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Environmental Impact Assessment of Composite Small Craft Manufacturing Using the Generic Work Breakdown Structure

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The number of studies on the environmental impact of products and services has increased in order to protect the environment. Recently, environmental impact assessments (EIA) and life cycle assessments (LCA), typically used for evaluating environmental impacts, have been gaining in popularity. Accordingly, this study performed an EIA using LCA methodology focusing on the manufacture of composite small craft. A work breakdown structure (WBS) is used in most shipyards to manage the overall life cycle of a craft. Therefore, for the EIA performed as part of this study, the generic WBS for environment (GWBSE) was defined by utilizing existing shipyard information. Unlike a general WBS with a determined structure, the GWBSE structure supports different combinations depending on the objectives; the EIA can be performed by combining different methods, materials, and product structures used in the manufacturing process for composite craft. Further, this study developed an application to effectively perform EIA utilizing GWBSE. The EIA was performed according to the manufacturing method and the combination of materials used for small leisure craft; the results were then analyzed.

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NOMENCLATURE

i = Index of generic object
j = Index of manufacturing process
k = Index of material choice
l = Index of environmental indicator
I = Total number of generic objects
L = Total number of environmental indicators
EI_{jk} = Environmental impact value of the target product against to the manufacturing process j and material k
p_{ijkl} = Environmental impact score of generic object i, manufacturing process j, material choice k, environmental indicator l
w_l = Weighted value of environmental indicator l
r_i = Proportion ratio of generic object i

1. Introduction

With the goal of protecting the environment, there has been an increase in the number of studies[1,2] that have pre-analyzed the environmental impact and have undertaken a prediction and assessment of a project, process, product, or service. The shipbuilding industry is no exception. Several research on environmental assessment have been carried out with respect to the design, production, and operation of ships. Hayman et al.[3] studied technologies for reducing the environmental impact during the entire life cycle of ships except during disposal. Tincelinet et al.[4] developed design criteria for reducing the environmental impact from the viewpoint of ship design and operation.

Environmental impact assessment (EIA) and life cycle assessment (LCA) are typical methodologies used for assessing the environmental impacts of products and services. The EIA approach involves quantifying the potential environmental impact of executing a specific project. The main objective of performing an EIA is to incorporate

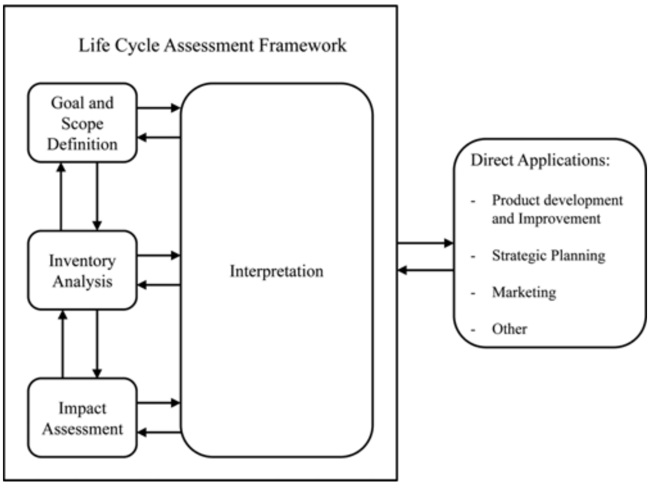

Fig. 1 LCA framework (ISO 14040)[5] (Adapted from Ref. 5 on the basis of OA)

environmental factors in the decision-making or planning of the project, ultimately helping establish eco-friendly choices during the decision-making process. LCA can be defined as a method that assesses environmental impact with a focus on the life cycle of a product or service, including the securing of raw materials, design, production, use, disposal, and recycling. Fig. 1 shows the basic LCA framework and execution process as laid down in international standards (ISO 14040).[5] The LCA framework consists of four steps; definition of goal and scope, inventory analysis, impact assessment, and life cycle interpretation. EIA and LCA have the same definition and the majority of recent studies regard LCA as being a part of EIA.[6-8] Tukker[9] said that LCA is a convenient tool to execute the EIA while comparing the EIA and LCA methodologies. In addition, the author claimed that EIA and LCA are fundamentally the same. LCA is merely used as a detailed tool, such as for comparison with other product systems; however, EIA deals with a wider comparison, and is used to focus on the decision-making process in companies and organizations. Finnvedena and Moberg[10] also claimed that EIA and LCA have a complementary relationship with each other, after discussing the characteristics of the various methodologies to analyze the impact on the environment. Manuilova et al.[11] proposed a method for applying an EIA, by investigating a case study on carbon capture and storage (CCS).

