Can we design buildings within planetary boundaries? An exploration into using a top-down benchmarking approach for embodied carbon

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Abstract: The way we build, occupy, and dismantle architecture contributes heavily to the global problem of climate change. Accounting for the embodied emissions from buildings is just as important as measuring operational emissions. It's widely recognised that including Life Cycle Assessment (LCA) during design can inform decisions to reduce emissions. However, it is difficult to complete a LCA during the early stages and to define appropriate targets for achieving a project that is within the planetary boundaries (a concept involving earth system processes). Therefore, there is a need for benchmarks that respond to the scale of design decisions and allocate carbon emission targets for different building elements. To support designers in early decision making, this paper explores how a top-down benchmarking approach can be applied to both the building and elemental levels of LCA results. Functional units are applied using full-time employee to create a cap. The approach is applied to typical and non-typical building typologies from the same case study, a koala rehabilitation centre in Queensland, Australia. The case study was selected to form a discussion around the application of top-down building and elemental benchmarks in commercial architecture practice and test limitations. The paper asks the question: how can top-down benchmarks best support early design decisions to reduce the environmental impact of a building? The results show that whilst top-down benchmarks are good at connecting building scale benchmarks with a global carbon budget, the sharing principles used to achieve the benchmark limit their application on non-typical building typologies.

Keywords: Top-Down Benchmark, Embodied Carbon, Commercial, Early Design, Life Cycle Assessment, Planetary Boundaries.

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1. Introduction

1.1. Targeting zero through whole life carbon

New buildings are being constructed at an unprecedented rate, with 260 billion square metres of new construction expected to be added in the next 40 years, the equivalent of rebuilding a city the size of Paris every single week (Lebot 2017). Globally, the building and construction industry contributes 39% of all carbon emissions (Lebot 2017). Many countries have committed to making this industry net zero by 2050 (United Nations 2015). To achieve net zero, consideration throughout the design process needs to be in the context of whole life carbon, which includes both operational and embodied carbon (LETI 2020). In many cases off-setting carbon emissions will compensate for emissions that cannot be designed out. To reduce the reliance on this strategy the Living Future Institute released a Zero Carbon standard limiting projects to 500 $kgCO_2/m^2$ over the full life cycle, before a project can begin to explore offsetting strategies (International Living Future Institute 2020). The London Energy Transformation Initiative (LETI) also presents recommended limits in a similar range. For non-domestic buildings, 1000 $kgCO_2/m^2$ is presented as a baseline, 600 $kgCO_2/m^2$ is presented as best-practice for 2020, and 350 $kgCO_2/m^2$ is presented as best-practice for 2030 (LETI 2020). All these values are targeted towards commercial buildings with a reference service life of 60 years. They also claim to be linked to the initiative to limit global warming to 1.5°C by the IPCC (IPCC 2018). However, none have been transparent about how or even if they have accounted for a global carbon budget or either 50 or 66% confidence.

1.2. Benchmarks to support the Design Process

Between academic literature and green building rating systems, a wide range of benchmarks can be found for the environmental performance of buildings. The term ‘benchmark’ has many different meanings, and other terms can also be used in its place. EN 16231 outlines the act of benchmarking as a “process of collecting, analysing and relating performance data of comparable activities with the purpose of evaluating and comparing performance between or within entities” (European Committee for Standardization 2012). In this context, the benchmark becomes a “reference or standard value for comparison derived from the benchmarking” (European Committee for Standardization 2012). However, these definitions are still very broad and require a more descriptive framework. The literature provides very few systematic frameworks to set benchmarks and the earliest approaches are documented in the final results of IEA Annex 31 and in the results from working group 4 of ISO TC 59 SC17. ISO 219331-1 (Hernandez Iñarra 2012).

1.3. Spectrum of Performance

Many of the existing benchmarks that can be found in academic literature, building legislation, and building rating systems, fall along a spectrum. Positions along this spectrum have been defined by Häkkinen et al (2012) and Lützkendorf (2012), who differentiate between limit, reference, best practice, and target values (Table 1).

