LOW CARBON LIVING CRC

Precinct Information Modelling

Technical Investigations:

Precinct Object Library Implementation

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Acronyms

BIM Building Information Model

IFC Industry Foundation Classes

PIM Precinct Information Model

Executive Summary

This technical investigation canvases a range issues concerned with the development of a PIM Object Library, specifically to address carbon management, though the principles could be applied within a broader context. It deals with:

- levels of detail, identifying the broad classes of objects that must be handled at a precinct scale to support carbon management use cases;
- terminology, proposing how the ambiguity and complexity of varying domain nomenclature can be managed to yield some consistency;
- property data, reporting an investigation of available property sets to support carbon management in the built environment, and
- linkages to reference data relevant to implementing a precinct object library for low carbon urban policy, planning and design application

Precinct Model Types

The core concept of the PIM framework addresses two fundamental tasks:

- The functionality to be able to model at various levels of detail or granularity, that mirrors the life cycle phases of a precinct from inception (simple, broad) to operations (complex, detailed)
- The capability to apply embodied carbon data at these different scales of application

Across all disciplines of urban infrastructure we consider four levels of detailed typology:

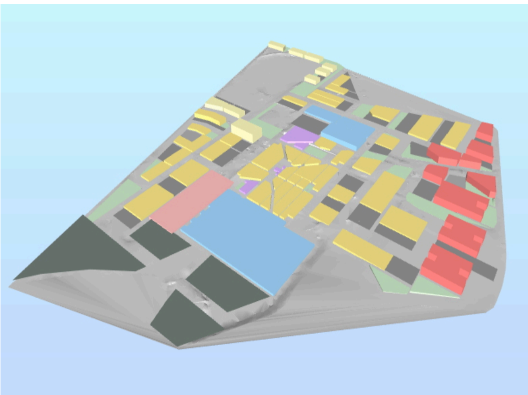
- Functional Zone
- Built Facility
- Elemental
- Occupancy

Functional Zone Typology

A precinct model at initial concept stage will designate geographic zones or simple volumes and spaces to represent the high level activities in the precinct.

Each object has intrinsic geometric properties (dimensions, volume, area), specified functional usage (residential, commercial, or other use types), possible performance properties (energy, carbon, water and waste), or cost properties (construction cost $/m2, operational cost $/person or $/function).

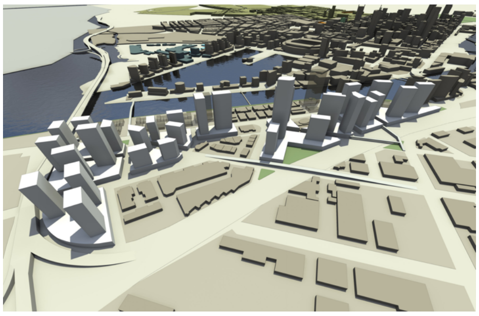
Figure 1 Tonsley Park Master Plan, Adelaide, South Australia



Built Facility Typology

At this level of detail PIM, activities are modelled as 3D forms that are approximations of the scale of development required, and with more attention to the relationships between the objects. Infrastructure elements representing transport and open space are also shown.

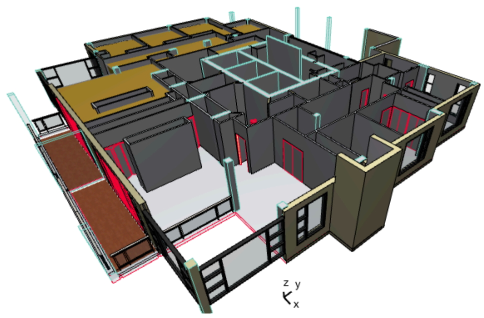
Figure 2 Fishermans Bend, Melbourne, Victoria



Elemental Typology

At the most detailed level all infrastructure and buildings are authored in BIM tools, with all elements described accurately and with detailed properties of the chosen types or products.

Figure 3 Typical floor of an apartment building

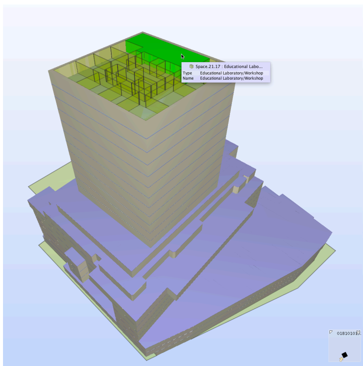


These levels broadly correspond to the Uniclass2 classification system as shown in Figure 1:

Occupancy Typology

Occupancy focusses on the functions carried out in a precinct by its users. It can address the requirements as a basis for a design (a brief), or it can model the operations of the facility for example in terms of energy consumption or patterns of energy usage by occupancy type

Figure 4 Spatial usage in a University Building



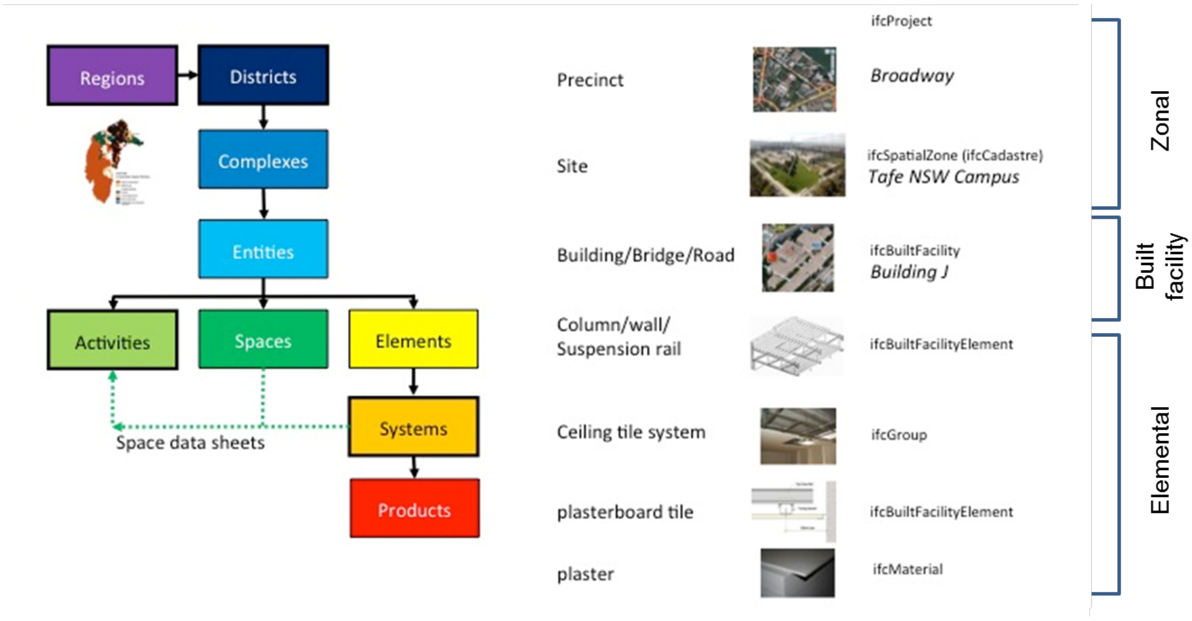


Figure 5 Typology Classification according to Uniclass 2015

These four levels of detail broadly correspond to the Uniclass2 classification system as shown in Figure 5. Note that *Activities* and *Spaces* relate directly to the Occupancy typology.

NCOS Precincts

The National Carbon Offset Standard (NCOS) undertaken by the Commonwealth Department of the Environment "…provides a framework and details requirements for carbon accounting and offsetting for organisations, products, services and events". The latest publication - NCOS Precincts – specifically addresses the carbon neutrality at a precinct scale and thus has direct relevance to this project.

The report (NCOS 2016) canvasses the current challenges in carbon accounting for precincts and the *Summary findings* identify a broad range of issues in establishing data and undertaking credible analysis (see Appendix 1 for an extract).

We identify a number of specific issues in the NCOS report:

- the definition of a Precinct matches the PIM approach
- the definition of precinct boundaries is problematic for many aspects of accounting for the impact of measures, for example precinct/city emission inventories
- there is a question as to whether public infrastructure should be included
- tools and methods to analyse impacts are weak

Importantly, "availability of consistent, repeatable data" is a common theme presenting a major challenge.

Application of PIM

The PIM solution provides a integrated framework for representing the data required to achieve carbon neutrality of the urban assets that encompass a precinct. In respect of the NCOS concept "built form" PIM defines "built facility types" (see *Technical Investigations: PIM Schema*) that allows for an all-inclusive approach to modelling built form.

The adoption of the PIM framework gives a common foundation for tool-makers, owners and users to store and access data in the current absence of a consistent, published standard for implementation.

