

# Building information modelling-based integrated design process for green building applied in O•PARK2 and potential contribution to carbon neutral construction

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## ABSTRACT

To achieve carbon peaking and carbon neutrality targets of mainland China and Hong Kong, carbon reduction in the building sector is a critical task due to its high contribution to total carbon emissions. Decarbonisation approaches in both operation and construction phases should be considered. A building information modelling (BIM)-based integrated design process (IDP) is introduced to connect the design, construction and operation as an entirety from the initial stage of a project to enhance the green building and decarbonisation design. Taking a real case of a Design-Build-Operate project, O•PARK2, this study investigates the benefits and problems in a BIM-based IDP in regard to green building and its potential impact on carbon neutrality during construction. A BIM-based IDP enables decision-making to be based on comprehensive and optimal information, which is well proved by the O•PARK2 project with the BEAM Plus being upgraded from Gold to Platinum. The carbon reduction potential during the construction phase is as high as 45%, which can only be actualised if decarbonisation specialists are involved from the planning phase. Although the BIM-based IDP possesses many unique advantages, the management of its long feedback loop and the complicated procedures should be optimised in the future.

**KEYWORDS** BIM-based IDP; BEAM Plus; decarbonisation; green building; building information modelling; integrated design process

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## 1. Introduction

The mitigation of climate change and reduction of carbon emissions have raised incremental concerns amongst governments, non-government organisations and the general public since the publication of the United Nations Framework Convention on Climate Change in 1992 (UNFCCC, 1992). The greenhouse gas (GHG) benchmark published by The World Bank indicates that carbon emissions have kept increasing from 1990 (World Bank, 2022), which is consistent with the continuous rising of global temperatures (NASA, 2022). Hence, more and more countries and regions have published peak emission and carbon reduction commitments in recent years. China aims to achieve peak emissions by 2030 and carbon neutrality by 2060 (SCPRC, 2021), while Hong Kong will strive to achieve carbon neutrality before 2050 (HKSAR, 2020). To achieve the carbon neutrality targets, carbon reduction in the building sector should be a major part of this effort considering its significant contribution to global carbon emissions (IPCC, 2011; WEF, 2016). The carbon emissions from the building sector in all developing and developed countries have exceeded 30% of total carbon emissions (Kisku et al., 2017). In China, the building sector contributed 30% of total carbon emissions in 2014 (Lu et al., 2016), which increased to 51.3% in 2018 (BEE, 2021). Therefore, building design consultants and contractors, who are responsible for design, construction and operation, play an important role in carbon neutrality in the building sector.

Building operations in Hong Kong account for 90% of electricity consumption and 60% of total carbon emissions

in Hong Kong (HKGFA, 2020). According to a report from the United Nations Environment Programme, the operational emissions and construction embodied emissions account for 72% and 28% of total carbon emissions from the building sector (UNEIEA, 2017). Hence, the current carbon reduction plans in the building sector mainly focused on the operation phase, which is reflected by the promulgation of green building standards from different countries, such as LEED in the U.S., nationwide house energy rating scheme (NatHERS) in Australia, national standard for green building assessment (GB/T 50378) in China and BEAM Plus in Hong Kong. With the wide application of green building standards, the carbon emissions from the building sector can be significantly reduced, but the contribution of embodied carbon emissions from the construction phase can increase to 75% of the total carbon emissions of a building (Habert et al., 2020). The sustainable construction studies reveal that carbon emissions during construction phase can be significantly reduced via optimising rebar (Jing et al., 2014), concrete (Adesima, 2020) and project management (Murtagh et al., 2020). Therefore, many green building standards, such as LEED, the Building Research Establishment Environmental Assessment Method (BREEAM), BEAM Plus, etc., try to involve the life cycle assessment (LCA) of buildings to enhance carbon reduction during the construction phase as well, indicating that consideration of the combination of construction and operation in relation to carbon emissions from the building sector is necessary. One computational case study reported that the application of a building information modelling (BIM)-based integrated

design process (IDP) can achieve 30% carbon emissions reduction in the operation phase and 20% embodied carbon emissions reduction in the construction phase (Gan et al., 2019). However, it is difficult to integrate green building design and carbon reduction construction in the design phase because these two parts of sustainable design work involve two different design categories. The green building rating system normally includes the aspects of land use, water consumption, material aspects, energy use, indoor air quality and operational performance (HKGBC, 2019). With this mindset, the deliverable of engineering work is no longer only concrete, piping and machines, but a live and long-lasting system that offers better green performance. Moreover, green construction material specialists and engineers should participate in the IDP to recommend the application of decarbonisation materials and ensure that the design criteria are met.

An IDP is a design method that collaborates all relating disciplines to consider the whole life cycle at the design phase, including design, construction, operation and occupancy, depending on the joint engineers' backgrounds. It has already been proved that the implementation of an IDP can enhance building performance during operation, especially as regards water and energy consumption (Alajmi, 2021; Shibeika et al., 2021). A coherent interdisciplinary team formed at the initial project stage and a specified management system are necessary for an effective IDP system (Bocheńska-Skałeczka and Walter, 2020). BIM can easily enhance the communication efficiency among all experts and engineers at all stages in an IDP framework. Moreover, the unique modelling functions (Barone et al., 2021) with accurate quantification of materials and elements (Manca et al., 2020) can provide more comprehensive comparisons among different designs and easier pick-up information to all engineers with different knowledge backgrounds in an IDP, which enhances the design optimisation for higher stability, a longer lifetime, greater energy efficiency and less carbon emissions for the entire project life cycle. This is especially true under the contract type of Design-Build-Operate (DBO), whose operator is also the designer at the same time and participates throughout the IDP. Considering that the carbon emissions from the building sector are mainly contributed during operation and construction phases, evaluation of feasibility and potential benefits of a BIM-based IDP during the design phase at the initial stage of one DBO project in relation to carbon emissions mitigation and sustainable development is more important in the whole life cycle.