Table 12: Spectrum of Performance

Value	Definition
Limit	Minimum acceptable performance
Reference	Average performance or ‘Business as Usual’
Best-Practice	Top 10% or ‘Best in Class’
Target	Aspirational level of performance

1.4. Top-Down and Bottom-Up Benchmarks

Top-down benchmarks are generated through approaches that scale global carbon budgets down to an industry level. The global budgets typically used are the 2-degree target from the Paris agreement or 2000 Watt Society (Jochem et al. 2004). More recently, global budgets have been developed from reports produced by the Intergovernmental Panel on Climate Change (IPCC 2018). Top-down benchmarks can be considered as “externally motivated benchmarks” (Braune and Wittstock 2011), and must be “translated into building specific targets” (Häkkinen 2012). In New Zealand, studies have presented a framework for translating the 2˚C and 1.5˚C into a residential housing budget (Chandrakumar et al. 2019; McLaren et al. 2020). These studies produced a top-down benchmark in the form of a target value that could then be broken down into operational and embodied benchmarks

Bottom-up benchmarks can generate reference or best practice values for the whole building or relating to parts of the building. These benchmarks can be calculated from studies on assessing reference buildings (Thomas Lützkendorf, Kohler, and König 2012; Ji et al. 2016). or bottom-up benchmarks to be successful, the data needs to be not only available, but also up to date. Research has identified that bottom-up benchmarks found in the literature are context specific and cannot be as easily adopted by another country or transferred from residential to commercial buildings (Lavagna et al. 2018).However, a key benefit of bottom-up benchmarks is the direct association with specific parts of the building, allowing a design team to quickly focus problem solving efforts.

1.5. Problems with benchmarks for application in the design process

Many of the benchmarks that exist today were developed to regulate the performance of the whole building. Hollberg, et al. argued that an issue with the holistic development of benchmarks is that “they only provide limited guidance during the design process” (Hollberg, Lützkendorf, and Habert 2019). This is due to the whole-building benchmark value only indicating if the design does or does not meet the desired performance. As designing for the reduction of embodied carbon is an emerging area, “the designer does not have the ‘feeling’ of how much better the building could perform” (Hollberg, Lützkendorf, and Habert 2019). For this reason, Hollberg, et al. argued that there is a need for bottom-up benchmarks on an elemental level to support design decision making. Yet, attempting to use both a bottom-up elemental and top-down whole-building benchmark creates another issue, as there is a disconnection between the units used for each, making the two hard to link. These benchmarks are also generated using different methods which do not always align with one another. Therefore, it is difficult to connect decisions on building structure or material selection back to determining if the building overall is within the planetary boundaries. To resolve the disconnection issue, this paper aims to generate a top-down building benchmark and apportion it down to a top-down building benchmark to support designers and the scales they work within.

2. Method

The proposed method uses planetary accounting principles to create a top-down building benchmark for designers. To benefit the design process in a similar way to Hollberg, et al., whose approach combined top-down and bottom-up benchmarks (Hollberg, Lützkendorf, and Habert 2019), the top-down building benchmark is divided into top-down elemental benchmarks. The top-down building and elemental benchmarks are both being presented as a target values, as they define an aspirational level of performance. The aim of this approach is to encourage optimisation of the different building elements and support the analysis of the building's environmental impact during early design but can be applied at all design stages.

2.1. Generating Top-down Building Benchmarks

In this paper the 1.5°C carbon budgets, at 50% and 66% confidence, published from the IPCC (IPCC 2018) are used as a starting point. Planetary accounting methods provide guidance on applying sharing principles to divide the global carbon budget down to a fair share for new construction. Equation 1 represents the approach mathematically.

Equation 1 – Commercial Top-Down Benchmark

$$TF=\left(\left(\left(\left(CB_G \times \left(\frac{P_C}{P_G}\right)\right)\times\left(\frac{E_C}{E_T}\right)\right)\times\left(\frac{V_C}{V_C+V_R}\right)\right)\times\left(\frac{M_C}{M_C+M_R}\right)\right)$$

Where: TF – Top-Down Building Benchmark per m2, CBG – Carbon Budget Global 2020-2050 1.5ºC, PC – Population Country, PG – Population Global, EC – Emissions for the Construction Industry, ET – Emissions Total for country, VC – Economic Value of Commercial Sector 2020-2050, VR – Economic Value of Residential Sector 2020-2050, MC – Average Cost per Square Meter for Commercial Buildings, MR – Average Cost per Square Meter for Residential Buildings.