Carbon Data

There have been several potential Australian sources of embodied carbon data:

- ausLCI and ALCAS
- BPIC LCI
- ICM
- BASIX
- Accurate
- EVAH/EcoSpecifier extended LCA Database
- National Object Library (NOL)

Currently under development:

- CEMP - Carbon Emissions Measurement Platform (CSIRO/EI)

International options include

- coBuilder
- BIMobject

Figure 6 Potential Sources of Embodied Carbon Data

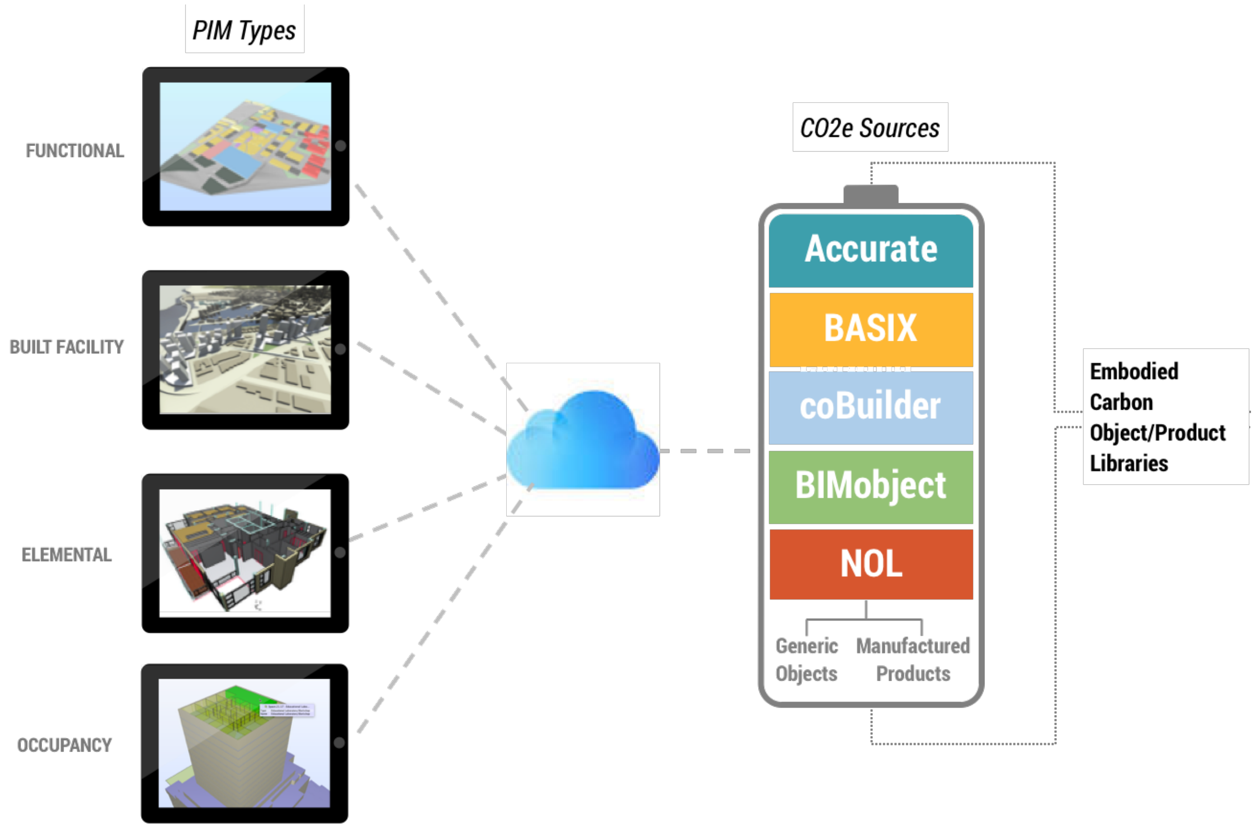


Figure 6 above sets out a number of key sources of embodied carbon data and indicates that LCI data should address the different uses. That is, be applicable for different states of the information "exactness" of objects across the various stages of a precinct's development and use.

The *Scoping Study* (Newton et al, 2013) identified and reviewed several potential sources of embodied carbon data, but as the Study documents this data "has limitations and hurdles for existing LCI/embodied energy/carbon databases and the requirements to become directly applicable to Australian precinct assessment tools" (Scoping Study, Table 4.9 Hurdles and limitations of existing LCI databases and requirements). This assessment rules out ausLCI, ALCAS and BPIC LCI

The availability of appropriate carbon data is discussed below in relation to the four levels of precinct information granularity.

Functional

The defintion of *land uses* across a precinct is an appropriate level of detail for analysis in early concept planning. The companion PIM report *Technical Investigations: Land Use and Development Types* sets out a nascent national government method of classifying land use for development purposes. Given this comprehensive definition a review of appropriate embodied carbon sources was carried out.

The CRC-LCL ICM project (RP 2007) published results of its economic input/output modelling (see *Appendix: ICM Assessment for Object Library Embodied Carbon Data*), which we assessed for application for (all) potential object types. An initial search was undertaken for functional categories (as the NSW Land Use types) but a consistent matching set of IOPC classifications could not be established.

Built Facility

As mentioned above, in the *Technical Investigations: Land Use and Development Types* report a set of *Permitted Use* types are defined, that in effect are *built facility* types. For this typology we have a strong set of terms but again no source of appropriate embodied carbon data.

BASIX, the NSW Government's tool for assessing residential dwellings for energy and water efficiency has adopted a range of *building envelope* types, which provides an emerging articulation of object types on which to analyse performance and sustainability. These types are more useful than *building product* data in this context as they can apply to simple geometricmodels or "shells" and support earl gross calculations. BASIX recognises Floors, Walls, Skylights, Windows and Ceiling and Roofs.

However BASIX envelope types only apply to residential housing for BASIX online analysis. It has a very restricted set of alternatives, and is also limited to NSW data (not national).

Elemental

At this level of typology we are dealing with *building products* or *materials* either by themselves (steel sheet) or as a composite assembly for any manufactured product that would be part of a built asset. This level of detail has had much more focus on embodied carbon sources.

Work by building product manufacturers and their representative organisations such as BPIC have developed Life Cycle Inventory (LCI) data for a small (8) range of generic *material product types* but this data is only cradle to gate and does not include final delivery to site or demolition. More recent work by the Gypsum Board Manufacturers Association (GBMA) bridges this final gap for plasterboard products as documented in *Life Cycle Assessment of the Australian/New Zealand plaster board* industry report (Scion, 2014), the resultant *ausLCI* however is still therefore completely inadequate as a comprehensive industry source.

The EVAH Institute/LCAdesign

Discussions with the Evah Insitute have identified some resources to support the expansion of CO2e data for our PIM test cases.

This can include best practice and business-as-usual options for a diverse set of built facility types including building elements, but alos infrastructure and other non-building element types.

Embodied CO2 Module in Accurate.

A significant development has been the publishing of the CSIRO *Implementation of Embodied CO2 Module in Accurate*. This has a much larger range of approximately 150 product material definitions.

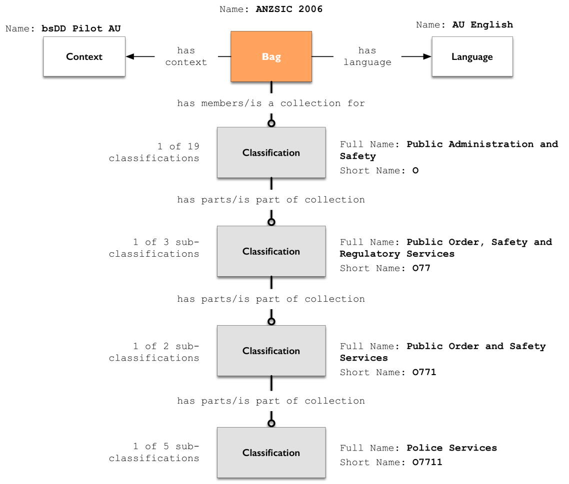
This data currently, as far as we can ascertain, is the best dataset for embodied carbon at an elemental and materials scale. Use of this data requires sufficient detail to be identified in a precinct information model in order to apply the metrics at that level, then aggregate.

Occupancy

Occupancy typologies refer to users, residents, persons or organisations, carrying out various activities for personal, public or commercial functions. Associated with those functions are the consumption of energy or aggregated embodied carbon impacts that are expended in the carrying out of the function. The Scoping Study (Newton et al, 2013) examines Precinct Assessment Indicators in Table 3.3 pp57-60 of which many those indicators depend on occupancy data. The PIM framework includes the concepts described above, to enable linking operational data with occupancy types.

The *Broadway Precinct* model has utilised the City of Sydney's adoption of the ANZSIC 2006 Industrial Classification for their Floor Space Employment survey. This is an example of the categorisation of businesses used to see how patterns of business operations change over time with implications for planning.

Figure 7 Classification of Business Types



See under *Managing Terms and Concepts* below for more details of the technical implementation.

Environmental Product Declarations

coBuilder AG is a Norwegian company providing a European-wide (and emerging global) web service to create and maintain *Environmental Product Declaration* certificates (EPD). To deliver these documents they have developed a leading skill in examining the relevant National and International standards that apply to product performance. They make templates available for product manufacturers to create a certificate for each product on-line, so building up a comprehensive online product repository.

coBuilder's main focus appears to be EPD development and assisting product manufacturers to deliver compliant certification for EPDs. This regulatory requirement in the EU has meant that manufacturers are defining the embodied carbon properties of their products rather than relying on particular product- or material-specific organisations (such as Steel and Concrete associations or BPIC for example).

Online BIM Object Libraries

BIM is at a level of maturity now that has alloed for BIM libraries to be increasingly available. However, these are all addressing the elemental typology of a precinct and do not touch on the more general, aggregated functional and built facility typologies.

BIMobject

BIMobject is a Swedish organisation that delivers BIM objects in multiple formats (including IFC). BIMobject provides a large repository of international library objects - reputedly over 250,000 objects and, many more product-specific configurations, in common formats. See [BIMobject 2016]

"BIMscript® and LENA is their technology and a solution designed to streamline and accelerate the process of BIM content creation. This delivers both an open and freely accessible scripting language as well as a BIM object authoring solution".

Online libraries such as BIMobjects might serve as sources of elemental embodied carbon data for Australian and New Zealand use.

ARCOM US (the equivalent of Natspec in Australia and MasterSpec) recently announced their agreement with BIMobject, following a decision to move from a text based specification service to a database solution, integrating with the BIMobject, and linking directly to the library objects and their associated properties etc. BIMobject supports multiple classifications to suit many different national and or sector needs.

National Object Library

The National Object Library (NOL) being developed by Natspec and CIL NZ aims to provide rich generic and product-specific library objects to suit the building and infrastructure development sectors. NOL is collaborating with NBS in the UK who have developed their (UK) National Object Library .

At present the NOL has published a consultation draft of the *International BIM Object Standard, Including Part B - Australian Requirements* for industry review. Its purpose " … has been developed for use by all construction professionals – from specifers to manufacturers and BIM content developers to assist in the creation of BIM objects. Nation-specifc annexes, where produced, take into consideration local regional differences in regulations, standards and practices".

The NOL provides no associated embodied carbon data.

Summary

There is no single solution today for providing embodied carbon data to support sustainability analysis and modeling in a PIM *or* a BIM environment.

The *Accurate* developments represent the best interim solution, while the industry waits for either the NOL or international BIM and EPD vendors to establish a robust service.

