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Commitment Indicators for Tracking Sustainable Design Decisions in Construction Projects

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Abstract: The construction industry is considered one of the largest contributors to climate change through its consumption of natural resources and generation of greenhouse gases. Much of this can be attributed to inadequate decision making and follow-up within construction companies. To mitigate this problem, considerable research on Sustainable Development (SD) reports on decision support systems have been developed in order to make sound decisions with respect to the environment. Nonetheless, and despite the availability of such tools, these systems fail to track the commitment to SD decisions and goals during the different phases of construction projects in general and the design phase in particular. As such, this study identified three standard SD indicators: waste reduction, energy consumption, and carbon emissions as the main contributors, and developed the framework to track the project stakeholders' commitment to the relevant SD indicators during the project design phase. The developed framework was validated via an expert panel and used to create a Sustainable Development Commitment Tracking Tool (SDCTT-D). The SDCTT-D tool was also applied in an infrastructure project case study. The results of this study gauged the usability of the developed tool and corroborated the research premise.

Keywords: sustainable development; commitment indicator; energy efficiency; waste management; carbon emissions; project design; commitment

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1. Introduction

Several environmental problems plague the world today due to rapid industrial development in many regions. These include ecological degradation, pollution, and resource depletion, which have become global political and economic concerns. Such problems have resulted in a societal consensus to enhance environmental protection measures while pursuing social and economic development [1]. In order to protect the environment, various government agencies and international organizations are exploring the concept of Sustainable Development (SD) and identifying various strategies in SD to adapt to climate change requirements and alleviate environmental problems [2]. SD helps organizations to manage their limited resources and provides them with a competitive advantage over others during the climate change era [3]. However, the decision to shift an organization towards SD requires consensus and commitment from all participants to realize the objectives of SD [4]. Hence, this paper is the second sequel to developing the Sustainable Development Commitment Tool (SDCTT-D), which is aimed to align the commitment of different project parties to the committed SD decisions. The tool development passed through three stages that were discussed in detail in the first sequel, as well as the methodological steps followed in tool development [5]. The intention of this paper is to highlight the commitment indicators included in the second phase of the project, the design phase. The paper also specifies which of those indicators has the highest rank based on expert opinion. As such, this study provides a novel approach that aligns the project participants' SD commitment during the design phase with those assigned by the organizational leader to help track the degree of SD commitment by the project team and identify any pitfalls.

2. Developing Sustainable Development Commitment Indicators in the Project Design Phase

This section discusses the commitment indicators identified from an extensive literature review in relation to the second stage of the project, the design phase. These indicators will inform the development of the SDCTT-D tool to help project participants track their commitment in this phase. According to Kuprenas [6], the project design phase is an early stage where project structure, features, major deliverables, and success criteria are designed to achieve project goals. Thyssen et al. [7] argued that, in the design phase, the project architects and engineers must ensure that project drawings and documents contain space orientations, materials, and specifications aligned with the project owner's vision and regulations. The commitment indicators revolve around best practices in three SD decisions—waste, energy consumption, and reduction of carbon emissions—where the best practices and indicators used in the design phase to achieve the selected SD decisions will be identified.

2.1. Commitment Indicators for Waste Reduction

The following paragraphs discuss the indicators included in the first SD decision trigger, waste reduction, in the design phase.

Ng and Xie [8] argued that identifying the availability of allocated resources for the project is an indicator of the project designer's commitment to reducing project waste. According to Ng and Xie, resource allocation is the condition and quantities of resources available to the project to help the designers manage the project materials. In support of this, Anshassi et al. [9] highlighted that overlooking such information will cause issues during the construction and, ultimately, project failure in attaining the waste reduction goals. Chang and Tsai [10] pinpointed that the designers must identify the resources demanded from the project design based on the project's requirements of materials, equipment, and technology. In support of this, Anshassi et al. [9] highlighted that, from the demands of the project resources, designers could specify the resource capacity (the resources that can be spared for the project from the organization) of the project to avoid wastage. Ng and Xie [8] indicated that the resource gap could be identified from what the project design required and the actual resources available for the project. Chang and Tsai [10] specified that identifying this gap helps project designers to close it by designing the exact number of resources needed for the project to prevent resource waste.

Agarwal and Prakash [11] highlighted that an indicator of project designers' commitment to reducing waste is the integration level of recycled and reused construction materials in the project design. According to Azari and Kim [12], using those materials in the project conserves natural resources and reduces the materials sent to landfills at the project's end. Agarwal and Prakash [11] argued that the integration process starts by identifying the available reused/recycled materials in the market. Pressley et al. [13] highlighted that involving contractors and suppliers in the project materials design is an essential step to attain their viewpoint regarding reused/recycled materials' selection. Florez et al. [14] specified that project designers must integrate the selected recycled/reused materials in the project design in a way that reduces waste and minimizes the use of virgin materials. Agarwal and Prakash [11] argued that to ensure the efficiency of the designed project's reused/recycled materials, conducting a material life-cycle assessment through simulation is essential. According to Pressley et al. [13], this assessment helps identify the selected materials' environmental impact from material extraction to its use and specifies to what extent using those materials can minimize project waste.