The sharing principles used to calculate a top-down benchmark are one possible method to achieve a calculated value. The intention of this paper is not to investigate the effect of applying different top-down sharing principles. The method selected is for demonstration purposes only.

2.3. Capping the Top-Down Building Benchmark

The above approach to generate a top-down building benchmark provides a square meter rate that can be used to check the total performance of proposed buildings. An issue with a square metre rate is that it allows projects with larger areas to consume a larger proportion of the budget regardless of how many people occupy it. This issue conflicts with the first sharing principle, where every person is entitled to an equal share of the global carbon budget. Therefore, there is a need to cap the top-down building benchmark using functional units specific to a project. To generate a cap, the last economic sharing principle is replaced with a per full-time employee sharing principle. Here project specific characteristics are used to derive a cap value per equivalent full-time employee.

Equation 2 – Top-Down Building Benchmark Limit per Employee

$$T_E = \left(\left(\left(\left(CB_G \times \left(\frac{P_C}{P_G} \right) \right) \times \left(\frac{E_C}{E_T} \right) \right) \times \left(\frac{V_C}{V_C + V_R} \right) \right) \times \left(\frac{\left(\frac{V_C}{P_C} \right)}{\left(\frac{T_{LC}}{T_J} \right)} \right) \right)$$

Where: T_E – Top-Down Building Benchmark per Employee, T_{LC} – Building Life Cycle Length in years, T_J – Average Job Length in Years

2.4. Top-Down Elemental Benchmarks

Top-down benchmarks at an elemental level serve the designer in supporting an understanding of embodied carbon emissions in different parts of the building and when those emissions occur over the building's life cycle. Dividing up the top-down building benchmark creates elemental target values that enable carbon hot spots to be identified during concept design without a full data set available. As top-down elemental benchmarks, they can be used to answer the question: are all parts of the building within their carbon budgets? In this paper, these values are generated from the results of an externally validated, independent reference building. The target values are used to create guides for operational and embodied emissions.

2.5. Calculating LCA of the Case Study Building

To calculate the embodied carbon emissions over the life cycle of the case study, etoollcd was used as the material library is localised to Australia. The service life was set to 60 years. As the project is in the concept stage, templates were made to standardise the wall, floor and roof construction assemblies.

2.6. Case-Study – Koala Rehabilitation Centre

The case study selected for this paper is to test the top-down benchmarking approach and is not to be used as a reference or benchmarking building for other buildings. This case study is a concept design for a Koala rehabilitation center in Queensland, Australia. Two buildings from the proposal have been selected, an office with standard number of employees per floor area to represent a typical typology and a koala rehabilitation center with low employees per floor area to represent a non-typical typology. Of course, employees in each building are not necessarily mutually exclusive. The comparison between typical and non-typical building typologies tests the top-down benchmarking approach against a spectrum of commercial building typologies.

