building characteristics organized hierarchically and by pertinent metrics and indicators that the context rule-sets in the new tool can query (Figure 1).

Figure 7 Cases Studies

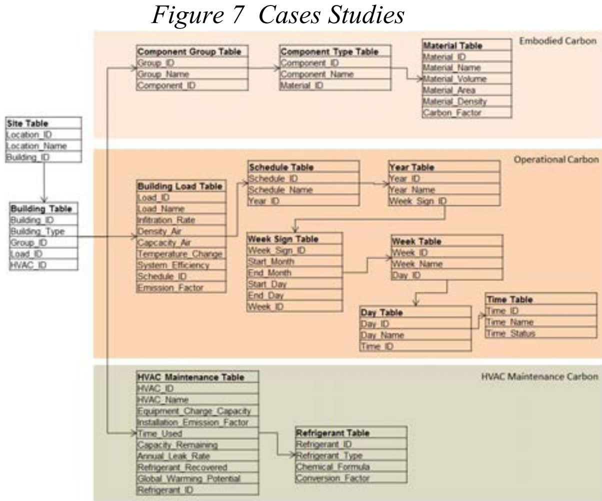

Figure 8 Detailed Diagram of Database

MISSING DATA IN EARLY DESIGN STAGES REQUIRED FOR ENERGY SIMULATION:

To automatically populate any missing data, the new tool utilizes decision tree algorithm (Figure 9) to maintain and generate essential information for early design stages. The decision tree learning approach 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 Decision trees act as a method for classification and predictive modelling. A decision tree partitions data into smaller segments called terminal nodes. Each terminal node is assigned a class label. The non-terminal nodes, which include the root and other internal nodes, contain attribute test conditions to separate records that have different characteristics. The partitioning process terminates when the subsets cannot be partitioned any further using predefined criteria. Based on this research, C4.5 algorithm can be used to segment groups of building type and develop amount of material weight by building GFA to help architects produce energy simulation that achieve customer carbon target.

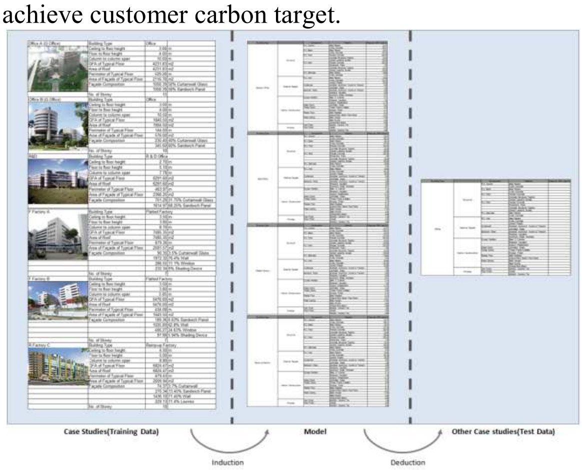

Figure 9 Classification

The algorithm grows a decision tree in a recursive fashion by partitioning the training records into successively purer subsets. If define {Dt} as the set of training records that reach a node t. The general recursive procedure is defined as below(Tan,2004):
1. If {Dt} contains records which belong the same class {Ct}, then t is a leaf node labelled as {Ct}
2. If {Dt} is an empty set, then t is a leaf node labelled by the default class, {Cd}
3. If {Dt} contains records which belong to more than one class, use an attribute test to split the data into smaller subsets.
It recursively applies the procedure to each subset until all the records in the subset belong to the same class. The C4.5 algorithm assumes that each combination of attribute sets has a unique class label during the procedure. If all the records associated with {Dt} have identical attribute values except for the class label, then it is not possible to split these records any future. In this case, the node is declared a leaf node with the same class label as the majority class of training records associated with this node. For an example, if the building type is Office, the materials (Anodized Aluminium Mullion &Transom,Laminated Glass) which belongs to curtainwall will be implemented into the decision tree model.