However, global online libraries are becoming a powerful provider of object data and likely to influence developments here in Australasia.

Managing Terms and Concepts

The buildingSMART Data Dictionary (bSDD) is a library of concepts and the relationships between them. It is used to identify objects in the built environment and their specific properties regardless of language, so that for example "door" or "Embodied Carbon" means the same thing in New Zealand as it does in Australia or the UK.

The data dictionary is open and international, allowing architects, engineers, consultants, owners and operators on one side, and product manufacturers and suppliers on the other side, from all around the world to agree and share product definitions. When everyone shares the same concepts, the building process becomes more efficient.

Features and Benefits

- Shared reusable concept definitions reduce costs and improve quality
- The property definitions are available to all software, worldwide
- Automatic rule checking prevents miscommunication and data duplication
- Connect objects to BIM-specific products
- Property sets can be extended for specific requirements
- Add or overlay classification requirements
- Map between different users and applications
- Enable checking and validation of data

The bsDD is proposed as a means to specify detail naming and attribution of PIM object instances that are instantiated using generic PIM entity definitions.

For example, shown in Figure 9, is a part of a simulation to demonstrate how a PIM model may be used in practice

Implementation

We have populated the bsDD with the concepts derived from the New South Wales Department of Planning for land uses and development types. This allows for the functional/zonal PIM use case to use instances of the entity IfcSpatialZone named in a standardised manner e.g."Child Care Centre", link embodied carbon property set definitions hosted in the bsDD, finally link to an Embodied Carbon database such as an online version of the Accurate *Embodied CO2 Emissions Module.*

See the companion PIM report *Technical Investigations: Land Use and Development Types* for a full description of this PIM model simulation.

Figure 8 Land use concepts in bsDD

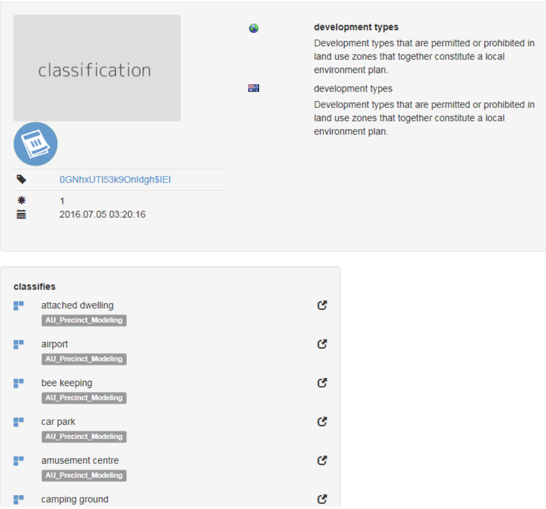


Figure 9 Development type concepts in bsDD

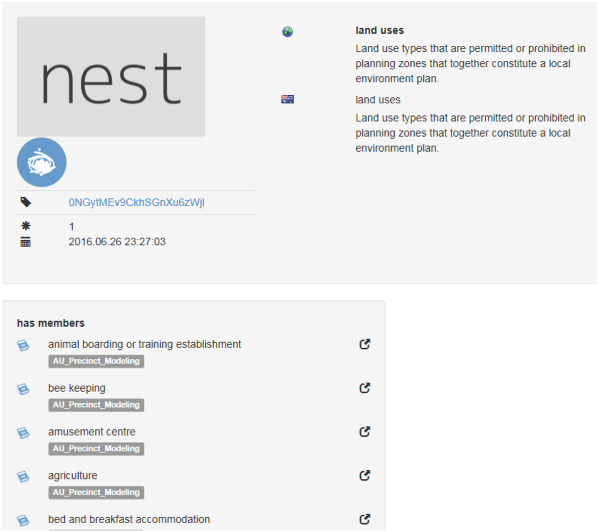
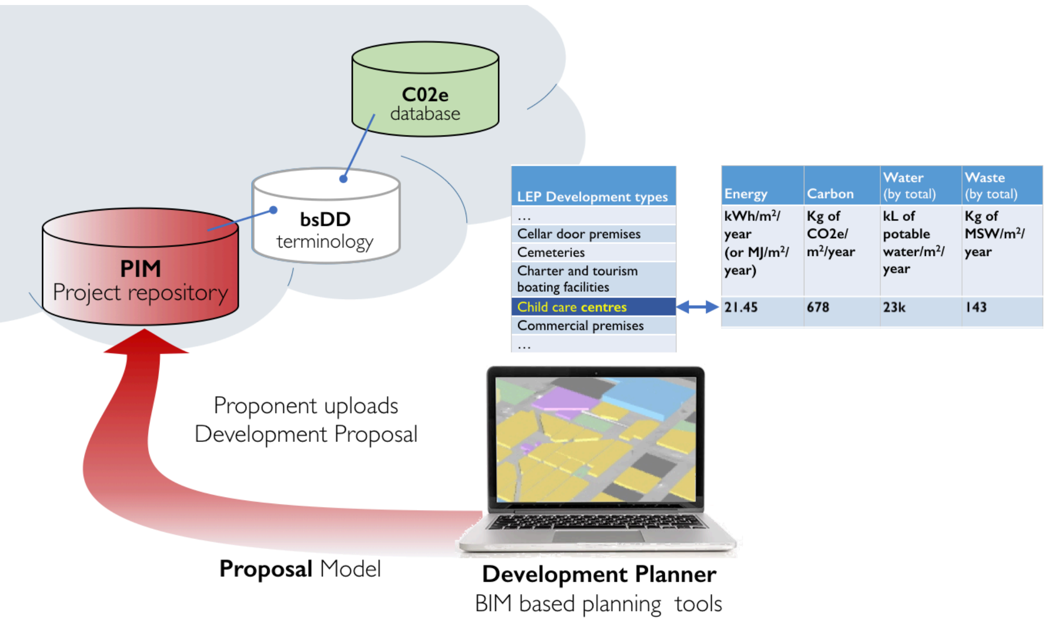


Figure 10 bsDD linking Development Types to CO2e data



Embodied and Operational Carbon Metrics

Precinct objects need to be identified and defined in a manner that facilitates connection to correspondingly defined LCI data.

Carbon measures are applicable throughout the lifecycle of a precinct as shown in Figure 11 (Source: *Scoping Study, 2013*). The following tables show examples of carbon measures for each of the PIM use cases.

Figure 11 Classification of embodied and operational data involved in the life cycle of a precinct

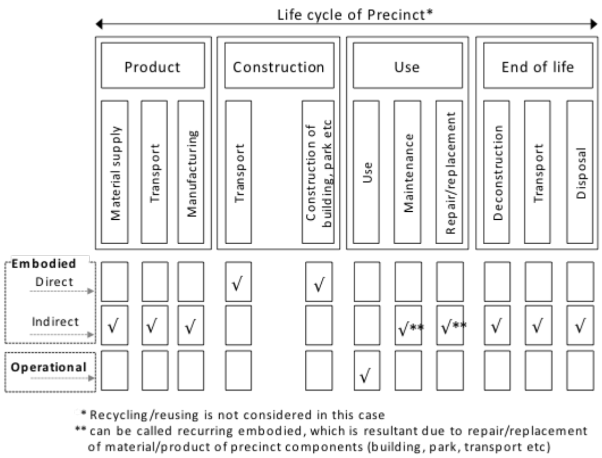


Table 1 Examples of LCI data for embodied carbon by PIM use case

Classification	Precinct Object	PIM Entity	LCI Data
Zonal Functional	Land use areas (commercial, residential, industrial)	IfcSpatialZone	Schematic kgCO2e/m2 of zonal area
Built Facility	Development types (office building, detached house, apartment)	IfcBuiltFacility (IfcBuilding, IfcRoad, IfcRailway, IfcBridge, IfcTunnel, IfcCivicSpace)	Schematic kgCO2e/m2 of "floor space"
Elemental	Product type (aluminium window, door) Material composition (concrete, steel, timber)	IfcBuiltFacilityElement (IfcColumn, IfcBeam, IfcSlab) IfcMaterial	Detail kgCO2e/m3 or /lineal m of material composition

Table 2 Examples of LCI Data for operational carbon by built facility type

Built Facility Type	Carbon	Energy	Water	Waste
Building (commercial, residential)	kgCO2e/m2/year	kWh/m2/year (or MJ/m2/year)	kL of potable water/m2/year	kg of MSW/m2/year kg of recycled waste/m2/year
Transport (road, rail)	kgCO2e/km/year	kWh/km/year		
Civic space (park/reserve)	kgCO2e/m2/year	kWh/m2/year (or MJ/m2/year)	kL of potable water/m2/year	kg of MSW/m2/year kg of recycled waste/m2/year

Instantiating Carbon Data

Because of the lack of consensus in Australia regarding standards for carbon metrics we have examined a European project led by the industry group SBAlliance . Its mission is to "... bring together operators of rating and certification tools for sustainable buildings, standard setting organisations, national building research centres as well as key property industry stakeholders and manufacturers of construction products." Its purpose is to link "SBA metrics with construction product manufacturers' BIM e-Catalogues ". It proposes an approach based on the European generalisation of the French INIES database which currently proposes such a mechanism for French construction product manufacturers to register the energy consumption life cycle analysis results of their products. The approach also utilises IFC properties that can be associated to BIM objects.

In IFC, a property set (Pset) is a collection of one or more relevant properties describing key attributes of an object in a model. Table 3 shows the applicable IFC property sets plus the further properties that have been identified by the SBAlliance (and also some additional properties proposed by Ecospecifier) to support the needs of sustainability assessment. Refer to Appendix 1 for further detail on all of these properties.

Table 3 Properties for sustainability assessment

IFC Property Sets
Pset_EnvironmentalImpactIndicators
Pset_EnvironmentalImpactValues
Sustainable Building Alliance Metrics
A Resource depletion
Use of non-renewable primary energy
B Indoor environment quality
Thermal comfort
Indoor air quality
C Building emissions
Global Warming Potential
Ecospecifier Sustainability Metrics
Human Health
Ecotoxicity
Biodiversity Impacts
Building Synergy

Linking to Reference Data Sources

For buildings and building elements estimating, a costing reference such as Rawlinsons (2011) extended Building Types Classification provides cost rates. Relative to the built facility these are based on the area of each occupancy type within that building (in square metres). At an elemental level the cost rates are provided per amount (number of units, or lineal metre, or square metre, or cubic metre) of a specified material or product. Costing references also contain some multiplication factors to be used to factor costing with regard to the location of the construction works, therefore allowing for the inclusion of transportation costs.