Liu et al. [15] stated that using Building Information Modeling (BIM) during project design helps identify the exact resources needed for the project and prevents wastage. In support of this, Nikmehr et al. [16] highlighted that employing BIM in the design process is an indicator of project participants' commitment to reducing project resource waste. According to Lévy ([17] p. 4), BIM is "an architectural software environment in which graphic and tabular views are extracted from data-rich building models composed of intelligent, contextual building objects". Cao et al. [18] highlighted that BIM helps professionals (in architecture and construction) attain insights into the project from the data to improve the design, building management, and construction. Liu et al. [15] indicated that the first step in utilizing BIM in the project design is identifying the materials' design elements that lead to waste reduction. Wei et al. [19] argued that to effectively employ BIM in the design, collecting all the information regarding materials' design elements (from previous projects and historical data) is an essential step in BIM analysis. Najjar et al. [20] highlighted that materials information gathering via life-cycle assessment (LCA) is where the process of extracting raw materials, manufacturing, site transportation, installation, demolition, and recycling will be analyzed to evaluate the best materials selection regarding the environment. Byun et al. [21] indicated that the information collected about material construction elements (LCA) could be used to integrate them into BIM software and analyzed to identify the project's best design that reduces waste and minimizes the environmental impacts of the project. Antón and Díaz [22] asserted that the integration of BIM with LCA materials' performance at the early design phase enables BIM tools with a source of information to conduct a complete project LCA that improves the project environmental performance as well as the decision-making processes. Liu et al. [15] argued that BIM enables designers to simulate architectural and structural design requirements through a BIM-based material analysis tool to make necessary adjustments to reduce project waste.

Sadafi et al. [23] highlighted that incorporating flexibility into project design is an indicator of the project designers' commitment to reducing waste during the project design phase. According to Gil and Tether [24], design flexibility is a concept where techniques such as adaptation (one space with multiple functions without architecture alternating [25]) and transformability (changing exterior and interior spaces [26]) could be considered to bring resource-efficiency and flexibility into the project design. Ellenberger [27] argued that buildings designed to change their functions over the project life-cycle reduce resource consumption, while Sadafi et al. [23] asserted that incorporating flexibility into project design first requires identifying the design elements that can be altered into different forms of usage during the project's life. Ellenberger [27] highlighted that designers must specify the project's architectural spaces for the selected design elements based on their functionality or ability to meet users' needs with fewer restrictions. Gil and Tether [24] specified that the adaptation of project spaces within project design should be allowed to accommodate the growing working space. Sadafi et al. [23] argued that to maximize the effectiveness of design flexibility, designers need to conduct a risk analysis containing design changes to reduce wastage and compensate for scarce information at the design stage.

According to Bonnes et al. [28], involving experts with experience in sustainability work to improve and expand the design team's knowledge regarding waste reduction is an indicator of participants' commitment to waste reduction. In support of this, Tabassi et al. [29] pinpointed that including experts in the design team is to seek a professional opinion regarding green design practices and incorporate new design techniques to ensure waste reduction. Bonnes et al. [28] highlighted that incorporating green expertise into the design team starts by identifying professionals with sustainable design experience to stimulate the design team to go beyond current practice. Boudeau [30], meanwhile, specified that pre-qualifying the identified professionals based on their knowledge and experience in waste reduction is an essential step in expanding the design team. In support of this, Boddy et al. [31] argued that project participants should choose the most suitable professionals with waste reduction experience from the pre-qualified list to be included in the design team, while Bonnes et al. [28] indicated that the project design team must integrate the ideas and techniques from the chosen experts into the project's design to ensure waste reduction.

Therefore, the commitment indicators discussed previously exhibit parameters in sequential order. For the purpose of this study, these parameters are considered as a reflection of the degree of project participants' commitment to waste reduction in the design phase. Hence, the first steps of each indicator imply a low commitment, and the combination of all parameters indicates excellent commitment, as shown in Table 1.

Table 1. Design Phase Commitment Indicators and Degrees for Waste Reduction [5].