Most small crafts are made of composite materials glass fiber reinforced plastic (FRP). The composite crafts show a competitive purchase price, low weight, low production and life cycle cost than aluminums and steel crafts.[12] The environmental impacts of the composite small crafts depend on the material used and the manufacturing process. Hence, in this study, EIA was performed using the LCA methodology with a focus on the manufacturing process and material choice for composite small crafts, in order to arrive at a composite design with the least environmental impact. Although it is possible to evaluate the environmental impact of a composite small craft by applying the LCA method, the application of EIA is necessary in shipyards to develop small crafts, considering various aspects such as future production control and environmental regulations. The EIA model was constituted by referring to the impact assessment and inventory analysis steps in the LCA. The LCA target was defined using the work breakdown structure (WBS), which is a project management tool. Subsequently, an EIA was performed by inputting real small craft data into the proposed EIA model. The plan for utilizing the WBS in the EIA will be discussed.

WBS is an effective tool in managing long-term and large projects. General ships are commonly a product of projects that require development times of more than 1 to 2 years, they are managed as a concept that is equivalent to a project for developing a single system. Thus, WBS is a very useful management tool that can be used by shipbuilding industries to manage project information. The product WBS (PWBS)[13] and the ship WBS (SWBS) are typical example of the WBS in shipbuilding industries. In particular, the SWBS has been used by the US Navy for shipbuilding and management.

However, because this study focused on the small craft, and the type of information handled differs from that for the general ships, the WBS used in existing large shipyards cannot be used as is. Therefore, Lee et al.[14] developed the generic-sailing yacht WBS (Generic-YWBS) to manage the development of sailing yachts and an application to manage the Generic-YWBS. The Generic-YWBS has a similar structure to the product information based on the generic product-oriented WBS (GPWBS), proposed by Koening et al..[15] The GPWBS is a product-oriented WBS that overcomes the limitations of the SWBS. It breaks down a structure of general ships according to system functional units and expresses the information relating to production and design. The GPWBS defines a single WBS item by combining the product structure, stage, and work types. Interim products, such as blocks, can be defined and organically managed by integrating process and equipment information through the above concept. The Generic-YWBS employs the GPWBS concept of defining single WBS items by combining various parameters. It defines WBS items with single definitions by constituting and combining group data relating to sailing yachts.

Accordingly, the Generic-YWBS can configure a single WBS item by combining items in the lowest category, by defining five basic data groups and constituting each group as a three-step sub-structure (Group-Category-Item). Fig. 2(a) shows the five data groups and sub categories of the Generic-YWBS. Each category has sub-items; however, they are omitted in Fig. 2(a). Figs. 2(b) and 2(c) show how to define an actual WBS item by a combination of the items in the Generic-YWBS. As shown in the Fig. 2(b), a WBS item could be defined by a combination of two sub-items from other groups. In addition, it is possible to have a combination of three sub-items as shown in the Fig. 2(c). In particular, the group 3 in the Fig. 2(a), which is an item that is defined on the basis of the results of the life cycle analysis of sailing yachts, the end of the life stage is not considered. In other words, the activities related to the disposal of the craft were excluded from the purview of the system because there are no items to be managed by the shipyard.

This study defines the generic WBS for environment (GWBSE) by utilizing the important concepts and information of the GPWBS and Generic-YWBS reported in previous studies; it proposes a method and application for performing an EIA using the GWBSE. This study utilized the LCA methodology to simply perform an EIA. In particular, because this study proposes the use of GWBSE in the inventory analysis step for defining the EIA items, repetitive tasks can be minimized and effective EIA can be performed. The objective was to perform EIA for a relevant craft by utilizing actual composite small