To reveal the impacts of a BIM-based IDP in the initial design period on green building and carbon neutrality of a non-conventional building in a DBO project, a food waste treatment facility named O•PARK2, was chosen as the example project for this study. The detailed method of the BIM-based IDP applied in O•PARK2 is introduced, followed by a comparison between the BEAM Plus green

building evaluations of tendering stage and the final detailed design to illustrate the impacts of a BIM-based IDP on the operation phase. The contribution of BEAM professionals to the BEAM Plus grade upgraded from Gold to Platinum is analysed. Moreover, three design scenarios are compared to investigate the carbon emissions reduction potential during the construction phase of the O•PARK2 project, assuming the involvement of decarbonisation specialists to indicate the impacts of a BIM-based IDP during the construction phase. The aims of this study are to investigate the benefits of BIM-based IDP application at the initial design phase with specialists in green building for operation phase carbon reduction with a real case and with decarbonisation specialists in construction phase carbon reduction with a model study.

## 2. Methodologies applied in O•PARK2

### 2.1. Introduction of O•PARK2

O•PARK2 is a DBO project of the Environmental Protection Department in Hong Kong located at Sha Ling, North District of the New Territories. O•PARK2 is the second organic resources recovery centre to adopt anaerobic digestion technology in Hong Kong to convert food waste into biogas for electricity generation and fertiliser as a by-product for landscaping or agricultural applications. In addition to providing electricity and heat for its own facilities, the surplus biogas produced can be converted into about 24 million kilowatt-hours of electricity annually, sufficient for use by some 5,000 households. O•PARK2 is expected to be commissioned in 2023 with a treatment capacity of 300 tonnes of food waste per day. With the commissioning of O•PARK2, the decrease in use of fossil fuels for electricity generation together with an annual reduction of about 110,000 tonnes of food waste to be disposed of at landfills will prevent the emission of some 67,000 tonnes of greenhouse gases annually.

As a technical requirement of O•PARK2, architectural, civil and structural, building services, electrical and mechanical (E&M) and process engineers as well as BIM coordinator and BEAM professionals are necessary to constitute the design team. Therefore, the O•PARK2 project has a natural advantage when adopting an IDP. The framework of this study is shown in Figure 1. The BEAM professionals in the O•PARK2 BIM-IDP engineering team mainly contribute to decarbonisation in the operation phase, while the decarbonisation materials specialists may hypothetically be involved in the team at the design stage and make contributions to the decarbonisation in the construction phase.

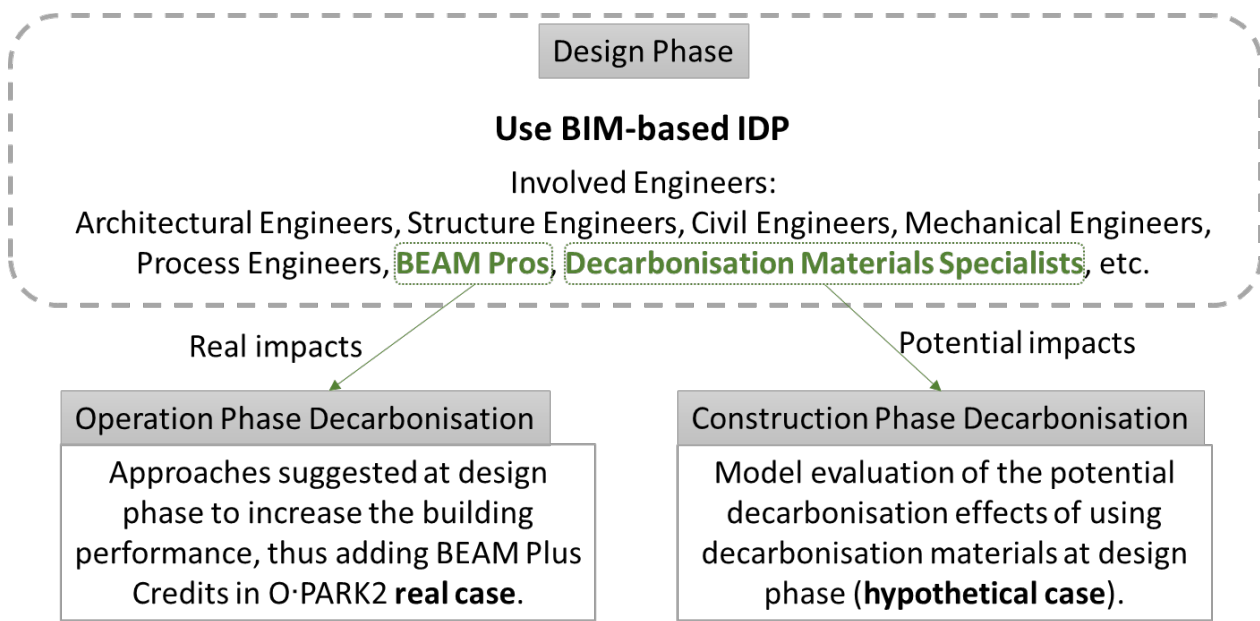


Figure 1. Framework of this study.

BIM Uses: Design generation, reviewing, revision, and drawing generation.