	Extent of Commitment			
Commitment Indicators for Waste Reduction	**1: Low Commitment**	**2: Medium Commitment**	**3: High Commitment**	**4: Excellent Commitment**
Availability of resources	Identify resource demand from project design	Specify designed resource capacity	Specify the resources gap	Close resources gap
The level of reused and recycled construction and demolition materials	Identify the available reused and recycled materials available in the market	Involve contractors and suppliers in materials design	Integrate the selected recycled and reused materials in the project design	Conduct materials' life-cycle assessment
The usage level of BIM computer modeling in the project to reduce waste	Identify the design elements	Collect necessary information	Integrate and analyze construction materials' elements in the design	Use BIM-based material analysis tools
Incorporate design flexibility factors	Identify the design elements	Define the effectiveness of the architectural spaces	Allow for adaptation of the space	Conduct risk analysis
Involve green expertise in terms of waste management	Identify professionals with expertise in green design	Pre-qualify applicants	Select the most suitable professionals with experience in waste management	Integrate green experts' design ideas

2.2. Commitment Indicators for Energy Consumption Reduction

The next commitment indicator set in the design phase is designated to be the energy consumption decision trigger.

Riesz and Elliston [32] highlighted that incorporating renewable energy sources in the project design is an indicator of project designers' commitment to reducing energy consumption. According to Li et al. [33], renewable sources vary from solar, wind, and other alternative energies and help minimize fossil fuel usage to generate energy and reduce operating costs. Rani et al. [34] argued that to include renewable energy sources in the project design, project participants must first identify the available renewable energy technologies in the market. Riesz and Elliston [32] specified that the design team selects suitable renewable technologies that can be used in the project design from the available ones. Waal et al. [35] pinpointed that the selected technologies must be integrated with the project design to achieve the desired energy reduction, while Rani et al. [34] discussed that, to ensure the synergy of the designed renewable systems, the design team needs to use a dynamic simulation for the designed renewable energy technologies to maximize their effectiveness.

Whitmarsh et al. [36] indicated that including experts with experience in energy reduction techniques within the design team is an indicator of the project designers' commitment to energy reduction goals. In support of this, Brunsgaard et al. [37] pinpointed that including experts in energy reduction within the design team helps them expand their knowledge and incorporate new design techniques to minimize project energy consumption. Sayigh [38] argued that to include a new energy expert in the design team, project participants must first identify professionals with experience in energy reduction design techniques. In support of this, Brunsgaard et al. [37] highlighted that project participants need to pre-qualify the identified applicants based on their knowledge, years of experience, and previous projects and select the most suitable professionals for the project. Sayigh [38] specified that the design team must integrate the ideas and techniques that emerged from energy experts into the project design to ensure energy reduction.

Cemesova et al. [39] stated that BIM could be used in the project design to reduce energy consumption. Yuan et al. [40] argued that the usage level of BIM during the design phase is an indicator of project designers' commitment to attaining energy reduction goals. According to Eleftheriadis et al. [41], BIM tools can visualize building energy performance by using the information from the project energy system. Cemesova et al. [39] pinpointed that BIM enables designers to develop various combinations of energy-saving designs and analyze different types of project equipment to predict energy efficiency and select the best alternative. In support of this, Gourlis and Kovacic [42] highlighted that BIM is capable of optimizing the project design machines, electrical systems, and buildings shall achieve the desired energy levels. Schneider-Marin et al. [43] indicated that incorporating BIM in the project design starts by identifying design elements of project systems and areas with a high potential for energy consumption. Schlueter and Geyer [44] argued that collecting information regarding the selected design elements from historical data and previous projects to feed BIM software is essential to optimize project energy design. In support of this, Gourlis and Kovacic [42] asserted that integrating the collected information into BIM software to analyze project systems over the project's life cycle is vital to maximizing its use. Meanwhile, Eleftheriadis et al. [41] argued that using the BIM analysis tool enables designers to select the best combination of energy systems and optimize project energy design by making necessary design adjustments to those systems to reach the optimal energy level.

Sun et al. [45] highlighted that an indicator of designers' commitment to reducing project energy consumption is to consider operation and maintenance factors for project energy systems and equipment to ensure energy reduction. According to Hassanain et al. [46], those factors reduce systems maintenance and improve energy efficiency and are considered essential elements in reaching the project's energy reduction goal. In support of this, Broughton [47] highlighted that including those factors within project design starts by identifying information regarding accessibility, modularization, standardization, and machine maintenance of the selected project's systems and equipment. Sun et al. [45] argued that, apart from project systems and equipment information, seeking input from maintenance personnel is essential to include their viewpoints in project design and helps the design team ensure energy reduction durability. Hassanain et al. [46] stated that the project design team must ensure that both operational considerations and energy equipment maintenance information are integrated into the project design to ensure its effectiveness. Further, Sun et al. [45] specified that to maximize the integration of maintenance factors into the project design, designers need to use a simulation program to simulate annual loads and peak demands for project systems to identify maintenance reduction opportunities that lower energy consumption.