C 4.5 ALGORITHM:

C4.5 builds decision trees from a set of training data using the concept of information entropy, which is a measure of the uncertainty in a random variable in information theory. If $\{D_t\}$ is the training data, and $f(C_i,D)$ stands for the number of training data in $\{D_t\}$ which belongs to class $\{C_d\}$, $|D|$ denotes the number of training data $\{D_t\}$and Gain(A) is the weight value of the certain attribute. Then the entropy of the set $\{D_t\}$:

$$Info(D) = -\sum_{i=1}^{n}(f(C_i,D)/|D|)*\log_2(f(C_i,D)/|D|)$$

Figure 10 Information entropy of dataset

After dataset {Dt} has been partitioned in accordance with any one attribute {A}:

$$Info_A(D) = \sum_{i=1}^{n}(|D_i|/|D|)*f(D_i)$$

Figure 11 Information entropy of dataset

Consequently, when build the decision trees base on C4.5, $Gain(A) = Info(D) - Info_A(D)$, compare the Gain(A) value, set the highest one as the decision leaf.

CASE STUDIES:

In this research, six case studies will be analyzed by using C4.5 algorithm.

Building Type	Construction	Material	(kg/m2)
Office A (G.Office)	Structure	Steel Rebars	102.49
Office A (G.Office)	Structure	In-situ Concrete	270.63
Office A (G.Office)	Structure	Precast Concrete	450.00
Office A (G.Office)	Structure	Polystyrene Foam	1.65
Office A (G.Office)	Structure	Concrete Structural Topping	65.00
Office A (G.Office)	Structure	Cement Levelling Screed	201.60
Office A (G.Office)	External Façade	Steel Rebars	30.82
Office A (G.Office)	External Façade	In-situ Concrete	143.25
Office A (G.Office)	External Façade	Cement Plaster	39.59
Office A (G.Office)	External Façade	Aluminium	1.81
Office A (G.Office)	External Façade	Laminated Glass	1.82
Office A (G.Office)	External Façade	Rockwool Insulation	0.00
Office A (G.Office)	Interior Construction	Steel	31.86
Office A (G.Office)	Interior Construction	Rockwool Insulation	1.52
Office A (G.Office)	Interior Construction	Gypsum Plasterboard	14.16
Office A (G.Office)	Interior Construction	Laminated Glass	0.32
Office A (G.Office)	Interior Construction	Timber	0.35
Office A (G.Office)	Interior Construction	Plywood	0.13
Office A (G.Office)	Interior Construction	Gypsum-fibre board	6.27
Office A (G.Office)	Interior Construction	Mineral-fibre board	6.98
Office A (G.Office)	Finishes	Ceramic	2.48
Office A (G.Office)	Finishes	Carpet	4.52

Table12Office Type A (G.Office)

Building Type	Construction	Material	(kg/m2)
Office B (G.Office)	Structure	Steel Rebars	20.58
Office B (G.Office)	Structure	In-situ Concrete	48.03
Office B (G.Office)	Structure	Precast Concrete	457.07
Office B (G.Office)	Structure	Polystyrene Foam	1.70
Office B (G.Office)	Structure	Concrete Structural Topping	66.02
Office B (G.Office)	Structure	Cement Levelling Screed	204.76
Office B (G.Office)	External Façade	Steel Rebars	29.60
Office B (G.Office)	External Façade	In-situ Concrete	137.55
Office B (G.Office)	External Façade	Cement Plaster	50.69
Office B (G.Office)	External Façade	Aluminium	1.26
Office B (G.Office)	External Façade	Laminated Glass	0.65
Office B (G.Office)	External Façade	Rockwool Insulation	0.00
Office B (G.Office)	Interior Construction	Steel	20.92
Office B (G.Office)	Interior Construction	Rockwool Insulation	0.63
Office B (G.Office)	Interior Construction	Gypsum Plasterboard	2.93
Office B (G.Office)	Interior Construction	Laminated Glass	0.21
Office B (G.Office)	Interior Construction	Timber	0.27
Office B (G.Office)	Interior Construction	Plywood	0.09
Office B (G.Office)	Interior Construction	Gypsum-fibre board	47.16
Office B (G.Office)	Interior Construction	Mineral-fibre board	4.69
Office B (G.Office)	Finishes	Ceramic	0.86
Office B (G.Office)	Finishes	Carpet	4.41

Table13Office B (G.Office)