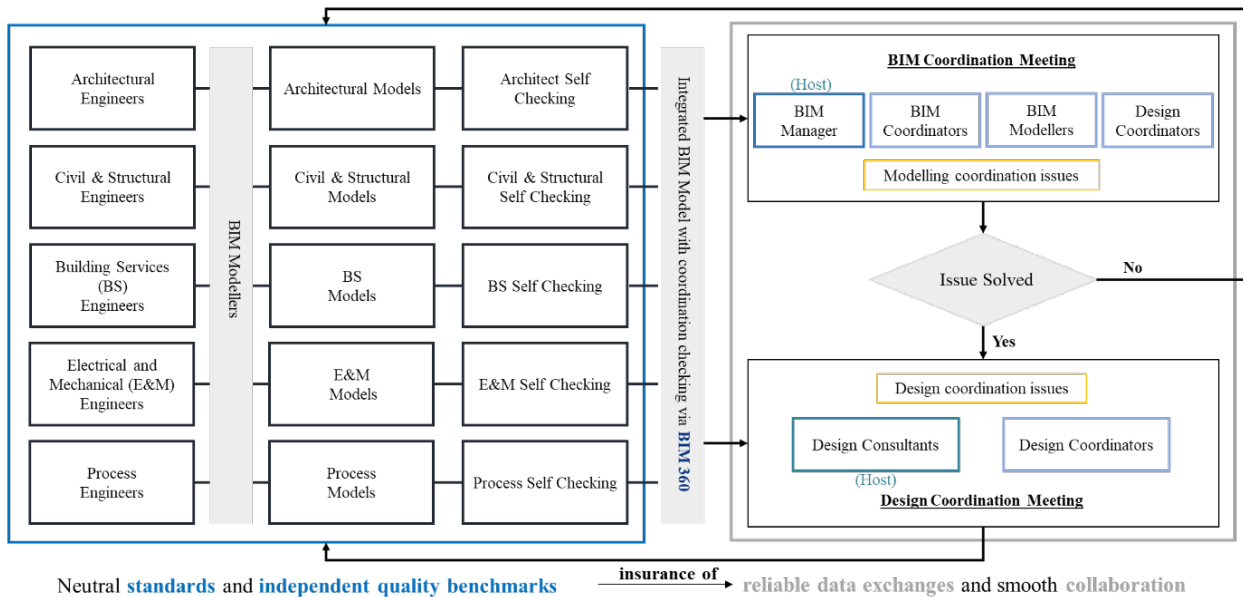


Figure 2. Workflow of the IDP with the application of BIM.

### 2.2. BIM-based IDP

The intrinsic difference between the IDP and conventional design process is that the IDP significantly enhances communication among engineers from different specialisms with an effective feedback loop, thus comprehensively optimising the design output arising from multi-disciplinary collaboration.

For the O·PARK2 project, a broad range of experts are included in the IDP working team, such as architects, structural engineers, mechanical engineers,

E&M engineers, landscape architects, BIM managers, construction managers, planning managers, cost controllers, maintenance and operation specialists, green building consultants, energy consumption consultants, hazard and operability analysis consultants, signage consultants, and treatment process designers. The iterative process allows extensive information exchange among broader team members' collective knowledge via a feedback loop with a multiple-comments procedure along with the design development progress, which lasts for the entire life cycle of the project. The independent consultant and employer's