Eley [48] argued that utilizing net-zero energy design in the project design is an indicator of the designers' commitment to reducing energy consumption. According to Aksamija [49], net-zero energy is an energy system design that balances the amount of energy used by the building with the amount of energy generated on-site through renewable power generation. Eley [48] further pointed out that the first step to achieving net-zero energy is to ensure building envelope efficiency through double insulation and exceptional air sealing. Harkouss et al. [50] highlighted that the design team must identify equipment and technologies with high energy efficiency in the market that suits the project's purpose, budget, and building envelope, while Aksamija [49] argued that the design team needs to select the best combination of the carefully chosen equipment and technologies to be incorporated into project design to achieve energy efficiency. Mazzeo and Oliveti [51] highlighted that, to ensure maximum benefit of the designed equipment and technologies, designers need to run a building assessment through an energy simulation to model building energy with various design variables to predict building energy performance. In support of this, Mavrigiannaki et al. [52] specified that this assessment helps identify which energy-saving measurements allow the project to achieve net-zero energy, specify which project areas have high energy consumption, and develop strategies to reduce them during the design stage.

Therefore, within each commitment indicator reviewed previously, there are specific parameters characterized as a series of actions. These parameters are reflected in this study as an indication of the degree of project participants' commitment toward energy consumption reduction in the design phase, whereby the first steps of each indicator reflect a low commitment, and the amalgamation of all parameters implies excellent commitment, as shown in Table 2.

Table 2. Design Phase Commitment Indicators and Degrees for Energy Consumption Reduction [5].

	Extent of Commitment			
Commitment Indicators for Energy Consumption Reduction	**1: Low Commitment**	**2: Medium Commitment**	**3: High Commitment**	**4: Excellent Commitment**
Incorporation level of renewable energy sources into the project	Identify the renewable energy technologies available in the market	Select suitable renewable technologies	Integrate the selected renewable technologies with project design	Use dynamic simulation to check project systems synergy
Involve green expertise in terms of energy reduction	Identify professionals with expertise in green design practices	Pre-qualify applicants	Select the most suitable professionals with experience in energy reduction	Integrate green experts' design ideas
The usage level of BIM computer modeling in the project to reduce energy consumption	Identify the design elements	Collect necessary information	Integrate and analyze renewable energy technologies in the design	Use BIM analysis tools to optimize energy design
The consideration level of operating and maintenance factors during the design	Identify equipment accessibility, standardization, modularization, ease of maintenance for the selected energy equipment and machines	Seek inputs from maintenance personnel	Integrate energy equipment maintenance and operation considerations in the design	Simulate annual loads and peak demands
Design for net-zero energy	Identify innovative technologies and renewable power generation available in the market	Decide on the most fitting energy-efficient equipment and techniques	Achieve design energy efficiency through reducing the demand for energy	Conduct an asset assessment to identifying energy saving

2.3. Commitment Indicators for Carbon Emission Reduction

The final commitment indicator set in the design phase is designated to fulfill the carbon emission reduction decision trigger.

De Medeiros et al. [53] emphasized that expanding the design team's knowledge in the field of carbon emission by involving experts in carbon emissions reduction design is an indicator of project participants' commitment to carbon reduction goals. Ho et al. [54] highlighted that expanding the design team starts by identifying professionals with carbon reduction expertise to stimulate the team and go beyond the current design practices. De Medeiros et al. [53] argued that, according to the specified professionals' resumes, the design team must recruit pre-qualified applicants based on their experience in carbon reduction. Lu et al. [55] asserted that the design team needs to select the most suitable carbon reduction experts for inclusion in the team, while Ho et al. [54] specified that in order to involve carbon experts in the team effectively, their suggested design ideas must be integrated into the project design.

Changhai and Xiao [56] argued that using BIM computer modeling to reduce carbon emissions in the project design is an indicator of the designers' commitment to the carbon reduction goal. In support of this, Xu et al. [57] highlighted that BIM helps the design team run different simulations by changing project materials, systems, and machines' selection and using their carbon data to check carbon emissions according to the simulation's results. According to Changhai and Xiao [56], using BIM for the project design first requires identifying the design elements with high carbon emissions. Eleftheriadis et al. [58] stated that collecting necessary carbon data, whether from previous projects or manufacturing data, is an essential step in running BIM software effectively. Gan et al. [59] emphasized that the collected data must be run through BIM to analyze project-designed materials, systems, and machines over the life cycle to identify the project's carbon emissions. Galiano-Garrigós et al. [60] argued that BIM tools enable designers to optimize project carbon design from materials' and energy systems' selection and make necessary adjustments that reduce project carbon emission.