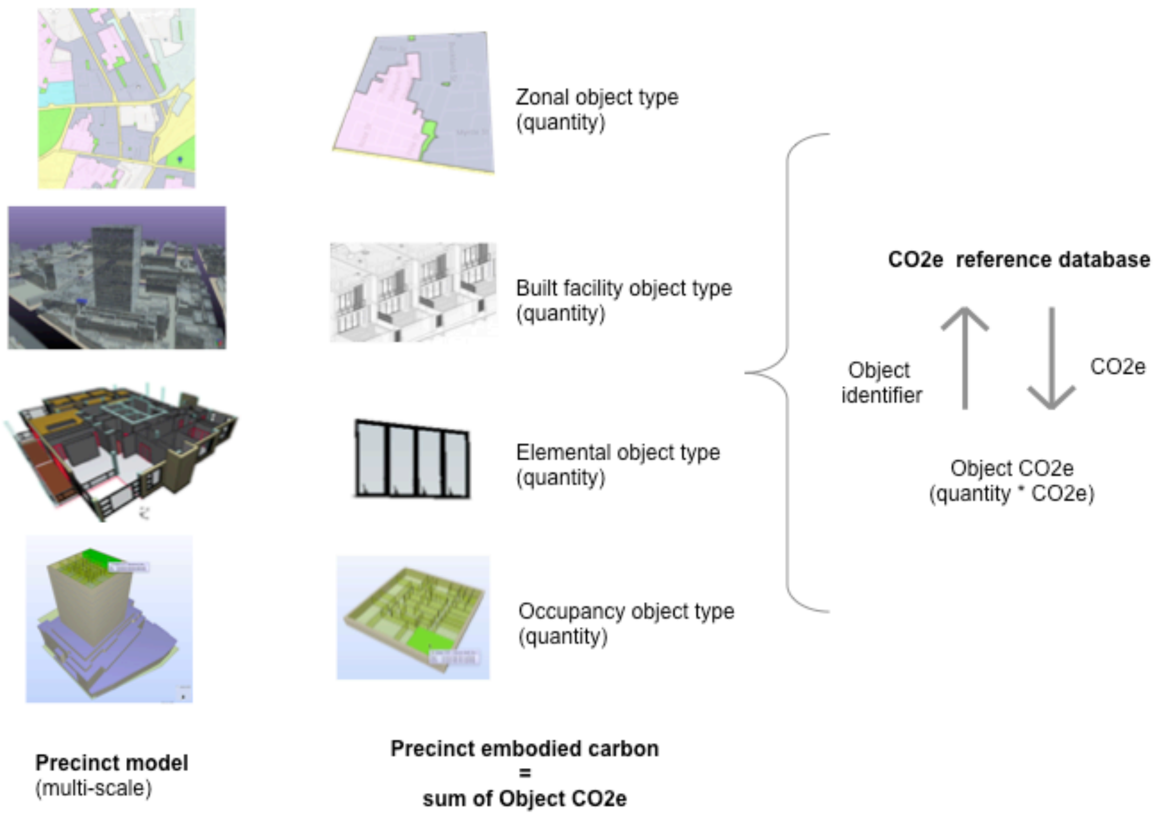
The Integrated Carbon Metrics (ICM) project within the CRC for Low Carbon Living proposes to deduce carbon measures based on national sector-based accounting numbers. Therefore, the ultimate metrics are stated in terms of equivalent carbon per dollar.

To calculate the embodied carbon for a precinct at any of the PIM use case scales, the interaction of two reference sources is required. ICM provides an embodied carbon measure per dollar spend, and the costing database provides the dollar value per object type. The PIM model of the precinct provides the quantity of each object type. By multiplying these three numbers together and aggregating across all the object types defined in the PIM model, a measure of the precinct's embodied carbon can be calculated.

There is, however, a significant proviso with regard to using this methodology in practice: a comprehensive set of object types needs to exist in both the ICM database and the costing database with a 1:1 correlation between the object types. Currently, there are no metrics in the ICM that can be applied at the broader zonal and built facility scales.

Figure 12 shows the generic methodology.

Figure 12 Calculating carbon based on CO2e reference data



Appendix 1

Extract of NCOS Precincts: Summary findings

Table 4 Summary findings (Note: Column 4, *Other findings* is excluded here)

Theme		Common practices	Common challenges
Definition of 'precinct'		▪ Precincts are defined by their scale, geography, unified planning or management intents and a sense of place. Succinctly, a precinct can be defined as a district, as of a city, marked out for governmental, commercial, industrial or civic purposes.	
Boundaries		▪ Generally, precinct emissions inventory boundaries encompass a number of material scope 1, 2 and 3 emissions sources associated with operations occurring within the precinct boundary.	▪ There is no clear guidance as to the treatment of any operations within a precinct that may independently pursue carbon neutrality. In such cases, how is double counting of neutrality to be avoided?
		▪ In application, there is significant inconsistency in the boundaries adopted by different tools and projects for precinct/city emissions inventories.	▪ Inconsistencies between boundaries set in case studies indicate that appropriate boundary setting is a challenge.
Emissions sources	Stationary energy	▪ It is common to include the energy consumed by buildings (private and public) in precinct-scale emissions inventories. Inclusion of stationary energy consumed by in-precinct infrastructure is less common, however, PAS 2070 and the GPC would require that such sources be included, if material.	▪ Determination as to whether to include public infrastructure.
	Transportation	▪ There is no consistent approach to the inclusion of transport sources in emissions inventories. ▪ However, both the GPC and PAS 2070 require the inclusion of in-boundary and transboundary transport emissions in emissions inventories for cities.	▪ Availability of appropriate, repeatable data.
	Industrial processes & product use (IPPU) emissions	▪ There is no clear trend from the case studies as to the treatment of industrial emissions from within a precinct. ▪ Both the GPC and PAS 2070 require the inclusion of IPPU sources in emissions inventories for cities.	▪ Availability of consistent, repeatable data.
	Agriculture, Forestry and Other Land use (AFOLU)	▪ With the exception of the purchase of carbon credits generated from land use projects as offsets, on site land use or carbon sinks are not included in the emissions inventories of the case studies, nor explicitly in the GPC. ▪ Both the GPC and PAS 2070 require the inclusion of AFOLU sources in emissions inventories for cities.	▪ Availability of appropriate, repeatable data.
	Water and Waste	▪ No tools and only one case study assessed emissions associated with waste and water. ▪ Both the GPC and PAS 2070 require the inclusion of waste and wastewater emissions sources in inventories for cities. ▪ Interestingly only PAS 2070 requires the inclusions of emissions associated with water provision. This is optional under the GPC.	▪ Availability of appropriate, repeatable data.
	Renewable energy	▪ No methods for the treatment of on-site renewables in an emissions inventory were found in any of the case studies.	
		▪ Across the case studies, renewable energy purchased from off site was undertaken either under a GreenPower™ equivalent contract, or was purchased directly from a large scale off site renewable energy facility, with accompanying proof of heritage and	

Theme	Common practices	Common challenges
	surrender of certificates.	
Food, products and other consumption	▪ No examples of inclusion found. ▪ PAS 2070 requires the inclusions of emissions associated with food and drink consumption. This is optional under the GPC.	▪ The inherent complexities and uncertainties in any quantification approach would make inclusion in an NCOS method problematic.
Embodied carbon in the built form	▪ Whilst embodied carbon is often considered in the carbon footprints of small-scale systems (such as products, services, organisations, events or buildings), its inclusion at a precinct scale is not common. ▪ PAS 2070 does not require the inclusions of the embedded emissions of building materials. This is optional under the GPC.	▪ High level of complexity and inherent uncertainties quantification.

Appendix 2

The following IFC defined property sets are adopted for the PIM schema to capture sustainability metrics.

Pset_EnvironmentalImpactIndicators

'Environmental impact indicators are related to a given "functional unit" (ISO 14040 concept). An example of an elemental functional unit is a "Double glazing window with PVC frame" and the unit to consider is "one square meter of opening elements filled by this product". The first five properties capture the characteristics of the functional unit. The following properties are related to environmental indicators. There is an international consensus agreement for the first five. The rest of the indicators are not yet fully and formally agreed at the international level'.

Property name	Property type	Data type	Description
Reference	Single value	IfcIdentifier	Reference ID for this specified type in the project model.
FunctionalUnitReference	Single value	IfcLabel	Reference to a database or a classification.
Unit	Single value	IfcText	The unit of the quantity the environmental indicators values are related with.
LifeCyclePhase	Enumerated value from: • Acquisition • Cradletosite • Deconstruction • Disposal • Disposaltransport • Growth • Installation • Maintenance • Manufacture • Occupancy • Operation • Procurement • Production • Productiontransport • Recovery • Refurbishment • Repair • Replacement • Transport • Usage • Waste • Wholelifecycle • UserDefined • NotDefined	IfcLabel	The whole life cycle or only a given phase from which environmental data are valid.