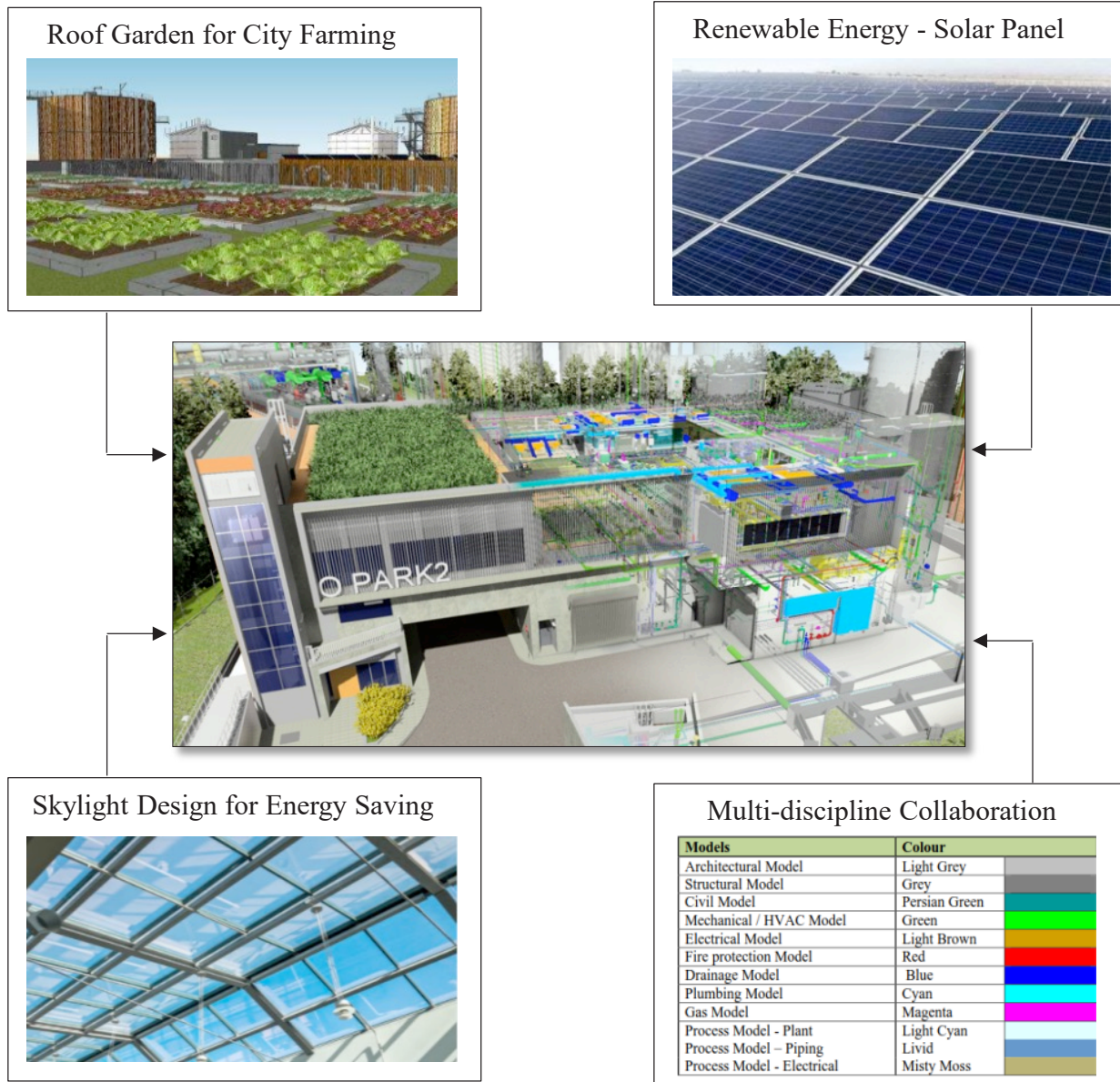


Figure 3. BIM model of O•PARK2 indicating the IDP and energy-efficient design.

representative are also involved in the IDP to provide constructive comments effectively.

The BIM of the O•PARK2 project is a database of design, properties, quantities and schedules. The models of design authoring are architecture, landscape, structure, civil, building services, E&M and treatment process (Figure 2). The 3D BIM model is essential to enable all stakeholders to store the information using a Common Data Environment (CDE) in a central location and to collaborate effectively in regard to modelling and solving problems. Communication and sharing of design expectations between teams of differing fields of expertise is streamlined via BIM 360.

BIM is applied as a shared and synchronising platform to manage the IDP iterations. Weekly BIM coordination meetings and bi-weekly BIM coordination workshops are

arranged, allowing all authors to share their views and show latest updates in one linked complete model. The schematic workflow of the BIM-based IDP is shown in Figure 2. BIM also facilitates green building design and sustainability analysis, including a roof garden for city farming, solar panel design and the modelling for energy-saving skylight design as shown in Figure 3.

### 2.3. BEAM Plus

According to Development Bureau Technical Circular No. 2/2015 and Environment Bureau Circular Memorandum No. 3/2015 on “Green Government Buildings” (DEVB, 2019), all new government buildings above 5000 m<sup>3</sup> shall aim to obtain the second-highest grade

or above under green building labelling, e.g., BEAM Plus assessment, in order to demonstrate an integrated, healthy and environmentally sustainable design. BEAM Plus New Building v1.2 (HKGBC, 2012) including all six categories, namely site aspects (SA), material aspects (MA), energy use (EU), water use (WU), indoor environmental quality (IEQ) and innovations and additions (IA), was used for BEAM Plus assessment during the tendering, design and final application periods. The credits, bonus, selection criteria and final calculation methods are based on the manual of BEAM Plus New Building v1.2 (HKGBC, 2012). During the tendering period, a preliminary strategy for BEAM Plus NB v1.2 gold is adopted without consultation with the BEAM professional. One BEAM professional became involved in the BIM-based IDP team of O•PARK2 soon after the letter of acceptance. For EU 1 – reduction of CO<sub>2</sub> emissions – and EU 2 – peak electricity demand reduction – they are simulated based on the detailed design with the software eQuest. Weather, building, energy input, heating, ventilation and air conditioning (HVAC) system and equipment plant data are major simulation inputs. The annual energy consumptions and the peak electricity demands of the baseline case set as the Building Energy Code (BEC) standard (EMSD, 2018) and the design case are the major outputs. Under the collaboration of the BEAM professional, building services engineers, E&M engineers and energy modeller via the BIM-based IDP, the BEAM Plus grade was successfully promoted from Gold to Platinum.

#### 2.4. Carbon accounting and decarbonisation strategies during the construction phase

The system boundary of carbon accounting for O•PARK2 is set as the civil construction phase. Hence, the life cycle inventories of construction materials cover the partial product life cycle from resource extraction to the site gate, i.e., “cradle-to-gate”. The waste production and consumables such as fuel, water and paper are estimated from the first two years of construction site performance. The construction material inventories are abstracted from the final approved BIM. The materials for the current design and the potential carbon reduction strategies are compared. In other words, O•PARK2’s design and decarbonisation design are compared to investigate the benefit of involving decarbonisation materials specialists in the IDP in this study. In addition, the conventional construction approaches are set as business-as-usual (BAU), which serves as the baseline for comparison. The detailed energy and material differences in two scenarios and BAU are shown in Table 1.

Table 1. The construction inventories comparison among three design scenarios for O•PARK2.