Lai et al. [61] pinpointed that there is a strong relationship between carbon emission and energy generation, where increasing energy generated from traditional methods leads to an increase in carbon emissions. In support of this, Adams and Achiempong [62] highlighted that incorporating renewable energy sources (such as solar and wind power) in the project design is an indicator of designers' commitment to reducing project carbon emissions. Nguyen and Kakinaka [63] argued that the first step to integrating renewable energy sources and technologies into project design is to identify their availability in the market. Schandl et al. [64] posited that the project design team selects suitable renewable technologies from the available ones to be in the project design and achieve the desired carbon emission level, while Wang et al. [65] specified that the selected renewable technologies must be integrated into project design to reduce emissions. Further, Nguyen and Kakinaka [63] indicated that to ensure renewable technologies are integrated into the design, the project design team needs to run a dynamic simulation to check total carbon emissions and optimize the technologies' design by changing the selection of renewable technologies.

Ubando et al. [66] argued that minimizing the project design's carbon footprint is an indicator of designers' commitment to reducing carbon emissions. According to Fabris [67], a design footprint is a process of evaluating and measuring the building's carbon emissions associated with building materials, machines, and systems used in the design to anticipate project carbon emissions. Trovato et al. [68] highlighted that to minimize project footprint, the design team must identify the project design footprint based on the design selection of project materials, equipment, and machines. He et al. [69] specified that the collected information about the design footprint helps the design team specify the design elements with high carbon-reduction opportunities, and Xiao et al. [70] asserted that the design team must select different alternatives to the design elements with high carbon emission to refine project details' design and reduce carbon emissions. Ubando et al. [66] argued that to check the project design footprint, the design team needs to conduct a life-cycle assessment for the entire project design. In support of this, Xian and colleagues [70] highlighted that this assessment considered all project flows (energy, materials, waste) in and out of the system to calculate project environmental impact, particularly carbon emissions.

Vuarnoz et al. [71] argued that considering maintenance and operational factors for project machines and equipment during the design to minimize carbon emissions is an indicator of the project designers' commitment to carbon reduction goals. In support of this, Monga and Zuo [72] highlighted that incorporating those factors by the designers, guiding the project systems' and machines' selection process to choose the lowest maintenance of the systems and machines all reduce their carbon emissions. Schagaev and Kirk [73] stressed that to incorporate maintenance factors into project design, the design team must first identify equipment and machine standards, modularization, and maintenance requirements to check their carbon emissions. Monga and Zuo [72] specified that the design team needs to seek input from maintenance personnel regarding machines and equipment selection along with their maintenance information. Vuarnoz et al. [71] stated that all collected maintenance information must be integrated into the machine and equipment selection process during the project design to ensure carbon minimization. Schagaev and Kirk [73] argued that to ensure the integration of maintenance factors to project design, designers need to simulate the carbon emissions of the selected machines and equipment to determine the emissions profile and change their selection to achieve the desired carbon emission level.

Hence, the previously discussed commitment indicators contained parameters with sequential characteristics. In this study, these parameters are considered as an indication of the degree of project participants' commitment toward carbon emission reduction in the design phase. Henceforth, the first parameter of each indicator reflects a low commitment, and the incorporation of all parameters reflects the excellent commitment, as shown in Table 3.

Table 3. Design Phase Commitment Indicators and Degrees for Carbon Emission Reduction [5].

	Extent of Commitment			
Commitment Indicators for Carbon Emission Reduction	**1: Low Commitment**	**2: Medium Commitment**	**3: High Commitment**	**4: Excellent Commitment**
Involving green expertise in terms of carbon emission reduction	Identify professionals with expertise in green design practices	Pre-qualify applicants	Select the most suitable professionals with experience in carbon emission reduction	Integrate green experts' design ideas into project design
The usage level of BIM computer modeling in the project to reduce carbon emissions	Identify the design elements	Collect necessary information	Integrate and analyze renewable energy technologies to identify carbon emissions	Use BIM analysis tools to optimize design of mechanical systems and reduce emissions
Incorporation level of renewable energy sources into the project to reduce carbon emissions	Identify the renewable energy technologies available in the market and their carbon emission level	Select suitable renewable technologies	Integrate the selected renewable technologies with project design	Use dynamic simulation to check project total carbon emissions
Minimize the design's carbon footprint for the project (Net Zero Carbon)	Identify the total carbon footprint for the project design	Specify carbon reduction opportunities	Select alternative layouts, materials, and equipment to reduce carbon emissions	Conduct life-cycle assessment based on the carbon footprint
The consideration level of operating and maintenance factors during the design to minimize carbon emissions	Identify equipment accessibility, standardization, modularization, and ease of maintenance for the equipment and machines selected in the project	Seek inputs from maintenance personnel	Integrate equipment maintenance and operation considerations in the design	Simulate annual loads and peak demands to determine the carbon emission profile

2.4. Expert Panel Results and Discussions

The identified commitment indicators regarding the selected SD decision in the design phase were evaluated and ranked by a panel of eight experts. The first sequel of this paper provides more detailed information about the expert panel and ranking process [5]. Table 4 shows the ranking results of the identified commitment indicators. The overall rank is the continuation of the first sequel of this paper, which discussed the commitment indicator ranking for the definition and planning phase.