Building Type	Construction	Material	(kg/m2)
R&D	Structure	Steel Rebars	38.17
R&D	Structure	Steel Structure	16.93
R&D	Structure	In-situ Concrete	98.29
R&D	Structure	Precast Concrete	450.00
R&D	Structure	Polystyrene Foam	1.65
R&D	Structure	Concrete Structural Topping	65.00
R&D	Structure	Cement Levelling Screed	201.60
R&D	External Façade	Steel Rebars	96.83
R&D	External Façade	In-situ Concrete	449.98
R&D	External Façade	Cement Plaster	130.77
R&D	External Façade	Aluminium	1.19
R&D	External Façade	Laminated Glass	0.54
R&D	External Façade	Rockwool Insulation	0.00
R&D	Interior Construction	Steel	20.47
R&D	Interior Construction	Rockwool Insulation	0.64
R&D	Interior Construction	Gypsum Plasterboard	2.97
R&D	Interior Construction	Laminated Glass	0.11
R&D	Interior Construction	Timber	0.26
R&D	Interior Construction	Plywood	0.10
R&D	Interior Construction	Gypsum-fibre board	43.67
R&D	Interior Construction	Mineral-fibre board	4.69
R&D	Finishes	Ceramic	1.00
R&D	Finishes	Plastic	0.51
R&D	Finishes	Carpet	4.09

Table14Research and development (R&D)

Building Type	Construction	Material	(kg/m2)
Factory A	Structure	Steel Rebars	39.48
Factory A	Structure	In-situ Concrete	103.58
Factory A	Structure	Precast Concrete	360.00
Factory A	Structure	Polystyrene Foam	1.65
Factory A	Structure	Concrete Structural Topping	65.00
Factory A	Structure	Cement Levelling Screed	201.60
Factory A	External Façade	Steel Rebars	12.64
Factory A	External Façade	In-situ Concrete	20.26
Factory A	External Façade	Cement Plaster	16.24
Factory A	External Façade	Aluminium	0.04
Factory A	External Façade	Laminated Glass	0.05
Factory A	External Façade	Steel	0.00
Factory A	Interior Construction	Steel	0.29
Factory A	Interior Construction	Steel Rebars	26.75
Factory A	Interior Construction	In-situ Concrete	124.31
Factory A	Interior Construction	Cement Plaster	34.36
Factory A	Interior Construction	Laminated Glass	0.34
Factory A	Interior Construction	Timber	0.24
Factory A	Interior Construction	Plywood	0.12
Factory A	Interior Construction	Aluminium	0.92
Factory A	Finishes	Ceramic	5.01

Table 15Factory A (F . Factory)

Building Type	Construction	Material	(kg/m2)
Factory B	Structure	Steel Rebars	35.21
Factory B	Structure	In-situ Concrete	96.15
Factory B	Structure	Precast Concrete	540.00
Factory B	Structure	Polystyrene Foam	1.65
Factory B	Structure	Concrete Structural Topping	65.00
Factory B	Structure	Cement Levelling Screed	201.60
Factory B	External Façade	Steel Rebars	7.46
Factory B	External Façade	In-situ Concrete	34.67
Factory B	External Façade	Cement Plaster	9.58
Factory B	External Façade	Aluminium	0.05
Factory B	External Façade	Rockwool	0.00
Factory B	External Façade	Laminated Glass	0.05
Factory B	External Façade	Steel	0.00
Factory B	Interior Construction	Steel	0.28
Factory B	Interior Construction	Steel Rebars	23.07
Factory B	Interior Construction	In-situ Concrete	107.21
Factory B	Interior Construction	Cement Plaster	29.63
Factory B	Interior Construction	Laminated Glass	0.74
Factory B	Interior Construction	Timber	0.34
Factory B	Interior Construction	Plywood	0.16
Factory B	Interior Construction	Aluminium	1.13
Factory B	Finishes	Ceramic	3.56

Table 16Factory B (F.Factory)