ExpectedServiceLife	Single value	IfcTimeMeasure	Expected service life in years.
TotalPrimaryEnergyConsumptionPerUnit	Single value	IfcEnergyMeasure	Quantity of energy used as defined in ISO21930:2007.
WaterConsumptionPerUnit	Single value	IfcVolumeMeasure	Quantity of water used.
HazardousWastePerUnit	Single value	IfcMassMeasure	Quantity of hazardous waste generated.
NonHazardousWastePerUnit	Single value	IfcMassMeasure	Quantity of non hazardous waste generated.
ClimateChangePerUnit	Single value	IfcMassMeasure	Quantity of greenhouse gases emitted calculated in equivalent CO2.
AtmosphericAcidificationPerUnit	Single value	IfcMassMeasure	Quantity of gases responsible for the atmospheric acidification calculated in equivalent SO2.
RenewableEnergyConsumptionPerUnit	Single value	IfcEnergyMeasure	Quantity of renewable energy used as defined in ISO21930:2007.
NonRenewableEnergyConsumptionPerUnit	Single value	IfcEnergyMeasure	Quantity of non-renewable energy used as defined in ISO21930:2007.
ResourceDepletionPerUnit	Single value	IfcMassMeasure	Quantity of resources used calculated in equivalent antimony.
InertWastePerUnit	Single value	IfcMassMeasure	Quantity of inert waste generated.
RadioactiveWastePerUnit	Single value	IfcMassMeasure	Quantity of radioactive waste generated.
StratosphericOzoneLayerDestructionPerUnit	Single value	IfcMassMeasure	Quantity of gases destroying the stratospheric ozone layer calculated in equivalent CFC-R11.
PhotochemicalOzoneFormationPerUnit	Single value	IfcMassMeasure	Quantity of gases creating the photochemical ozone calculated in equivalent ethylene.
EutrophicationPerUnit	Single value	IfcMassMeasure	EutrophicationPerUnit: Quantity of eutrophicating compounds calculated in equivalent PO4.

Pset_EnvironmentalImpactValues

‘The following properties capture environmental impact values of an element. They correspond to the indicators defined into Pset_EnvironmentalImpactIndicators. Environmental impact values are obtained multiplying indicator value per unit by the relevant quantity of the element’.

Property name	Property type	Data type	Description
TotalPrimaryEnergyConsumption	Single value	IfcEnergyMeasure	Quantity of energy used as defined in ISO21930:2007
WaterConsumption	Single value	IfcVolumeMeasure	Quantity of water used.
HazardousWaste	Single value	IfcMassMeasure	Quantity of hazardous waste generated.
NonHazardousWaste	Single value	IfcMassMeasure	Quantity of non hazardous waste generated.

ClimateChange	Single value	IfcMassMeasure	Quantity of greenhouse gases emitted calculated in equivalent CO2.
AtmosphericAcidification	Single value	IfcMassMeasure	Quantity of gases
RenewableEnergyConsumption	Single value	IfcEnergyMeasure	Quantity of renewable energy used as defined in ISO21930:2007
NonRenewableEnergyConsumption	Single value	IfcEnergyMeasure	Quantity of non-renewable energy used as defined in ISO21930:2007
RessourceDepletion	Single value	IfcMassMeasure	Quantity of resources used calculated in equivalent antimony.
InertWaste	Single value	IfcMassMeasure	Quantity of inert waste generated .
RadioactiveWaste	Single value	IfcMassMeasure	Quantity of radioactive waste generated.
StratosphericOzoneLayerDestruction	Single value	IfcMassMeasure	Quantity of gases destructing the stratospheric ozone layer calculated in equivalent CFC-R11.
PhotochemicalOzoneFormation	Single value	IfcMassMeasure	Quantity of gases creating the photochemical ozone calculated in equivalent ethylene.
Eutrophication	Single value	IfcMassMeasure	Quantity of eutrophicating compounds calculated in equivalent PO4.

Additional relevant properties are adopted for the PIM schema from the Sustainability Building Alliance Research Project and Ecospecifier as follows.

Sustainable Building Alliance Research Project Metrics

Two standards are relevant:

EN 15804 EN 15804—2012 Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products

ISO 21930 ISO 21930:2007 Sustainability in building construction -- Environmental declaration of building products.

Property name	Property type	Data type	Description
A. Resource depletion			
Use of non-renewable primary energy	Single value	Functional equivalent kWh/m2	
B. Indoor environment quality			
Thermal comfort	Single value	% time out of range	For summer and winter settings of minimum and maximum temperature
Indoor air quality	Single value	ppm	Concentration of CO2 during the occupied period
	Single value	µg/m3	Formaldehyde concentration
C. Building emissions			

Global Warming Potential	Single value	Kg CO2	Global warming potential according to IPCC 2001

Ecospecifier Metrics

Property name	Property type	Data type	Description
Human health	Single value	Green Tag HH EcoPoint	
Ecotoxicity	Single value	Green Tag Tox EcoPoint	
Biodiversity impacts	Single value	Green Tag BIOD EcoPoint	
Building synergy	Single value	Green Tag SYN EcoPoint	

Appendix 3

The following property values show two sources of property values, but both are at the materials level only.

Property Values For Embodied Carbon Data

Source: CRC-LCL Integrated Carbon Metrics research [Weidmann, 2016]

IOPC	IOPC descriptor (IOPC = Input Output Product Classification)	Embodied carbon factor [kg CO2-e/$]	Unit
9110010	Gravel	0.60665	t
9110020	Sand	0.62343	t
9190030	Limestone (incl shell and coral)	0.48709	t
14930020	Plywood	0.69020	m^3
14930030	Glued laminated lumber	0.37129	m^3
14940010	Fibreboard (excl fibre paperboard and particle board)	0.64638	m^3
14940030	Particle board (incl laminated) and similar board of wood or other ligneous materials	0.69270	m^3
20210010	Clay bricks (excl refractory bricks)	0.96704	No
20310010	Cement (incl hydraulic and portland) (excl adhesive or refractory)	4.41220	t
	100% Ordinary Portland Cement (OPC) 25MPa concrete	1.86940	m^3
	30% Fly ash 25MPa concrete	1.69620	m^3
	30% Ground Granulated Blast Furnace Slag (GGBFS) 25MPa concrete	1.57560	m^3
	100% Ordinary Portland Cement (OPC) 40 MPa concrete	2.19040	m^3
	30% Fly ash 40 MPa concrete	2.00090	m^3
	30% Ground Granulated Blast Furnace Slag (GGBFS) 40 MPa concrete	1.83080	m^3
	Geopolymer concrete 90% fly ash 40 MPa	1.10100	m^3
	Geopolymer concrete 90% slag 40 MPa	0.86630	m^3
14940040	Laminates of timber and non-timber materials	0.72844	m^2
20290020	Terracotta tiles	1.01970	m^2
	Plasterboard	0.93122	m^2
14920020	Roof trusses, wooden	0.68069	No
	Concrete pipes	0.92822	t
	AAC blocks	0.93538	m^3
	Concrete bricks and blocks	0.93538	m^3
13310010	Carpets and other textile floor coverings (incl mats and matting) (excl felt and underfelt)	1.17370	m^2
14130010	Resawn/seasoned timber (incl kiln dried)(excl sleepers, palings & shingles)	0.59120	m^3
14990010	Parquetry strips etc., assembled into panels; shingles and shakes	0.68742	m^2
	Linoleum	0.73600	m^2

19200040	Rubber sheets, strips, plates, rods, profile shapes and primary forms (excl cellular)	1.08810	m^2
20320020	Plasters (incl plaster of paris)(excl dental plasters)	0.95876	m^2
	Fibre cement	0.73314	m^3

BASIX Envelope Types

BASIX recognises Floors, Walls, Skylights, Windows and Ceiling and Roofs. Wall types are shown here as an example.

Source: see https://www.basix.nsw.gov.au/basixcms/

Name	External (cladding)	Intermediate	Internal (lining)
brick veneer	brick/masonry	cavity and framing	plasterboard
cavity brick	brick/masonry	cavity	brick/masonry and plasterboard
framed (weatherboard, fibre cement, metal clad)	weatherboard, fibre-cement sheet, metal or the like	framing	plasterboard
concrete block / plasterboard	concrete block	-	plasterboard on battens/furring
concrete panel / plasterboard	concrete panel	-	plasterboard on battens/furring
single-skin autoclaved aerated concrete (AAC)	AAC block or panel	-	plasterboard on battens/furring
AAC veneer	AAC block or panel, and external finish	cavity and framing	plasterboard
AAC external, brick internal	AAC block or panel, and external finish	cavity	brick/masonry and plasterboard
reverse brick veneer	weatherboard, fibre-cement sheet, metal or the like	framing and cavity	brick/masonry
mudbrick or rammed earth	mudbrick or rammed earth		
insulated concrete form (ICF)	polystyrene formwork and external finish	poured concrete	polystyrene formwork and render
external insulated facade system (EIFS)	insulating panel and external finish	framing	plasterboard

Appendix 4

The following show aggregated elemental and functional types that the PIM Team believes should also have associated aggregated measures for embodied carbon.

Development types (taken from [NSW LEP, 2016)

- advertising structure
- agricultural produce industry
- air transport facility
- airport
- airstrip
- amusement centre
- animal boarding or training establishment
- aquaculture
- archaeological site
- attached dwelling
- backpackers' accommodation
- bed and breakfast accommodation
- bee keeping
- biosolids treatment facility
- boarding house
- boat building and repair facility
- boat launching ramp
- boat shed
- brothel
- building
- building identification sign
- bulky goods premises
- business identification sign
- business premises
- camping ground
- canal estate development
- car park
- caravan park
- cellar door premises
- cemetery
- charter and tourism boating facility
- child care centre
- classified road
- coastal protection works
- commercial premises
- community facility
- community land
- correctional centre
- crematorium
- dairy (pasture-based)
- dairy (restricted)
- depot
- drainage
- dual occupancy (attached)
- dual occupancy (detached)
- dwelling
- dwellinghouse
- eco-tourist facility
- educational establishment
- electricity generating works
- emergency services facility
- entertainment facility
- environmental facility
- exhibition home
- exhibition village
- extensive agriculture
- extractive industry
- farm building
- farm stay accommodation
- feedlot
- fish
- flood mitigation work
- food and drink premises
- forestry
- freight transport facility
- function centre
- funeral home
- garden centre
- general industry
- group home
- group home (permanent) or permanent group home
- group home (transitional) or transitional group home
- hardware and building supplies
- hazardous industry
- hazardous storage establishment
- health consulting rooms
- health services facility
- heavy industrial storage establishment
- heavy industry
- helipad
- heliport
- heritage conservation area
- heritage item
- heritage significance
- high technology industry
- highway service centre
- home-based child care
- home business
- home industry
- home occupation
- home occupation (sex services)
- horticulture
- hospital
- hostel
- hotel or motel accommodation
- industrial activity