Scope	Inventory	BAU <sup>a</sup>	Current Design	Decarbonisation Design
1	Power for equipment	Diesel generator	Diesel generator	BESS <sup>b</sup>
	Power for vehicles	Fuel oil	Fuel oil	Electric cars
2	Electricity	Purchase	Purchase	Solar panel <sup>c</sup>
3	Concrete	Ordinary Portland Cement (OPC)	30% of fly ash	60% of GGBS <sup>d</sup>
	Rebar	25% recyclable	42.8% recyclable	100% recyclable

<sup>a</sup> BAU represents business-as-usual;

<sup>b</sup> BESS represents battery energy storage system;

<sup>c</sup> Solar panel is for the construction site office;

<sup>d</sup> GGBS represents ground granulated blast-furnace slag.

Based on the Greenhouse Gas Protocol (2013) and the ISO 14064:2006 (ISO, 2006), GHG emissions from the construction phase of O•PARK2 are classified into three scopes: Scope 1 – direct GHG emissions and removals, Scope 2 – energy indirect GHG emissions and Scope 3 – other indirect GHG emissions. The GHG emission calculation is conducted with a pre-programmed Excel, which is based on the product of energy or material consumption amount and its correlated emission factor. If transportation of the material is necessary, GHG emission is also included with the different emission factors correlating with various transportation tools. The emission factors are given in Table 2. All information on the emission factors are from Hong Kong, either from government/company annual reports, suppliers or from relevant research papers based on studies in Hong Kong, except that the emission factor of ethyne is adopted from a case study in Guangzhou. These major materials are selected based on the real design for O•PARK2. The decarbonisation materials are 100% recycled rebar and foam concrete. 100% recycled rebar is a type of rebar in the original design. For decarbonisation, all types of rebar are replaced with 100% recycled rebar based on the strength comparison among different percentages of recycled materials. Foam concrete is chosen based on the recommendation and existing materials from concrete providers.

Table 2. Major materials, power sources, transportation approaches and their mission factors applied in this study.

Item	Description	Emission factor	Unit	Reference
Rebar	100% recycled	0.56	kg CO <sub>2</sub> -e/kg	Gan et al., 2017
	65% recycled	0.96		
	22% recycled	1.45		
	20.7% recycled	1.46		
	12% recycled	1.56		
	10% recycled	1.59		
	6% recycled	1.63		
	5% recycled	1.64		
Steel	0% recycled	1.70	kg CO <sub>2</sub> -e/m <sup>3</sup>	Based on the mix ID provided by the supplier.
	Constructional	1.75		
	20/20D	262		
	30/20D	207.58		
	45/10D	234.88		
Concrete	45/20D	234.88	kg CO <sub>2</sub> -e/m <sup>3</sup>	Based on the mix ID provided by the supplier.
	50/20D	256.58		
	Foam concrete	163.68		
Shotcrete		0.19	kg CO <sub>2</sub> -e/kg	
Cement mortar		0.19	kg CO <sub>2</sub> -e/kg	
Sand		0.01	kg CO <sub>2</sub> -e/kg	Yan et al., 2010a
Diesel	For diesel generator	2.62	kg CO <sub>2</sub> -e/L	EMSD & EPD, 2010
Ethyne		3.38	kg CO <sub>2</sub> -e/kg	Hong et al., 2015
Electricity	Year 2019	0.50	kg CO <sub>2</sub> -e/kWh	CLP, 2021
	Year 2020	0.37		
Water	Year 2018/19	0.42	kg CO <sub>2</sub> -e/m <sup>3</sup>	WSD, 2019
Wastewater	Year 2019/20	0.20	kg CO <sub>2</sub> -e/m <sup>3</sup>	DSD, 2020
	Cargo ship	0.02		
Transportation	Cargo truck (2t)	0.29	kg CO <sub>2</sub> -e/tkm <sup>b</sup>	GB, 2019
	Cargo truck (8t)	0.18		
	Cargo truck (18t)	0.13		

<sup>a</sup> The published value is 0.0074 kg CO<sub>2</sub>-e/kg;

<sup>b</sup> tkm is tonne kilometre.

### 3. BEAM Plus upgrading with the IDP

#### 3.1. Overall comparison between the tendering period and final design

The BEAM Plus credits comparison between the tender proposal period and the final approved design with the BIM-based IDP for O•PARK2 is illustrated in Table 3. Even though all six categories are involved in the BEAM Plus credits calculation in both the tender proposal and final approved design stages, the differences are mainly from SA, EU and WU categories, overall involving nine additional credits and one additional bonus, as given in Table 3. Moreover, with the BIM use during design, application of innovative technologies and providing education tours, three additional bonuses are achieved in the IA category. The overall grade increases from Gold to Platinum with the participation of the BEAM professional in the BIM-based IDP, indicating that the participation of the BEAM professional in the beginning of the design stage is effective. The modification points relating to SA, EU

and WU categories are discussed in detail in the following section.

Table 3. BEAM Plus credits comparison between the tender proposal period and the final approved design based on the IDP for O•PARK2.

Category	Credits		Details
	Tender	Final	
SA2a – Car Parking provisions	0	1	Seven car parking spaces are included in the layout, which include one car parking space for disabled persons. Two drop-off bays are provided to meet the minimum operational requirements.
SA2b – Public transport	0	1	A layout plan showing the pick-up/drop-off point of the shuttle bus.
EU1 – Reduction of CO <sub>2</sub> emission during operation	9	15	Future reduced annual energy consumption from 13% to 32% by applying highly efficient VRV and absorption chillers, energy-efficient lighting designs and renewable energy installation.
EU2 – Peak electricity demand reduction	1	3	Reduction in the maximum electricity demand increases from 10% to 26% by using renewable energy units (combined heat and power [CHP]).
WU4c – A combination of rainwater harvesting and recycle system	0	1 B*	An annual total of harvested rainwater and recycled water of 4,283,567 L, which is 814.6% of the annual total fresh water consumption in the WU baseline (525,819 L).
WU2 – Monitoring and control	1	0	It is removed during the design phase considering the trade-off between cost and BEAM Plus final result.
IA2 – Performance enhancement	0	3 B	Use BIM during the design phase; Twin-tank system for potable and flushing water is provided to ensure continual water supply during tank cleaning and Education tours will be arranged to introduce the benefits of green building, with accreditation of credits in this project.
Sum of difference	11	20 + 4B	
<b>Final result</b>	<b>Gold</b>	<b>Platinum</b>	

\* B means bonus.