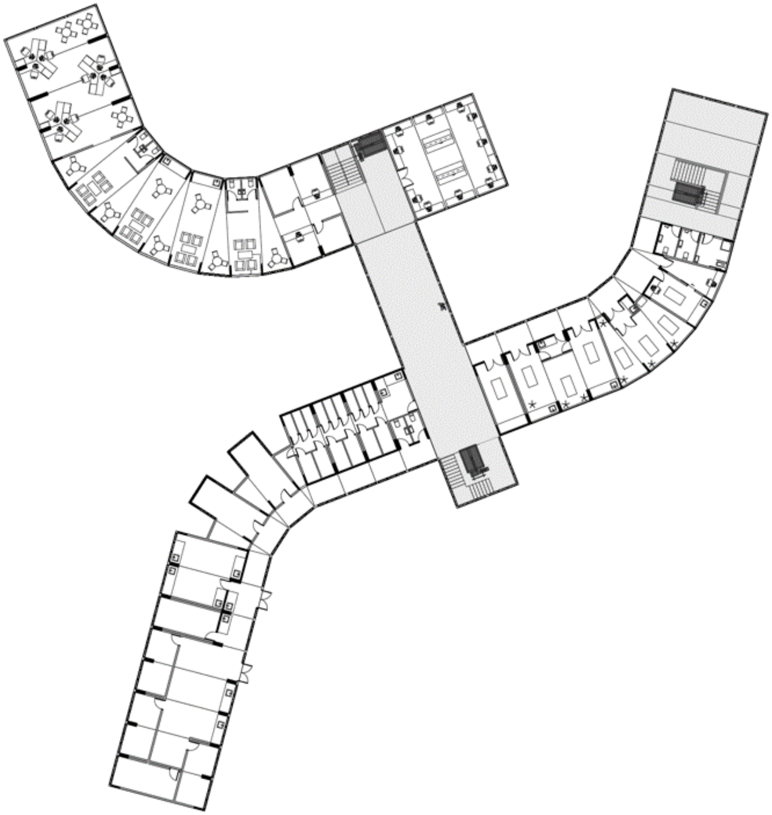

Figure 26: Representative floorplan of both buildings. Office building above and Koala clinic below.

3. Results

3.1. Top-Down Building Benchmarks

Based on the method outlined in this paper, the calculated target values for commercial buildings in Australia were 215 $kgCO_2/m^2$ and 160 $kgCO_2/m^2$ using the IPCC 1.5ºC budget at 50% and 66% confidence. These benchmarks can be considered against the target value in the Carbon Zero Standard by the Living Futures Institute, which is set at 500 $kgCO_2/m^2$ (International Living Future Institute 2020).

3.2. Top-Down Elemental Benchmarks

To support designers in early detection of embodied carbon hotspots, the top-down building benchmark is divided up using percentage ratios from a reference building. The reference building was a commercial typology available within eToolLCD and is assumed to be a representation of a standard Australian office building. No other building typologies are offered as reference buildings within the tool, so the office building has been applied to the analysis of the non-typical typology. Table 2 shows an example of the target values calculated using a reference office building.

Table 2: Office Building Element Level Benchmarks

Building Elements	**CB·50% (kgCO2/m2)**	**CB·66% (kgCO2/m2)**
Equipment	4.49	3.32
Substructure	22.22	16.45
Superstructure	11.32	8.38
Internal Finishes	5.55	4.11
Services Equipment	5.34	3.95
External Works	0.21	0.16
Operational Energy	162.99	120.65
Water Use	1.50	1.11

CB* = Carbon Budget at 1.5°C, Equipment* = Construction equipment and earthworks

3.3. Case Study Carbon Emissions

Figure 2 shows the partial LCA performance simulation results broken down into building element categories. Note that the substructure and operational energy were outside of the scope of the LCA for the case study and the focus was on the superstructure and internal finishes to evaluate the concept design. The top-down elemental benchmarks calculated above are shown as two lines to guide the expected distribution of emissions to achieve the top-down building benchmark. Representing the simulation data in this way shows how top-down elemental benchmarks can identify what parts of the building are using above their calculated share.