industrial retail outlet	rainwater tank	storage premises
industrial training facility	recreation area	swimming pool
industry	recreation facility (indoor)	take away food and drink premises
information and education facility	recreation facility (major)	telecommunications facility
intensive livestock agriculture	recreation facility (outdoor)	telecommunications network
intensive plant agriculture	relic	temporary structure
jetty	research station	timber yard
kiosk	residential accommodation	tourist and visitor accommodation
landscaped area	residential care facility	transport depot
landscaping material supplies	residential flat building	truck depot
light industry	resource recovery facility	turf farming
liquid fuel depot	respite day care centre	underground mining
livestock processing industry	restaurant or cafe	vehicle body repair workshop
marina	restricted premises	vehicle repair station
market	restriction facilities	vehicle sales or hire premises
medical centre	retail premises	veterinary hospital
mine	road	viticulture
mixed use development	roadside stall	warehouse or distribution centre
mooring	rural industry	waste disposal facility
mooring pen	rural supplies	waste or resource management facility
mortuary	rural worker's dwelling	waste or resource transfer station
moveable dwelling	sawmill or log processing works	water recreation structure
multi dwellinghousing	school	water recycling facility
navigable waterway	self-storage units	water reticulation system
neighbourhood shop	semi-detached dwelling	water storage facility
offensive industry	seniors housing	water supply system
offensive storage establishment	service station	water treatment facility
office premises	serviced apartment	watercourse
open cut mining	sewage reticulation system	waterway
parking space	sewage treatment plant	wetland
passenger transport facility	sewerage system	wharf or boating facilities
place of public worship	sex services	wholesale supplies
plant nursery	sex services premises	
port facilities	shop	
private open space	shop top housing	
pub	signage	
public administration building	small bar	
public land	spa pool	
public reserve	stock and sale yard	
public utility infrastructure		

Appendix 5

Embodied CO2 Emissions Module for AccuRate
Taken from Appendix A – Embodied Carbon Table (See [Dong Chen, et al, 2010])

Materials	Unit	Embodied CO2 (kg CO2 eq./unit)	Comments
Aerated autoclaved concrete block	m3	196.9	Adopt European data from Ecoinvent (2004, autoclaved aerated concrete block, at plant/kg/CH). Assumed raw material are transported within 100km Density is 550 kg/m3 (Hebel, 2009)
Aluminum	m3	35804.8	Employ closed-loop method for recycling allocation (EAA, 2005; ISO 14044, 2006). Assumed 70% recovery rate Assumed mixing as virgin (70%) and scrap aluminum (30%) (Koltun and Tharumarajah, 2006)
Bituminous roof membrane	m3	1012.5	Adopt European data from Ecoinvent (2007, bitumen sealing, polymer EP4 flame retardant, at plant/kg/RER)
Brickwork with extruded clay brick	m3	290.8	Density 1580kg/m3 Standard brick size (110 (W)×230 (L)×76 (H) 3.3kg of clay brick (extruded)
Brickwork with pressed clay brick	m3	344.8	Density 2097kg/m3 Standard brick size (110 (W)×230 (L)×76 (H) 4.1 kg of clay brick (pressed)
BST lightweight concrete	m3	1332.0	Density 2000kg/m3 (25-30MPa) sourced from Kirkside Products (2009)
Carpet (Nylon)	m3	2337.9	Assumed 50% for cut pile (0.175 g/cm3) and 3 50% for loop pile (0.150 g/cm) • surface pile mass for Nylon BCF carpet (25.2/100mm gauge) is 580g/m2 cut pile and 475 g/m2 loop pile (CIAL, 2009)
Carpet underlay (rubber)	m3	739.5	Rubber underlay Thickness 7.5mm (1.830±55 kg/m2) Sourced from NFA (2009)
Carpet 10 + felt underlay 10	m3	1169.0	Felt underlay data unavailable Only carpet is considered; • Assumed 50% for cut pile (0.175 g/cm3) and 3 50% for loop pile (0.150 g/cm) • surface pile mass for Nylon BCF carpet (25.2/100mm gauge) is 580g/m2 cut pile and 475 g/m2 loop pile (CIAL, 2009)
Carpet (10) + rubber underlay (8)	m3	1186.6	0.018m thickness (10mm carpet (nylon) with 8mm rubber underlay)• Density 185kg/m3
Ceramic tile	m3	1920	Adopt European data from Ecoinvent (2003, ceramic tiles, at regional storage/kg/CH) Assumed raw material are transported within 100km
Concrete block 190 dense-weight (not core-filled)	m3	153.9	Adopt Boustead data (UK dense concrete block) Thickness 190mm Density 1101kg/m3
Concrete block 190 dense-weight (core-filled at 1800 centres)	m3	186.3	Adopt Boustead data (UK dense concrete block) Thickness 190mm Density 1332kg/m3
Concrete block 190 dense-weight (core-filled at 1500 centres)	m3	189.5	Adopt Boustead data (UK dense concrete block) Thickness 190mm Density 1355kg/m3
Concrete block 190 dense-weight (core-filled at 1400 centres)	m3	190.6	Adopt Boustead data (UK dense concrete block) Thickness 190mm Density 1363 kg/m3
Concrete block 190 dense-weight (core-filled at 1000	m3	199.4	Adopt Boustead data (UK dense concrete block) Thickness

centres)			190mm Density 1426 kg/m3
Concrete block 190 dense-weight (core-filled at 600 centres)	m3	219.3	Adopt Boustead data (UK dense concrete block) Thickness 190mm Density 1568 kg/m3
Concrete block 190 dense-weight (fully core-filled)	m3	313.1	Adopt Boustead data (UK dense concrete block) Thickness 190mm Density 2239 kg/m3
Concrete block 190 light-weight (not core-filled)	m3	189.7	Adopt Boustead data (UK lightweight concrete block) Thickness 190mm Density 909kg/m3
Concrete block 190 light-weight (core-filled at 1800 centres)	m3	237.3	Adopt Boustead data (UK lightweight concrete block) Thickness 190mm Density 1137 kg/m3
Concrete block 190 light-weight (core-filled at 1500 centres)	m3	242.3	Adopt Boustead data (UK lightweight concrete block) Thickness 190mm Density 1161 kg/m3
Concrete block 190 light-weight (core-filled at 1400 centres)	m3	243.8	Adopt Boustead data (UK lightweight concrete block) Thickness 190mm Density 1168 kg/m3
Concrete block 190 light-weight (core-filled at 1000 centres)	m3	257.1	Adopt Boustead data (UK lightweight concrete block) Thickness 190mm Density 1232 kg/m3
Concrete block 190 light-weight (core-filled at 600 centres)	m3	286.8	Adopt Boustead data (UK lightweight concrete block) Thickness 190mm Density 1374 kg/m3
Concrete block 190 light-weight (fully core-filled)	m3	427.4	Adopt Boustead data (UK lightweight concrete block) Thickness 190mm Density 2048 kg/m3
Concrete block 140 dense-weight (not core-filled)	m3	174.2	Adopt Boustead data (UK dense concrete block) Thickness 140mm Density 1246 kg/m3
Concrete block 140 dense-weight (core-filled at 1800 centres)	m3	201.8	Adopt for Boustead data (UK dense concrete block) Thickness 140mm Density 1443 kg/m3
Concrete block 140 dense-weight (core-filled at 1500 centres)	m3	204.7	Adopt Boustead data (UK dense concrete block) Thickness 140mm Density 1464 kg/m3
Concrete block 140 dense-weight (core-filled at 1400 centres)	m3	205.7	Adopt Boustead data (UK dense concrete block) Thickness 140mm Density 1471 kg/m3
Concrete block 140 dense-weight (core-filled at 1000 centres)	m3	212.7	Adopt Boustead data (UK dense concrete block) Thickness 140mm Density 1521 kg/m3
Concrete block 140 dense-weight (core-filled at 600 centres)	m3	230.7	Adopt Boustead data (UK dense concrete block) Thickness 140mm Density 1650 kg/m3
Concrete block 140 dense-weight (fully core-filled)	m3	312.0	Adopt Boustead data (UK dense concrete block) Thickness 140mm Density 2231 kg/m3
Concrete block 140 light-weight (not core-filled)	m3	214.8	Adopt Boustead data (UK lightweight concrete block) Thickness 140mm Density 1029 kg/m3
Concrete block 140 light-weight (core-filled at 1800 centres)	m3	254.8	Adopt Boustead data (UK lightweight concrete block) Thickness 140mm Density 1221 kg/m3
Concrete block 140 light-weight (core-filled at 1500 centres)	m3	259.4	Adopt Boustead data (UK lightweight concrete block) Thickness 140mm Density 1243 kg/m3
Concrete block 140 light-weight (core-filled at 1400 centres)	m3	260.9	Adopt Boustead data (UK lightweight concrete block) Thickness 140mm Density 1250 kg/m3
Concrete block 140 light-weight	m3	272.8	Adopt Boustead data (UK lightweight concrete block) Thickness