Table 4. Expert Panel Results [5].

	Fulfill Waste Reduction	**Frequency of "5"**	**Frequency of "4"**	**Frequency of "3"**	**Frequency of "2"**	**Frequency of "1"**	**Average Rate**	**Rank**	**Overall Rank**	**Indicator Weight**
Commitments Indicators in Design Phase	Availability of resources	2	3	3	0	0	3.875	5	42	0.00509
	The usage level of reused and recycled construction and demolition materials in the project design	4	3	1	0	0	4.375	1	8	0.02671
	The usage level of BIM computer modeling in the project design to reduce waste	3	2	3	0	0	4	4	35	0.00611
	Incorporate design flexibility and durability (buildings that are designed with the flexibility to adapt to changing functions over long useful lives)	4	3	0	0	1	4.125	3	25	0.00855
	Involve green experts with waste management experience in the design team	3	4	1	0	0	4.25	2	18	0.01187
	Fulfill Energy Consumption Reduction	**Frequency of "5"**	**Frequency of "4"**	**Frequency of "3"**	**Frequency of "2"**	**Frequency of "1"**	**Average Rate**	**Rank**	**Overall Rank**	**Indicator Weight**
	Incorporation level of renewable energy sources into the project design	4	4	0	0	0	4.5	1	4	0.05342
	Involving green experts with energy reduction experience in the design team	4	4	0	0	0	4.5	2	5	0.04274
	The usage level of BIM computer modeling in the project design to reduce energy consumption	2	4	2	0	0	4	5	36	0.00594
	The consideration level of operating and maintenance factors during the design	4	3	0	0	1	4.125	4	26	0.00822
	Design for net-zero energy	3	4	1	0	0	4.25	3	19	0.01125
	Fulfill Carbon Emissions Reduction	**Frequency of "5"**	**Frequency of "4"**	**Frequency of "3"**	**Frequency of "2"**	**Frequency of "1"**	**Average Rate**	**Rank**	**Overall Rank**	**Indicator Weight**
	Involving green experts with carbon emission reduction experience in the design team	3	5	0	0	0	4.375	1	9	0.02374
	The usage level of BIM computer modeling in the project design to reduce carbon emissions	1	3	4	0	0	3.625	5	52	0.00411
	Incorporation level of renewable energy sources into the project to reduce carbon emissions	2	5	1	0	0	4.125	4	27	0.00791
	Minimizing design's carbon footprint for the project (Net Zero Carbon)	4	3	1	0	0	4.375	2	10	0.02137
	The consideration level of operating and maintenance factors during the design to minimize carbon emissions	5	2	0	0	1	4.25	3	20	0.01068

The next project phase is the project design. The first decision trigger in this phase is waste reduction, where the highest indicator is the usage level of reused and recycled construction materials (0.02671), and the lowest indicator weight is for the availability of the resources (0.00508). Therefore, incorporating recycled and reused materials in the project as much as possible reduces waste and limits the use of virgin materials. The next SD decision trigger is energy reduction. The resources' availability has minimal impact on the waste reduction outcome since the designers have detailed estimates of the resources allocated to the project, and they design the project according to that estimate. The highest weight is to incorporate renewable energy sources into the project design (0.05342), and the lowest is using BIM computer modeling in the project design to reduce energy use (0.00593). Hence, this varies the project energy sources that are used in order to include traditional ones and renewable energy as well, which leads to a significant reduction in the project's use of energy. Using BIM to reduce energy consumption is not commonly practiced by the designers to evaluate project energy consumption since it is heavily used in modeling the building and optimizing building spaces. The final decision trigger in the design phase is carbon emissions reduction. The highest indicator is involving green experts with carbon emission reduction experience in the design team (0.02374). The lowest is using BIM computer modeling in the project design to reduce carbon emissions (0.00411). Consequently, expanding design team knowledge by including experts in carbon reduction design improves the commitment to carbon mitigation. As for using BIM to reduce carbon emissions, experts that use BIM to model carbon emissions for buildings are limited; therefore, it received a low rank.