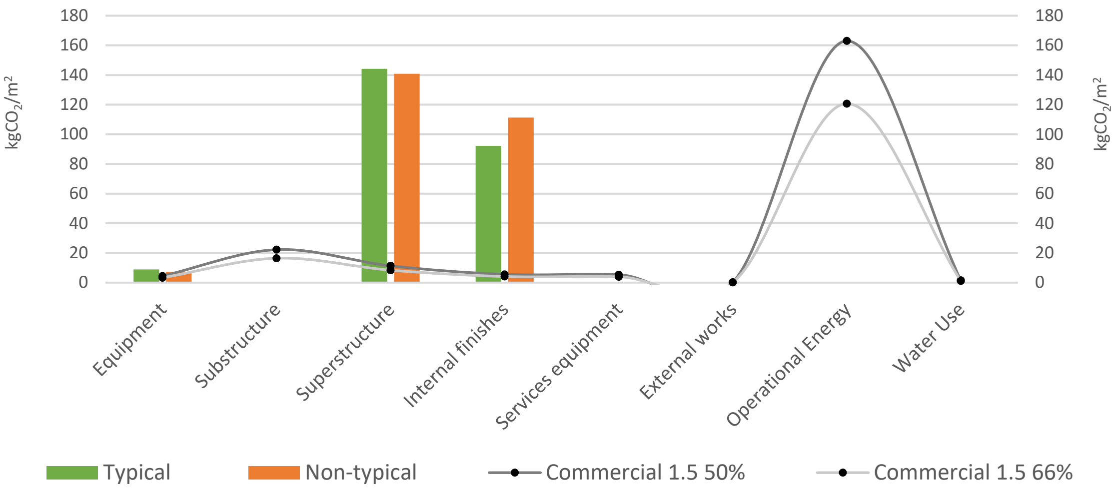

Figure 2: Top-Down Elemental Benchmarks using Building Element Categories

3.4. Caps Using Full-time Employee

To relate the top-down building benchmarks to project brief requirements of different buildings within the same project, a top-down building benchmark per equivalent full-time employee was calculated.

Table 13: Top-Down Building Benchmarks per Full Time Employee (rounded)

	CB 1.5 (50%)	**CB 1.5 (66%)**
kgCO2/employee	4200	3110

3.5. Top-Down Limit Benchmarks

The cap value was generated by multiplying the top-down benchmark per employee by the number of employees in the brief. This was then divided by the top-down building benchmark per floor area to generate a recommended area. Figure 3 shows a comparison between the recommended area and the area in the concept design. The consistency between the results for 50% and 66% (confidence from IPCC budgets) are aligned due to the top-down building benchmark per employee and per floor area being proportionally different by the same amount. The difference between the results for typical and non-typical building typologies are discussed below.

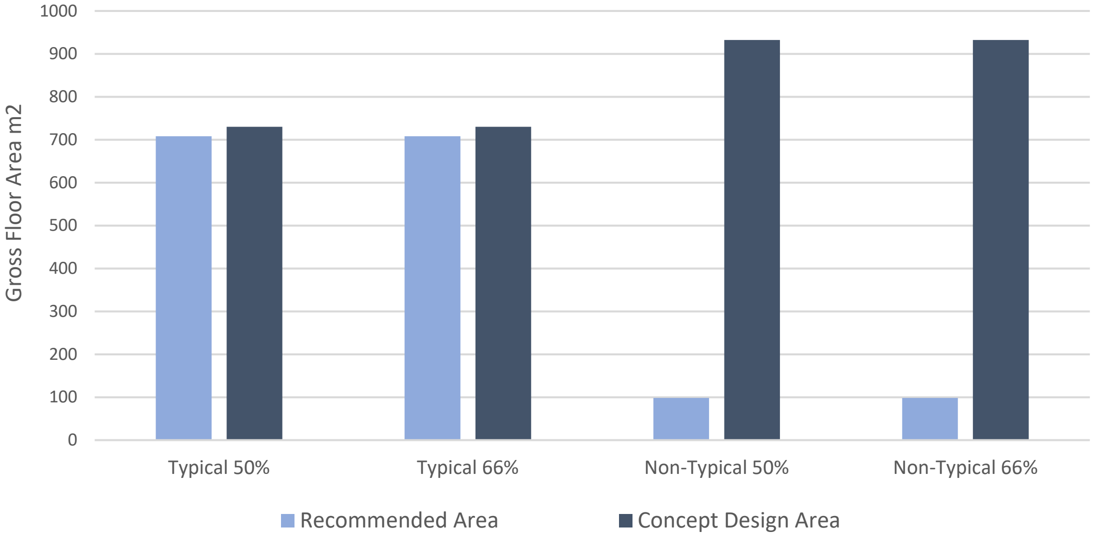

Figure 3: Recommended area v concept design area for typical and non-typical buildings