#### 3.2. Detailed improvements

The SA category includes the requirements relating to local transport, site design appraisal, landscaping and planters, neighbourhood daylight access, environmental management plan, air pollution during construction, noise during construction, water pollution during construction, noise from building equipment and light pollution. Relying on the BIM-based IDP, the BEAM professional suggested

adding seven car parking spaces and two drop-off bays to win two more credits compared to the tender proposal during the BIM-based IDP coordination meeting. Relying on the convenience of the BIM-based IDP, the proposal is realised in the final design, although O•PARK2's entrance area is already highly cramped (Figure 4a). The final design sketch generated from BIM is presented in Figure 4b.

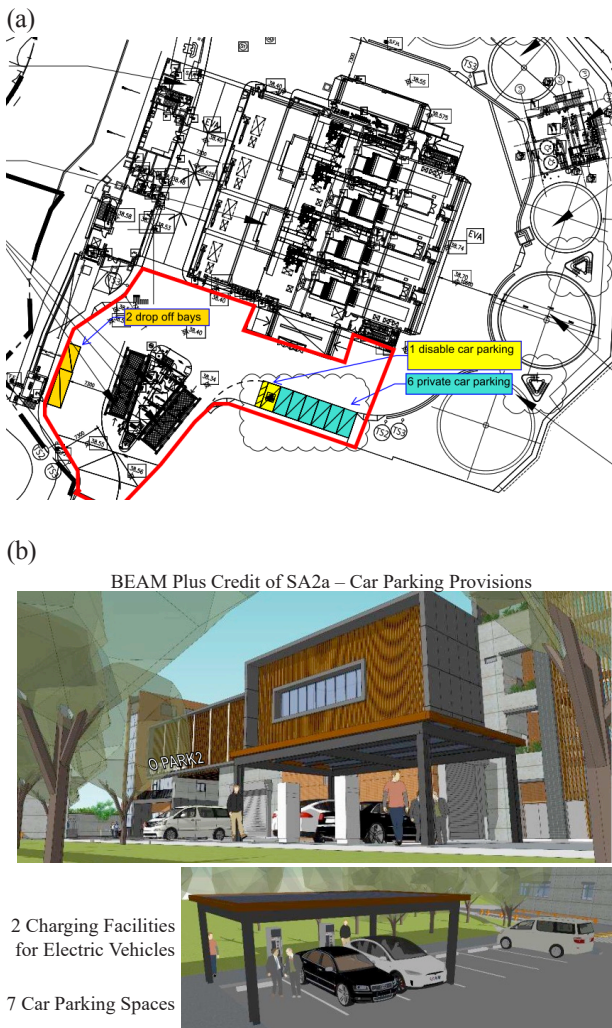


Figure 4. The addition of two drop-off bays and seven car parking spaces (including one disabled car parking space) in the cramped entrance area of O•PARK2 shown in the (a) layout; and (b) BIM design sketch.

EU refers to the requirements relating to minimum energy performance, reductions of annual energy consumption and peak electricity demand, embodied energy, renewable energy system, testing and commissioning, operations and maintenance as well as metering and monitoring. The detailed energy performance, including reduction of carbon emissions and peak electricity demand, is evaluated based on the detailed design information. The main energy consumption of O•PARK2 comes from air conditioning and lighting as

well as electricity and heat during operation of the plant. Based on the energy consumption properties, the buildings in O•PARK2 are separated into four areas for individual evaluation, including the central chiller plant in the office (Area A), variable refrigerant flow (VRV) in the office (Area B), mechanical ventilation at the treatment plant (Area C) and natural ventilation area (Area D). The example of labelled areas (Areas A and C are taken as examples due to their high energy consumptions) in the reception building roof layout as shown in Figure 5(a).

The annual energy consumption for the design case is 11,017,311 kWh (Area A: 769,850 kWh; Area B: 28,687 kWh; Area C: 10,218,347 kWh and Area D: 427 kWh). Compared to the annual energy consumption baseline case (11,523,055 kWh), the design case only achieves less than a 0.5% energy reduction, indicating that the credit for the EU category will be very low. Based on the communication between the BEAM professional and the E&M engineers, highly efficient VRV and adsorption chillers and energy efficient lighting are applied to reduce annual energy consumption. In the meantime, biogas produced in the process of organic waste treatment can also be used as a renewable energy source to generate electricity and heat through the combined heat and power (CHP) system (Figure 5b). To illustrate the potential energy consumption for all types of resources and energy recovery from both electricity and heat generation, heat is converted to the unit of kWh in the eQuest simulation. According to the simulation results, the energy used by the design case can be 100% covered by the renewable energy generated by the CHP system, which is 25,028,780 kWh/year. Therefore, 15 credits are obtained from the EU1 category. The energy simulation report also demonstrates that the minimum amount of electricity fed to the grid by the CHP will be 2,724 kWh/hour, which is greater than the total electricity peak (1,3678 kWh/hour) for the whole O•PARK2 area, indicating that full marks can be obtained by the EU2 category. In summary, the energy performance can be significantly enhanced before the E&M system is determined, which could not be realised without the BIM-based IDP.