3. Case Study

The design process of the complete SDCTT tool, overall project phases, and how the tool works to track the commitment of different project participants at the different decision gates were explained in detail in part one of this article series [5]. The developed commitment indicators for all project phases and their parameters were utilized in the SDCTT interface at each phase. Consequently, for demonstration purposes, the workings of the design phase, the SDCTT-D interface, were evaluated through a selective case study for a recently completed power plant. The plant functioned at a capacity of 600 megawatts obtained from a local utility company. The data were acquired and validated from the utility company via interviews and documentation. Based on the case study data, the following paragraphs discuss the different inputs to the SDCTT-D.

In the owner interface for the design phase, only one project participant was chosen by the owner, the PM-Consultant. The owner selected waste reduction and energy consumption as the SD decision trigger in this phase with a medium (50%) and low (25%) commitment level, respectively. Table 5 shows the owner inputs for the design phase.

Table 5. SDCTT-D Case Study Owner Inputs Interface.

Commitment Tracking in the Design Phase								
			Specify Project Participants in This Phase	**Collective Decisions Result from All Decision Makers**		**Participant 1**		**Decision Threshold to Pass it**
			Names			**PM-Consultant**		**1**
What decision trigger are you committed to?	Decision	Target Level of Commitment		Beginning of the Design Phase	End of the Design Phase	Beginning of the Design Phase	End of the Design Phase	
Waste Reduction	Yes	Medium 50%	Waste Reduction					
Energy Consumption Reduction	Yes	Low 25%	Energy Consumption Reduction					
Carbon Emissions Reduction	NA	NA	Carbon Emissions Reduction					

At the beginning of the phase, the PM consultant did not commit to waste reduction. Table 6 shows the input of the PM-Consultant in the SDCTT-D interface at the start of the design phase for the waste reduction trigger. However, for the energy consumption trigger, the user selected the following expected indicators and degree of commitment. The first one is the incorporation level of renewable energy to a 50% degree of commitment represented by selected suitable technologies. The second indicator is the usage level of BIM computer modeling to a 75% degree of commitment represented by BIM integration and analysis.

The next indicator is designed for net-zero energy to a 50% commitment degree represented by deciding on the energy-efficient equipment and techniques. At the end of the design phase, the PM-consultant commits to the waste reduction trigger, where he accomplished the following indicators and degree of commitment. First, the availability of resources was performed to a 75% commitment degree represented by specifying the resources gap between the project design resources demand and the available resources. The second selection is to incorporate design flexibility to a 100% degree represented by conducting risk analysis. As for the energy consumption reduction trigger, the PM consultant did not change the commitment level at the end of the design phase, and he performed what was expected at the beginning of the phase. The demonstration of the PM-consultant remaining inputs in the interfaces, as explained earlier, is shown in Table S1.

Table 6. Case Study Project Participant 1 Inputs Interface.

Participant 1	**PM-Consultant**	**At the Beginning of the Design Phase**							
What is Your Commitment at the Beginning of the Design Phase?					**First Parameter (25% of Commitment Degree)**	**Second Parameter (50% of Commitment Degree)**	**Third Parameter (75% of Commitment Degree)**	**Fourth Parameter (100% of Commitment Degree)**	
Are you Committed to the following Decision?		If Select No Justify Your Selection	Commitment Indicator for Waste Reduction	Is This Indicator Applicable to the Project?	Identify resource demand from project design	Specify designed resource capacity	Specify the resources gap	Close resources gap	Commitment Outcome for Waste Reduction
Waste Reduction	No	Extra Budget required	Availability of resources.	No	N	N	N	N	No Commitment
					Identify the available reused and recycled materials available in the market	Involving contractors and suppliers in materials design	Integrate the selected recycled and reused materials in the project design	Conduct materials' life-cycle assessment	
			The usage level of reused and recycled construction and demolition materials	No	N	N	N	N	
					Identify the design elements	Collect necessary information	Integrate and analyze construction materials' elements in the design	Using BIM-based material analysis tools	
			the usage level of BIM in the project design	No	N	N	N	N	
Waste Reduction					Identify the design elements	Defined the effectiveness of the architectural spaces	Allow for adaptation of the space	Conduct risk analysis	
			Incorporate design flexibility factors	No	N	N	N	N	
					Identify professionals with expertise in green design	Pre-qualify applicants	Select the most suitable professionals with experiences in waste management	Integrate green experts' design ideas	
			Involve green experts with waste management experience	No	N	N	N	N	

For the design phase, one project participant is appointed by the owner of this phase, the PM consultant. At the beginning of this phase, the PM consultant did not commit to the owner's commitment level for the waste reduction trigger due to a lack of budget. However, by expanding the project design budget, the PM consultant achieved a low commitment level of 25% to this trigger at the end of this phase. That commitment level is lower than what the owner chose for the waste reduction trigger, which is a medium commitment level. The second SD decision trigger in the design phase is energy consumption reduction. The PM consultant expects to reach a medium commitment level of 50% at the beginning of this phase. At the end of the design phase, he achieved the same commitment level, which is higher than what the owner required, which is a low commitment level. In this case, the consent dashboard reflects the same result as that for the PM consultant since there is only one project participant. Table 7 shows the complete owner design dashboard after including all project participants' inputs.