Building Type	Construction	Material	(kg/m2)
Factory C	Structure	Steel Rebars	68.70
Factory C	Structure	In-situ Concrete	181.01
Factory C	Structure	Precast Concrete	792.00
Factory C	Structure	Polystyrene Foam	1.65
Factory C	Structure	Concrete Structural Topping	65.00
Factory C	Structure	Cement Levelling Screed	201.60
Factory C	External Façade	Concrete Block	25.56
Factory C	External Façade	Concrete Mixture	5.11
Factory C	External Façade	Mortar Cement	2.01
Factory C	External Façade	Cement Plaster	12.13
Factory C	External Façade	Aluminium	0.02
Factory C	External Façade	Rockwool	0.00
Factory C	External Façade	Laminated Glass	0.01
Factory C	Interior Construction	Steel	0.00
Factory C	Interior Construction	Concrete Block	105.25
Factory C	Interior Construction	Mortar Cement	8.29
Factory C	Interior Construction	Cement Plaster	49.94
Factory C	Interior Construction	Timber	0.22
Factory C	Interior Construction	Plywood	0.08
Factory C	Interior Construction	Aluminium	0.20
Factory C	Finishes	Ceramic	0.44

Table 17Factory C (R.factory)

From these case studies, there are two steps:

1. Build a decision tree

Base on (Figure 11,12),If choose building type as root, |D|=132(number of total records) and sub-attribute is construction.

$$Info(D)= -22/132*\log_2(22/132)-24/132*\log_2(24/132) -21/132*\log_2(21/132)-22/132*\log_2(22/132) -21/132*\log_2(21/132)-22/132*\log_2(22/132) =2.583 \text{ bits}$$

$$Info_A(D)= 22/132*(-\log_2(6/22)-\log_2(6/22)-\log_2(8/22)-\log_2(2/22)) +24/132*(-\log_2(7/24)-\log_2(6/24)-\log_2(8/24)-\log_2(3/24)) +21/132*(-\log_2(6/21)-\log_2(6/21)-\log_2(8/21)-\log_2(1/21)) +22/132*(-\log_2(6/22)-\log_2(7/22)-\log_2(8/22)-\log_2(1/22)) +21/132*(-\log_2(6/21)-\log_2(7/21)-\log_2(7/21)-\log_2(1/21)) +22/132*(-\log_2(6/22)-\log_2(6/22)-\log_2(8/22)-\log_2(2/22))$$

=8.970 bits

Thus $Gain(A) = Info(D) - Info_A(D)$
$= 2.583-8.970=-6.387$ bits

Else sub-attribute is material:

$Info(D)=$
$-22/132*\log_2(22/132)-24/132*\log_2(24/132)$
$-21/132*\log_2(21/132)-22/132*\log_2(22/132)$
$-21/132*\log_2(21/132)-22/132*\log_2(22/132)$
=2.583 bits
$Info_A(D)= 70.700$ bits
Thus $Gain(A) = Info(D) - Info_A(D)$
$= 2.583-70.700=-68.117$ bits

Consequently, Following the criterion of Gain(A), The structure of decision tree like(Figure 18):

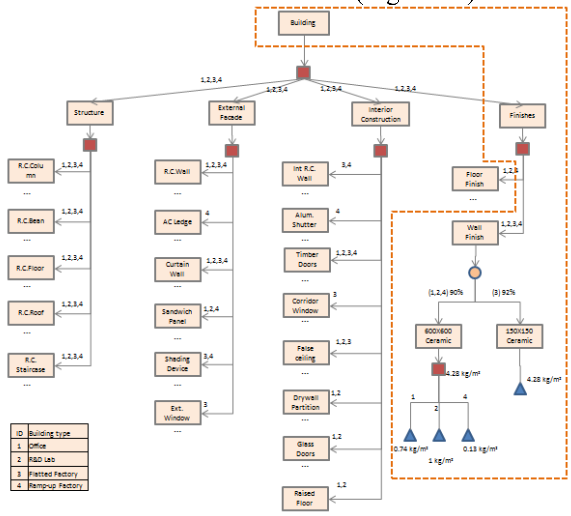

Figure 18 Decision Tree for Materials (kg/m2)

2. Get Missing data through decision tree

As explained in earlier sections, information incompleteness is present in early design stages. To estimate missing data, the result model is obtained from training data using C4.5 algorithm. In C4.5 it is an accepted principle that samples with the unknown values are distributed probabilistically according to the relative frequency of known values.