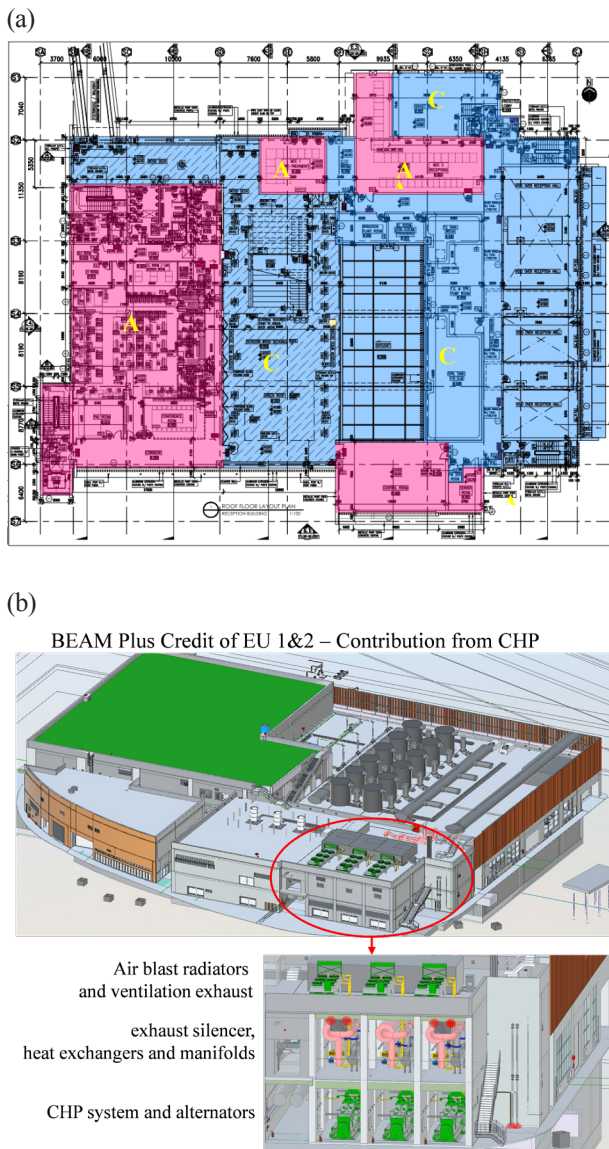


Figure 5. Information relating to the increase of BEAM Plus credits from Energy Use (EU), including (a) areas indication example at the roof of the reception building; and (b) the application of combined heat power (CHP) attributing high credits in the EU1 and EU2 categories.

WU refers to compliance with the requirements relating to water quality survey, minimum water saving performance, annual water usage, water recycling and effluent discharge to foul sewers. The water use is mainly optimised in two ways: water resource recycling and water conservation. The project is equipped with a sewage treatment plant which can treat and purify the wastewater generated while processing kitchen waste and meet the reuse standard. The treated effluent will be reused in O•PARK2 for vehicle washing and food waste dilution. In addition, a rainwater harvesting system is also designed and the collected rainwater will be used as the supplement in the water recycle system. With the collaboration among

the BEAM professional, the process engineer and the E&M engineer, the combined rainwater harvesting and recycling system can provide 4,283,567 L of water every year for O•PARK2's operation, which is equal to eight times the plant-wise annual water consumption.

It is remarkable that the addition of credits on BEAM Plus via the BIM-based IDP is not always true. The monitoring of water leakage and control systems is proposed at the tendering stage. Considering the high amount of rainwater and recycled water, water leakage and control are not necessary requirements. The reduction of one credit from this category will not affect the final result of BEAM Plus but can save a significant amount of investment in water leakage and control systems. The above information is from various team members of the BIM-based IDP; thus, the final decision is easily drawn with assurance. However, due to the iterative procedures of the IDP, the feedback loop could be prolonged. Thus, the decision-making in the IDP could be better managed with the full application of information storage and sharing properties of BIM.

#### 4. Decarbonisation potential in O•PARK2's construction phase

As aforementioned, the percentage of carbon emissions in the construction phase in a building's life cycle carbon emission is significantly increased after the design of buildings follows the local green building standards, such as BEAM Plus in Hong Kong. Hence, the carbon emission reduction potential in the construction phase is evaluated by comparing the carbon emissions from three design scenarios for O•PARK2. As illustrated in Figure 6(a), the carbon emissions from the construction site are mainly contributed by construction materials' utilisation in Scope 3 – other indirect emissions, which is independent of the design scenario. The total carbon emissions of BAU during the construction phase are 30,560 tCO<sub>2</sub>-e while the other indirect emissions (Scope 3) are 28,573 tCO<sub>2</sub>-e and contribute 94.5% of the total emissions. The current O•PARK2 design considers the application of decarbonisation materials, such as fly ash (FA) concrete and higher recyclable contents in rebar, so the total carbon emissions are 25,707 tCO<sub>2</sub>-e, realising a 15.89% carbon reduction. The carbon emissions of O•PARK2's construction period can be further reduced to 16,811 tCO<sub>2</sub>-e (i.e. a 45.0% reduction compared to BAU) if the decarbonisation technologies are considered from the planning period, including more application of environmentally-friendly materials, electrification of the construction site and utilisation of renewable resources. However, the combination of electrification and renewable energy utilisation can only reduce carbon emissions by 317 tCO<sub>2</sub>-e, which is equal to 15.93% of carbon emissions from Scopes 1 and 2 but around an insignificant 1% of those

from Scope 3. Hence, the application of green construction materials to reduce emissions from Scope 3 will generate maximum benefits for decarbonisation.