(core-filled at 1000 centres)			140mm Density 1307 kg/m3
Concrete block 140 light-weight (core-filled at 600 centres)	m3	298.2	Adopt Boustead data (UK lightweight concrete block) Thickness 140mm Density 1429 kg/m3
Concrete block 140 light-weight (fully core-filled)	m3	420.3	Adopt Boustead data (UK lightweight concrete block) Thickness 140mm Density 2014 kg/m3
Concrete block 110 dense-weight (not core-filled)	m3	230.3	Adopt for Boustead data (UK dense concrete block) Thickness 110mm Density 1647 kg/m3
Concrete block 110 dense-	m3	304.8	Adopt Boustead data (UK dense concrete block) Thickness 110mm Density 2180 kg/m3
Concrete block 110 light-weight (not core-filled)	m3	283.8	Adopt Boustead data (UK lightweight concrete block) Thickness 110mm Density 1360 kg/m3
Concrete block 110 light-weight (solid)	m3	375.7	Adopt Boustead data (UK lightweight concrete block) Thickness 110mm Density 1800 kg/m3
Concrete block 90 dense-weight (not core-filled)	m3	230.3	Adopt Boustead data (UK dense concrete block) Thickness 90mm Density 1647 kg/m3
Concrete block 90 dense-weight (solid)	m3	304.8	Adopt Boustead data (UK dense concrete block) Thickness 90mm Density 2180 kg/m3
Concrete block 90 light-weight (not core-filled)	m3	283.8	Adopt Boustead data (UK lightweight concrete block) Thickness 90mm Density 1360 kg/m3
Concrete block 90 light-weight (solid)	m3	375.7	Adopt Boustead data (UK lightweight concrete block) Thickness 90mm Density 1800 kg/m3
Concrete (standard)	m3	333.6	Density 2400 kg/m3 SimaPro (Australian LCI data, 2007)
Conpolcrete	-	-	Density 395kg/m3 Data not available
Copper (tube)	m3	55262.7	Assume extruded Adopt European data from Ecoinvent (2007, cold impact extrusion, steel, 1 stroke/kg/RER) Density is 1490kg/m3 from AccuRate (default value)
Cork tile	m3	861	Adopt European data from Ecoinvent (2003, cork slab, at plant/kg/RER) Density is 593 kg/m3 from AccuRate default
Fibre-cement sheet	m3	1668.6	Adopt European data from Ecoinvent (2004, fibre cement facing tile, at plant/kg/CH) Flat tile type Density (1490kg/m3) Transport within 200 km by truck for freight
Compressed fibre-cement sheet	m3	2239.7	Assumed that manufacturing process is similar to fibre-cement sheet (but density is different with fibre cement sheet) Density (2000kg/m3) Transport within 200 km by truck for freight
Glass (flat)	m3	1380.5	Adopt European data from Ecoinvent (2007, flat glass, uncoated, at plant/kg/RER) Only flat glass considered (uncoated) Assumed raw material are transported within 200km
Granite	m3	386.9	Adopt Dolomite from Australian data 2007 (Dolomite/AU U in SimaPro DB) Assumed raw material are transported within 500km Density is 2650 kg/m3 from AccuRate default
Hollow-core precast concrete panel (200mm)	m3	302.5	Assumed to be similar to general precast concrete production (50MPa general purpose concrete)Assumed transport within 100km Density (1680kg/m3
Hollow-core precast concrete panel (150 mm)	m3	302.5	Assumed to be similar to general precast concrete production (50MPa general purpose concrete) Assumed transport within 100km Density (1680kg/m3)
Lead	m3	30894	Adopt European data from Ecoinvent (2003, sheet rolling chromium steel/kg/RER) Assumed scrap use percentage 50%. Process includes lead from mining, concentrating and melting.

Linoleum	m3	1461.2	Adopt European data from IDEMAT (1998, Linoleum production) Input data considering Australian conditions
Marble	m3	397.1	Assumed to be similar to dolomite mining process Process considered mining process (limestone) and transportation Assumed raw material are transported within 500km Density is 2720 kg/m3 from AccuRate default
Masonite (soft)	m3	231.8	Adopt European data from Ecoinvent (2003, 3 fibreboard hard, at plant/m /RER and 3 fibreboard soft, at plant/m /RER) Assumed raw material are transported within 200km. Density is 1025 kg/m3 from AccuRate default
Mud brick	m3	36.4	Assumed that mixing energy consumption is similar to clay brick. Mixing data adopt European data from Ecoinvent (2004, plaster mixing/kg/CH) Assumed raw material is transported within 100km.
Particleboard (for flooring)	m3	513.8	Data is take from AusLCI data (2008, Particleboard, 19mm, Australia, AU/U) Density is 640kg/m3 from AccuRate (default value)
Plaster (cement : sand, 1:4)	m3	418	Adopt European data from Ecoinvent (2004, cement cast plaster floor, at plant/kg/CH) Assumed raw material are transported within 200km Density is 2000 kg/m3 from AccuRate (default value)
Plasterboard	m3	301.8	Adopt European data from Ecoinvent (2004, gypsum plaster board, at plant/kg/CH) Process includes production of plasterboard including drying process. Assumed raw material are transported within 200km Standard 10 mm thickness is considered
Plywood (softwood) without carbon sequestration	m3	650.1	Data taken from AusLCI data (2007, Plywood Structural, at mill, Australia /AU U) Density is 530kg/m3 from AccuRate (default value) Carbon sequestration (747kg of CO2-e/m3)
Plywood (softwood) with carbon sequestration	m3	-96.9	
Polycarbonate	m3	6944.3	Adopt European data from Ecoinvent (2007, polycarbonate, at plant/kg/RER) Process includes aggregated data for all processes from raw material extraction until delivery at plant Density is 1150 kg/m3 from AccuRate default
Rammed earth	m3	0.000	Assumed ‘0’ until information available
Reflective blind	m3	3745.6	Assumed Polyester is PET (polyethylene terephthalate) PET data taken from Australian LCI database from SimaPro (2008) Assumed transport within 200km
Roof tile (clay)	m3	422.8	Adopt European data from Ecoinvent (2005, roof tile, at plant/kg/RER). Assumed transport within 100km Density is 1922 kg/m3 from AccuRate default
Roof tile (concrete)	m3	564	Adopt European data from Ecoinvent (2007, concrete roof tile, at plant/kg/CH) Assumed transport within 100km Density is 2400 kg/m3 from AccuRate (default value)
Sand	m3	51	Data taken from Australian LCI DB in SimaPro (2007, sand) Assumed that sand processing operations take place at the mining site or nearby, and for this reason Assumed transport within 400km (NSW, QLD and VIC ACI plants)
Sandstone	m3	190	Adopt Dolomite from Australian data 2007 (Dolomite/AU U in SimaPro DB) Density is 2000 kg/m3 from AccuRate (default value)
Slate	m3	198.8	Adopt Dolomite from Australian data 2007 (Dolomite/AU U in SimaPro DB) Assumed transport within 200km Density is 2650 kg/m3 from AccuRate (default value)

Soft-board (MDF, 12mm)	m3	627.7	Australian national LCI DB (2008) MDF, 12mm, Australia, AU/U Carbon sequestration of MDF is 1096 kg of 3 CO2-e/m .
Soft-board (MDF, 12mm, with carbon sequestration)	m3	-468.3	
Soil (average)	m3	0.000	Assumed '0' in this stage
Steel	m3	12207	Australian LCI DB in SimaPro (2004, Steel, Bluescope Port Kembla, 20% recycled content/AU U)
Straw board	-	-	Data not available
Straw bale rendered	-	-	
Styrocon	m3	697	Adopt Ecoinvent (2005, Lightweight concrete block, polystyrene, at plant/CH U)
Timbercrete (solid low-density, 3 900kg/m)	m3	125.9	Assumed timbercrete manufacturing is similar to normal concrete blocks (even though Portland cement portion for timbercrete is slightly higher as 17% to normal concrete blocks). Assumed ingredient portion for solid low (or mid, high) density is similar to hollow low (or mid, high) density
Timbercrete (solid mid-density, 3 1000kg/m)	m3	139.0	
Timbercrete (solid high-density, 3 1100kg/m)	m3	153.8	
Timbercrete (hollow low- 3 density, 900kg/m)	m3	125.9	
Timbercrete (hollow mid- 3 density, 1000kg/m)	m3	139.0	
Timbercrete (hollow high- 3 density, 1100kg/m)	m3	153.8	
Timber (softwood)	m3	204.5	Australian national LCI DB (2008, Dried sawn wood product) Density (506kg/m3) CO2 sequestration (922.944 kg CO2/m3)
Timber (hardwood)	m3	396.7	Australian national LCI DB (2008, Dried sawn wood product, softwood) Density (677kg/m3) CO2 sequestration (1234.848kg CO2/m3)
Timber (hardwood, with carbon sequestration)	m3	-838.1	
Timber (Jarrah)	m3	505.1	Australian national LCI DB (2008, Dried sawn wood product, hardwood) Density (862kg/m3)CO2 sequestration (1572.288kg CO2/m3)
Timber (Jarrah, with carbon sequestration)	m3	-1067.1	
Timber (Mountain Ash)	m3	396.7	Australian national LCI DB (2008, Dried sawn wood product, hardwood) Density (677kg/m3) CO2 sequestration (1234.848kg CO2/m3)
Timber (Mountain Ash, with carbon sequestration)	m3	-838.1	
Timber (Radiata Pine)	m3	204.5	Australian national LCI DB (2008, Dried sawn wood product, softwood) Density (506kg/m3) CO2 sequestration (922.944 kg CO2/m3)
Timber (Radiata Pine, with carbon sequestration)	m3	-718.4	
Vinyl tile (for flooring)	m3	2525.6	Data taken from Australian LCI DB in SimaPro (2004, PVC compound for vinyl flooring)
Water	m3	0.3	Density (2050kg/m3)
Window film	m3	8309.25	Data taken from Australian LCI DB in SimaPro (1999, Water delivery in Australia)
Cellular insulation (without air gap)	m3	176	Adopt PET film data from Ecoinvent (2000, PET film production (average) A)