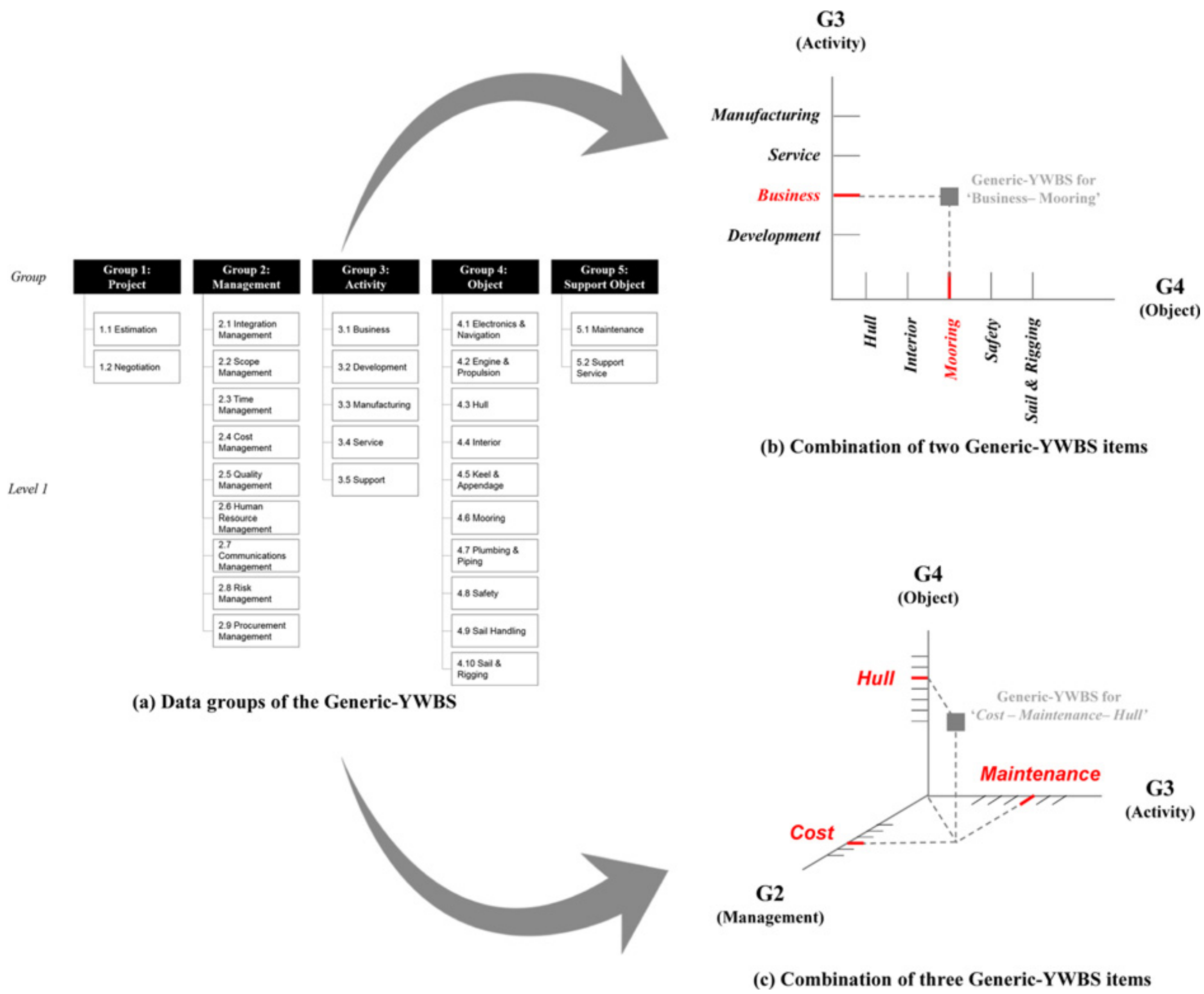

Fig. 2 Basic structure of the Generic-YWBS and utilization

craft information, and then verifying the efficacy of the method proposed in this study.

2. Assessment Model for Composite Craft Construction

2.1 Methodology

As mentioned earlier, the Generic-YWBS is a generic WBS designed by considering the characteristics of sailing yachts with the objective of integrated information management. Therefore, it offers a high degree of versatility and scalability, unlike existing WBSs.[14] This study defined a WBS for performing composite small craft EIA based on the basic structure and items of the Generic-YWBS, and defined the WBS by GWBSE. The EIA model for composite small craft utilizing GWBSE defined in this study is configured as follows.

The GWBSE should be designed to perform an EIA with respect to the composite craft manufacturing process. The Generic-YWBS is a standard for systematizing the performance line information and is used to define the standard craft production data, manage, model system construction (Hull Construction, Engine, Outfitting, etc.) and related process information of a target craft that is to be built. Therefore, an extended architecture is required to supplement the existing Generic-YWBS with information relating to the environmental factors, process, and composite material, which are the focus of the present study. This structure was defined as GWBSE and all the information required for the EIA is integrally implemented as the sub-items of GWBSE.

Subsequently, an inventory needs to be constructed for EIA. This step investigates and analyzes the basic material and method data with respect to the manufacturing process of a composite product; it then classifies the data in line with the previously extended GWBSE structure. In the next step, an algorithm is modeled to implement the EIA. EIA items are determined based on the LCA standard[5] or other reference data and weights are set to quantify the assessment items. Finally, EIA is performed for the manufacturing process of composite craft. This process defined the detailed items by employing a three-dimensional axis structure, which is a basic concept of the Generic-YWBS. EIA was then performed for the unit systems of the craft.

This methodology has the advantage of easily and quickly performing various design and production alternative assessments, based only on the WBS information, i.e., the system information of the craft without the detailed information and design results of the craft.