Table 7. The Design Phase Owner Dashboard.

Commitment Tracking in the Design Phase								
			Specify Project Participants in This Phase	**Collective Decisions Result from All Decision Makers**		**Participant 1**		**Decision Threshold to Pass it**
			Names			**PM-Consultant**		**1**
What decision trigger are you committed to?	Decision	Target Level of Commitment		Beginning of the Design Phase	End of the Design Phase	Beginning of the Design Phase	End of the Design Phase	
Waste Reduction	Yes	Medium 50%	Waste Reduction	No Commitment	Low Waste Reduction Commitment 25%	No Commitment	Low Waste Reduction Commitment 25%	
Energy Consumption Reduction	Yes	Low 25%	Energy Consumption Reduction	Medium Energy Reduction Commitment 50%	Medium Energy Reduction Commitment 50%	Medium Energy Reduction Commitment 50%	Medium Energy Reduction Commitment 50%	
Carbon Emissions Reduction	NA	NA	Carbon Emissions Reduction					
			Review Decision Maker Results	Consensus D		The Design Phase		
		Justification for No Commitment From Decision Maker:	Waste Reduction			Extra Budget Required		
			Energy Consumption Reduction					
			Carbon Emissions Reduction					

4. Conclusions

This paper is the second sequel to developing the SDCTT-D tool with a particular focus on the second project phase, the design phase. Through an extensive literature review, fifteen commitment indicators were construed for the design phase by integrating different SD indicators. The indicators reflect the project participants' commitment to SD decisions within the design phase of a project. Moreover, they represent best practices to be used in design to reduce project waste, energy consumption, and carbon emissions. Each indicator encompasses four parameters that reflect the commitment degree of project participants to SD decisions. The parameters reflect sequential activities that need to be fulfilled by the project participants in order to accomplish the leadership's SD decisions. The commitment indicators were validated through a selective expert panel specialized in sustainable infrastructure and project management to ensure the relevance of the developed indicators to track project participants' commitment to the leadership's SD decisions. In addition, the experts ranked these indicators to weigh and evaluate the commitment level of project participants at the SDCTT-D decision gate. According to the expert panel, all deduced SD commitment indicators and their parameters are valid for tracking the project participants' commitment to SD decisions in the design phase. Furthermore, based on the expert rankings, the following commitment indicators have the highest overall ranking, which include: incorporating renewable energy sources into the project design, involving green experts with energy reduction experience in the design team, and the usage level of reused and recycled materials in the project design.

The validated commitment indicators and their parameters were utilized in the SDCTT-D tool to assess commitment via best practice employment at the design stage. The first prequel to this paper [5] explained in detail how the total project phases interface with the complete SDCTT tool. Furthermore, the SDCTT-D tool interface tested its usability through a selective case study and was validated by the end-user of the tool. Through the case study, the SDCTT-D tool requires the project participant to estimate their commitment at the beginning of the design phase by identifying which commitment indicator (developed for the design phase) is to be applied to the project and the degree to which it satisfies the project owner's SD targeted decision. At the end of the design phase, project participants will re-evaluate their commitment by selecting the relevant SD commitment indicators and tracking the degree to which they satisfy that commitment. The tool also requires the project participants to justify the lack of commitment (if any) to the owner in order to solve that issue. Ultimately the SDCTT-D interfaces communicate all the commitment outcomes from each project participant with the project owner and other participants to ensure the availability of the right information.

According to the tool end-user, The SDCTT-D is a valid tool to track the project participants' commitment to SD decisions during the design stage, and it helps project teams align their commitment to the selected SD decisions. The SDCTT is the groundwork for the future development of performance indicators that link project participants' commitment to the target SD outcomes in the project. The SD tracking tool developed by this study provides a novel approach that aligns the project participants' commitment to the decisions made by the organization leaders. As such, the practical application of the SDCTT tool is to help the participants of the project track the information and measurements used to reach the project targets and, ultimately, the organization's goals and targets, pinpointing the weaknesses in the project participants' commitment toward SD decisions in the design phase. It is anticipated that the study findings will make a valuable contribution toward improving the environment and, by extension, society's well-being through the provision of sustainable designs that reduce project waste, energy consumption, and carbon emissions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14106205/s1, Table S1: title Case Study Tool Inputs of Project Participant in Design Phase.

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