4. Discussion

4.1. Using top-down elemental benchmarks to guide decisions.

Top-down elemental benchmarks have the clear benefit of foresight, allowing the design team to plan for the distribution of carbon emissions in a project before all the full analysis has been completed. In the context of this paper the top-down elemental benchmarks are limited to the building element categories within the LCA software, eToolLCD. They benefit the design process as they enable easy analysis of the building in parts and allow a design team to identify opportunities to make reductions early. The top-down elemental benchmarks are only meant to guide designers towards a recommended pathway to meeting the top-down building benchmark. As a guide the design team has the freedom to reallocate the area under the line graph (fig 4) to customise their own pathway. For example, in the context of the case study, the materials used for the superstructure and internal finishes are very high but could be balanced out by achieving large reductions in operational emissions. Overall, top-down elemental benchmarks enable the ability to make decisions between embodied and operational emissions early in the design. These benchmarks provide an opportunity for designers to be creative and innovative with creating new pathways to achieving reduction targets. Understanding how different pathways to achieving reduction targets can be specific to building typology is a large area for future research.

4.2. Is a top-down benchmarking approach fair?

This paper incorporates several sharing principles to calculate a carbon budget from the use of, per capita, grandfathering (assuming the same proportion of emissions from a previous period to apply to the next) and economic sharing principles. These were used to generate top-down building benchmarks per square meter of floor area. The foundational sharing principle assumes all people are entitled to an equal share of the global budget. A top-down building benchmark, using full time employees as a functional unit, has also been calculated to restrict financial privilege. Using functional units as a way of representing top-down building benchmarks has the potential to be applied in pre-design before any concept has been created using the method to generate a recommended area. This exercise could help design teams allocate targets for individual buildings in a large commercial project where there are several different functional requirements.

In the application of the top-down building benchmarks to the case study, figure 3 compared the size recommendations against the concept design area for a typical and non-typical building. The typical building had a very close match due to the program of the space being composed of different working stations creating a high employee per floor area ratio. Therefore, the number of functional units increased for this building, which increased the total budget and total floor area. On the other hand, the non-typical building (koala clinic), which hosted much of the koala rehabilitation facility had a very low carbon budget based on functional units. The large difference between the recommended area and concept design area is due to a low number of employees per floor area, as the building's primary purpose is to serve koalas.

Whilst allocating a carbon budget for animals kept as pets or grown for food would be possible, wildlife is a form of biomass that is assumed to be in a net zero or carbon positive life cycle. As the world experiences the negative effects of climate change, such as the destruction of natural environment and large species loss (as witnessed in Australia's unprecedented bushfire season), there is a growing need for architecture to supplement and support these animals. However, as an architectural typology that is considered as non-typical when compared to an office building, it falls outside of the scope of the top-down benchmarking approach used in this paper. The finding that a non-typical building typology may not always conform to a top-down benchmarking approach that works for office buildings is useful to be aware of for any commercial architectural practice, as the world does not just build offices.

5. Conclusion

In a time where climate change is one of the biggest threats to all life on earth, it is critical that the way we design buildings is within global carbon budgets set to limit warming to 1.5°C. As LCA becomes more frequently integrated into standard practice, different professionals and stakeholders have a need for environmental top-down benchmarks. For investors, building owners and clients top-down benchmarks help define full project target values that are within the planetary boundaries. For designers, these target values can be worked towards through the support of top-down elemental benchmarks to guide the design process and help manage external consultants, for example structural engineers. This paper also demonstrated that top-down elemental benchmarks can be used to enable partial building analysis with the context of other elemental target values as placeholders to allow for early detection of carbon hotspots.

Incorporating functional units into the framework for calculating a top-down building benchmarks allows caps to define how big a building should be relative to the project brief. In the context of the case study, top-down building benchmarks could be calculated per equivalent full-time employee. In the typical building (office) these benchmarks provided a close match to the designed building size. However, these cap values failed to adequately generate an appropriate size for the non-typical building (koala rehabilitation facility) as there were significantly less employees per floor area compared to the typical building. Additionally, wild animals could not be used as a functional unit to form a top-down benchmark. This limitation could also apply to other buildings that have non-typical programmes, meaning alternative functional units should be considered.

The application of the top-down benchmarking approach developed in this paper on typical and non-typical buildings ultimately calls for further discussions around how to appropriately generate, define and use benchmarks to support the design process. The proposed approach and case study analysis is one contribution to this discussion.

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