Cellulose fibre: loose fill (k=0.04)	m3	76.4	Assumed cellular insulation made from polyethylene (94%) and aluminum foil (6%)
Cellulose fibre (loose fill): R=1.0	m3	76.4	Assumed transport within 200km
Cellulose fibre (loose fill): R=1.5	m3	76.4	Assumed cellulose fibre made from recycled newspaper (except for phone books or glossy paper is used)
Cellulose fibre (loose fill): R=2.0	m3	76.4	Assumed transport within 200km
Cellulose fibre (loose fill): R=2.5	m3	76.4	Density is 38.6kg/m3 from AccuRate (default value)
Cellulose fibre (loose fill): R=3.0	m3	76.4	Assumed the same as above (only different thickness)
Cellulose fibre (loose fill): R=3.5	m3	76.4	Assumed the same as above (only different thickness)
Cellulose fibre (loose fill): R=4.0	m3	76.4	Assumed the same as above (only different thickness)
Glass fibre batt (k=0.057 3 density = 7 kg/m)	m3	22.3	Assumed the same as above (only different thickness)
Glass fibre batt (k=0.044 3 density = 12 kg/m)	m3	38.3	Assumed the same as above (only different thickness)
Glass fibre batt: R=1.0	m3	38.3	Assumed the same as above (only different thickness)
Glass fibre batt: R=1.5	m3	38.3	Assumed the same as above (only different thickness)
Glass fibre batt: R=2.0	m3	38.3	Adopt European data from Ecoinvent (2004, glass wool mat, at plant/kg/CH)
Glass fibre batt: R=2.5	m3	38.3	Adopt European data from Ecoinvent (2004, glass wool mat, at plant/kg/CH)
Glass fibre batt: R=3.0	m3	38.3	Assumed the same as above (only different thickness)
Glass fibre batt: R=3.5	m3	38.3	Assumed the same as above (only different thickness)
Glass fibre batt: R=4.0	m3	38.3	Assumed same as above (only different thickness)
Polyethylene foam (k=0.04)	m3	84.7	Data taken from Australian LCI DB in SimaPro (2007, LDPE, Low density polyethylene/AU/U) Density is 24 kg/m3 from AccuRate (default value)
Polyester or polyester blanket 3 (k=0.063, density:8 kg/m)	m3	93.3	Adopt European data from IDEMAT (2001,Polyester fabric) Density is 8kg/m3 from AccuRate (default value)
Polyester or polyester blanket 3 (k=0.045, density:16 kg/m)	m3	186.6	Adopt European data from IDEMAT (2001,Polyester fabric) Density is 16kg/m3 from AccuRate (default value)
Polyester or polyester/wool blanket: R1.0)	m3	186.6	Assumed the same as polyester or polyester 3 blanket (k=0.045, density 16kg/m) (only different thickness)
Polyester or polyester/wool blanket: R1.5)	m3	186.6	Assumed same as polyester or polyester 3 blanket (k=0.045, density 16kg/m) (only different thickness)
Polyester or polyester/wool blanket: R2.0)	m3	186.6	Assumed the same as polyester or polyester 3 blanket (k=0.045, density 16kg/m) (only different thickness)
Polyester or polyester/wool blanket: R2.5)	m3	186.6	Assumed the same as polyester or polyester 3 blanket (k=0.045, density 16kg/m) (only different thickness)
Polyester or polyester/wool blanket: R3.0)	m3	186.6	Assumed the same as polyester or polyester 3 blanket (k=0.045, density 16kg/m) (only different thickness)

Polyester or polyester/wool blanket: R3.5)	m3	186.6	Assumed the same as polyester or polyester 3 blanket (k=0.045, density 16kg/m) (only different thickness)
Polyester or polyester/wool blanket: R4.0)	m3	186.6	Assumed the same as polyester or polyester 3 blanket (k=0.045, density 16kg/m) (only different thickness)
Polystyrene expanded(k=0.039)	m3	58.7	Adopt European data from Ecoinvent (2007, polystyrene, expandable, at plant/kg/RER) Process includes production and thermoforming of EPS Density is 16kg/m3 from AccuRate (default value)
Polystyrene expanded R1.0	m3	58.7	Assumed the same as polystyrene expanded (k=0.039) (only different thickness)
Polystyrene expanded R1.5	m3	58.7	Assumed the same as polystyrene expanded (k=0.039) (only different thickness)
Polystyrene expanded R2.0	m3	58.7	Assumed the same as polystyrene expanded (k=0.039) (only different thickness)
Polystyrene expanded R2.5	m3	58.7	Assumed the same as polystyrene expanded (k=0.039) (only different thickness)
Polystyrene expanded R3.0	m3	58.7	Assumed the same as polystyrene expanded (k=0.039) (only different thickness)
Polystyrene expanded R3.5	m3	58.7	Assumed the same as polystyrene expanded (k=0.039) (only different thickness)
Polystyrene expanded R4.0	m3	58.7	Assumed the same as polystyrene expanded (k=0.039) (only different thickness)
Polystyrene extruded (k=0.028)	m3	140.5	Adopt European data from Ecoinvent (2007, polystyrene, extruded (XPS), at plant/kg/RER) Process includes the production of extruded polystyrene (melting of polystyrene pearls in the extruder, the discharge through a slot die, as well as the cooling with water) Density is 32kg/m3from AccuRate (default value)
Polystyrene extruded R1.0	m3	140.5	Assumed the same as polystyrene extruded (k=0.028) (only different thickness)
Polystyrene extruded R1.5	m3	140.5	Assumed the same as polystyrene extruded (k=0.028) (only different thickness)
Polystyrene extruded R2.0	m3	140.5	Assumed the same as polystyrene extruded (k=0.028) (only different thickness)
Polystyrene extruded R2.5	m3	140.5	Assumed the same as polystyrene extruded (k=0.028) (only different thickness)
Polystyrene extruded R3.0	m3	140.5	Assumed the same as polystyrene extruded (k=0.028) (only different thickness)
Polystyrene extruded R3.5	m3	140.5	Assumed the same as polystyrene extruded (k=0.028) (only different thickness)
Polystyrene extruded R4.0	m3	140.5	Assumed the same as polystyrene extruded (k=0.028) (only different thickness)
Polyurethane rigid foamed aged (k=0.028)	m3	86.3	Adopt European data from Ecoinvent (2003, polyurethane, rigid foam, at plant/kg/RER) Process includes the transports of the monomers as well as the production (energy, air emissions) of the PUR foam Density is 24kg/m3 from AccuRate (default value)
Polyurethane rigid foamed aged R1.0	m3	86.3	Assumed the same as polyurethane rigid foamed aged (k=0.028) (only different thickness)
Polyurethane rigid foamed aged R1.5	m3	86.3	Assumed the same as polyurethane rigid foamed aged (k=0.028) (only different thickness)

Polyurethane rigid foamed aged R2.0	m3	86.3	Assumed the same as polyurethane rigid foamed aged (k=0.028) (only different thickness)
Polyurethane rigid foamed aged R2.5	m3	86.3	Assumed the same as polyurethane rigid foamed aged (k=0.028) (only different thickness)
Polyurethane rigid foamed aged R3.0	m3	86.3	Assumed the same as polyurethane rigid foamed aged (k=0.028) (only different thickness)
Polyurethane rigid foamed aged R3.5	m3	86.3	Assumed the same as polyurethane rigid foamed aged (k=0.028) (only different thickness)
Polyurethane rigid foamed aged R4.0	m3	86.3	Assumed the same as polyurethane rigid foamed aged (k=0.028) (only different thickness)
Rockwool loose fill (k=0.04)	m3	101.6	Adopt European data from Ecoinvent (2003, rock wool, packed, at plant/kg/CH) Process includes mechanical packing and the administration of the rock wool factory. Density is 64kg/m3 from AccuRate (default value)
Rockwool batt (k=0.033)	m3	48.8	Adopt European data from Ecoinvent (2004, rock wool, at plant/kg/CH) Process includes melting, fiber forming & collecting, hardening & curing furnace, and internal processes (workshop, etc.). Transport of raw materials and energy carrier for furnace are also included (Not included are administration, packing and infrastructure) Density is 32kg/m3 from AccuRate (default value)
Rockwool batt R1.0	m3	48.8	Assumed the same as rockwool batt (k=0.033) (only different thickness)
Rockwool batt R1.5	m3	48.8	Assumed the same as rockwool batt (k=0.033) (only different thickness)
Rockwool batt R2.0	m3	48.8	Assumed the same as rockwool batt (k=0.033) (only different thickness)
Rockwool batt R2.5	m3	48.8	Assumed the same as rockwool batt (k=0.033) (only different thickness)
Rockwool batt R3.0	m3	48.8	Assumed the same as rockwool batt (k=0.033) (only different thickness)
Rockwool batt R3.5	m3	48.8	Assumed the same as rockwool batt (k=0.033) (only different thickness)
Rockwool batt R4.0	m3	48.8	Assumed the same as rockwool batt (k=0.033) (only different thickness)
Wool loose fill (k=0.08)	m3	602.6	Adopt European data from Ecoinvent (2007, wool, sheep, at farm/kg/US) Process includes sheep husbandry on pasture land. Machine infrastructure and a shed for machine sheltering and shearing is included. Inputs of fertilisers, feedstuffs, pesticides and irrigation as well as transports to the farm are considered. The direct emissions on the field are also included. Assumed transport within 1000km Density is 12kg/m3 from AccuRate (default value)
Wool/polyester batt 80/20 3 (k=0.059 density= 8 kg/m)	m3	334.6	Adopt wool from US data in Ecoinvent (2007, wool, sheep, at farm/kg/US) and polyester from European data from IDEMAT (1996, polyester fabric) Density is 8kg/m3 from AccuRate (default value)
Wool/polyester batt 80/20 (k=0.045 density= 16 kg/m) 3	m3	669.2	Assumed the same as wool/polyester batt 80/20 (k=0.059) Density is 16 kg/m3 from AccuRate (default value)
Wool/polyester batt 80/20 R1.0	m3	669.2	Assumed the same as wool/polyester batt 3 80/20 (k=0.045, density 16 kg/m)
Wool/polyester batt 80/20 R1.5	m3	669.2	Assumed the same as wool/polyester batt 3 80/20 (k=0.045, density 16 kg/m)

Wool/polyester batt 80/20 R2.0	m3	669.2	Assumed the same as wool/polyester batt 3 80/20 (k=0.045, density 16 kg/m)
Wool/polyester batt 80/20 R2.5	m3	669.2	Assumed the same as wool/polyester batt 3 80/20 (k=0.045, density 16 kg/m)
Wool/polyester batt 80/20 R3.0	m3	669.2	Assumed the same as wool/polyester batt 3 80/20 (k=0.045, density 16 kg/m)
Wool/polyester batt 80/20 R3.5	m3	669.2	Assumed the same as wool/polyester batt 3 80/20 (k=0.045, density 16 kg/m)
Wool/polyester batt 80/20 R4.0	m3	669.2	Assumed the same as wool/polyester batt 3 80/20 (k=0.045, density 16 kg/m)

Note: for detailed sources and assumptions used to obtain the embodied CO_2 for each building material/product, please refer to Seo (2010).

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