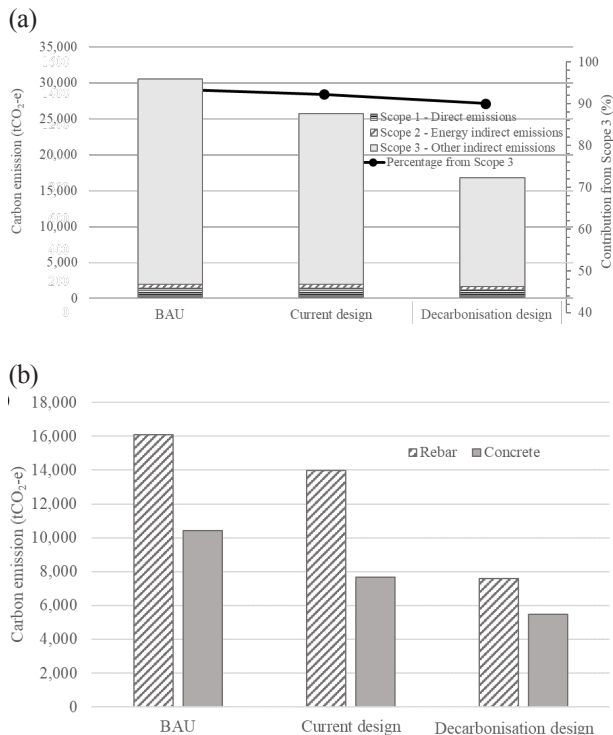


Figure 6. Comparison of the estimated carbon emissions from (a) O•PARK2's overall construction phase; and (b) rebar and concrete among the three design scenarios: business as usual (BAU), O•PARK2 design and carbon reduction design.

The other indirect emissions are mainly from the embodied carbon emissions from concrete and rebar, which are illustrated in Figure 6(b) for further comparison. The percentages of recyclable materials in rebar for BAU, the current design and decarbonisation design are 25% (USGBC, 2021), 42.8% and 100% respectively. With the increase of the recyclable material percentage, the carbon emissions from rebar for O•PARK2 decrease from 16,096 tCO<sub>2</sub>-e under BAU to 13,985 tCO<sub>2</sub>-e under the current design, and further reduce to 7,603 tCO<sub>2</sub>-e for the decarbonisation design. The current design of O•PARK2 uses fly ash to replace 30% of OPC in BAU, which reduces the embodied carbon emissions from concrete from 10,414 tCO<sub>2</sub>-e to 7,669 tCO<sub>2</sub>-e. With the replacement of 60% of OPC with ground granulated blast-furnace slag (GGBS), the carbon emissions from concrete can be further reduced to 5,472 tCO<sub>2</sub>-e. For the same building, the carbon reduction potential from modifications of concrete and rebar are significant, leading to around a 50% carbon reduction in other indirect emissions and 45% decarbonisation in total emissions in the civil construction phase compared to BAU. Therefore, involving decarbonisation specialists from the

planning stage and in the BIM-based IDP can significantly reduce carbon emissions. Moreover, information related to other aspects, such as construction technologies, economic evaluation and project schedule, can be integrated into the decarbonisation design process to comprehensively justify the decarbonisation approaches if the BIM-based IDP is implemented well.

## 5. Conclusion

This study analyses the contribution of BIM-based IDP application for green building design optimisation, corroborated by the upgrading of BEAM Plus during the design phase of a DBO project, i.e. O•PARK2 for food waste treatment in Hong Kong. In addition, the carbon emissions reduction potential during the construction phase is also evaluated based on the final design of O•PARK2 with different design scenarios to investigate the impact of involving decarbonisation experts in the BIM-based IDP on the overall carbon emissions reduction. The following major conclusions can be drawn.

- BEAM Plus credits are significantly increased with the BEAM professional's participation in the BIM-based IDP design team. The design modifications mainly focus on three major works, including the car park and added drop-off areas, the energy utilisation simulation and rainwater collection system. Modifications with a clear goal are the intrinsic reason for the upgrading of the BEAM Plus grade from Gold to Platinum.
- The BIM-based IDP helps the design team make more reasonable decisions by taking into account comprehensive information from all related engineers and specialists. The abandon of the water leakage monitoring and control systems in the O•PARK2 design is a good example.
- Decarbonisation specialists should have been involved in the design team at the planning stage, which may have provided the chance to further reduce carbon emissions during O•PARK2's construction phase by around 8,896 tCO<sub>2</sub>-e. This carbon emissions reduction amount to 34.6% of total carbon emissions from the construction phase under the current O•PARK2 design.

In general, with the application of the BIM-based IDP, the decision-making in regard to green building design and carbon-neutral construction can be more practical and economical with the comprehensive consideration by a team with various fields of knowledge and experience. However, the BIM-based IDP is not impeccable and the procedures should be further improved. The application of the BIM-based IDP for green building design and carbon neutrality is in its infant stage, so rich experience should be accumulated and shared to optimise it step by step, which will significantly facilitate the progress of achieving the carbon peaking and carbon neutrality targets.

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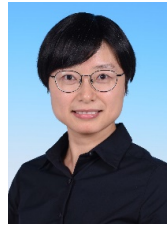
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