Building Type	Construction	Material	(kg/m2)
Office A (G.Office)	Structure	Steel Rebars	102.49
Office A (G.Office)	Structure	In-situ Concrete	270.63
Office A (G.Office)	External Façade	Laminated Glass	1.82
Office A (G.Office)	External Façade	Rockwool Insulation	0.00
Factory A	Structure	Concrete Structural Topping	65.00
Factory A	Structure	Cement Levelling Screed	201.60
Factory A	External Façade	Steel Rebars	12.64
Factory A	External Façade	In-situ Concrete	20.26
Factory B	Structure	Concrete Structural Topping	65.00
Factory B	Structure	Cement Levelling Screed	201.60
Factory B	External Façade	Steel Rebars	7.46
Factory B	External Façade	In-situ Concrete	34.67
Other (G.Office)	Unknow	Unknow	Unknow

Figure 19 Decision Tree for Materials (kg/m2)

For example (Figure 18), for a design model which is defined as an office in Revit, how can missing data such as construction, material and kg/m2 be obtained?

Here is the decision rules:

If BuildingType = Office Then
If Construction= Structure Then
Classification = Steel Rebars
else
Classification = In-situ Concrete;
...
elseifBuildingType = Factory Then
If Construction= Structure Then
Classification = Steel Rebars
else
Classification = In-situ Concrete;
...
elseifBuildingType = R&D Office Then
If Construction= Structure Then
Classification = Steel Rebars
else
Classification = In-situ Concrete;
...
elseifBuildingType = Ramp-Up Factory Then
If Construction= Structure Then
Classification = Steel Rebars
else
Classification = In-situ Concrete;
...

After the decision rules come out, the missing data will be solved.

VALIDATION

To validate the decision tree algorithm, An existing building in singapore, will be used as a test model. Carbon analysis and comparison will be performed between two design models, one representing early design stage (building information is unavailable) and the other representing detailed design stage (building information is complete); where the early-stage design model will depend upon decision tree algorithm for the automatic population of missing data.

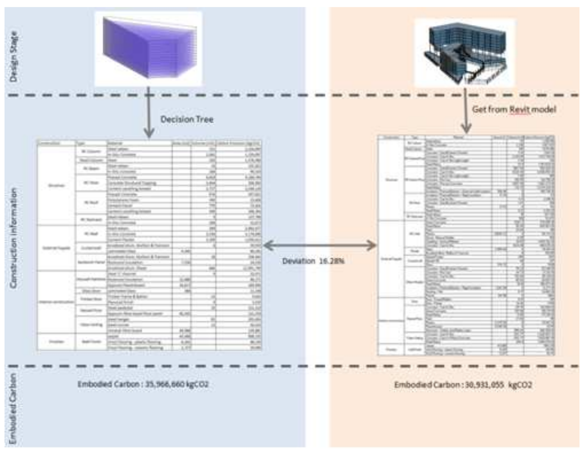

Figure 20 Decision Tree for Materials (kg/m2)

Using embodied carbon as a simple comparison, a quick tabulation of building information - number of count of material types - showed minimal difference. This is due to the nature of design and construction, where in detail design stages, the material construction can be customized to conform to certain design requirements. For instance during early design stage, the decision-tree algorithm draws reference from a limited set of case studies where sandwich panel is found to be present in a typical R&D building. Such material construction may not be exactly implemented in the finalized detailed design stage; thus the observed difference. For equal comparison, both design models have the same gross floor area (m2). Embodied carbon for the 2 design models (early-stage: 35,966,660 kgCO2, detailed-stage: 30,931,055 kgCO2) are compared and reflected a deviation of 16.28%. While this comparison have shown capabilities in the new tool to estimate carbon emission in early stages in so far as aiding designers to maintain a carbon perspective, the same result has also demonstrated the limitation of such approach where there is a lack of sufficient case study to generate a highly accurate decision tree.

CONCLUSION

The above research has highlighted the benefits of adopting a computational and data-centric approach in formulation of design support tools for carbon analysis. By addressing 2 key computational challenges of data interoperability and automation of simulation, through the formulation of SOM and DOM, carbon computation can now be presented with ease-of-use. With zero changes to design workflow, the new carbon tool will complement design processes, allowing more design iteration and performance evaluation within the same time constraint.

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