2.2 Implementation

This section deals with the process of performing an actual EIA based on the methodology defined in Section 2.1. As aforementioned, this study applied the EIA model by limiting the manufacturing process

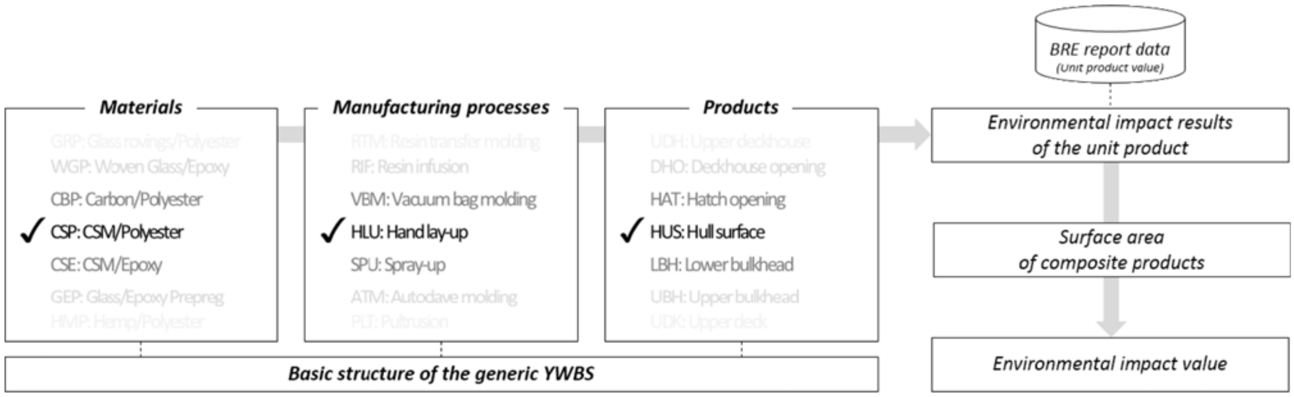

Fig. 3 An EIA model for composite small craft manufacturing process using the BRE report data

to the life cycle of the composite small craft. This is because most of the environmental impact is generated in the production or manufacturing process during the life cycle of the products.[16] In particular, this section limited the scope to the details of the process of building the hull with composites, during the manufacturing of a composite small craft, to explain the wayin which the EIA model can be applied to practical data.

Composite materials are extensively used in small crafts because of their low weight and easy maintainability using patches of the same type of fiberglass. Meanwhile, their environmental impact is calculated differently according to the manufacturing process of the composite product and the classification of the material used. The Building Research Establishment (BRE)[17] provided environmental impact scores for the manufacture of the composite material, based on single-skin and sandwich-unit members. This section deals in detail with the method of applying the EIA model to the process of building the hull for composite small craft. The EIA model for a composite small craft proposed in this study comprises four stages: 1) design of the GWBSE; 2) construction of the environmental assessment inventory; 3) environmental assessment of the unit element; and 4) environmental assessment of the total product. The basic structure and items of the GWBSE are developed as per the Generic-YWBS. The target of the GWBSE is limited to the assessment of the material, manufacturing process, and product. Further, the BRE report data is used for the construction of environmental assessment inventory. The detailed procedure of the EIA model is described in Fig. 3.

2.2.1 Design of the GWBSE to Perform the EIA

To perform the LCA process for specific products or projects, basic life cycle inventory (LCI) is required. Therefore, construction of the basic LCI database is a priority when performing the LCA. This study utilized concept of the basic WBS, which has similar role with the LCI database used when performing the LCA. The concept of the basic WBS is already being used in most shipyards and other industrial sites to manage engineering data.

The WBS signifies the breakdown of work into work package units in order to successfully execute a project. Most shipyards use the WBS concept to manage complex and varied processes and products. The study by Lee et al.[14] proposed the application of Generic-YWBSto GPWBS concepts to systematically manage the engineering information of sailing yachts. However, because group 1, 2, 3 and 4 in the Generic-YWBS are the segmented groups of projects, management, object,and activity, respectively, the groups do not directly include the information related to the EIA. Therefore, some additional structures must be designed into the existing concept of the WBS in order to apply WBS to the EIA model. Group 5 of the Generic-YWBS, which is a support object, includes an item that is not included in the classification of other groups and basically supports other items.

Therefore, for this study, it was decided to use the group 5 of the Generic-YWBS, proposed in the existing study, by partially extending it. The object group was partially supplemented to express the detailed items used for generating composite products and the combination of future materials.

Next, the extended WBS was supplemented using the information used in the EIA. The basic concept of the Generic-YWBS is to flexibly allow the use of WBS through the combination of various items based on the WBS objectives. The manufacturing process for composite small craft must consider the respective features, according to the various combinations of materials, manufacturing processes, and applicable targets. Therefore, the GWBSE implementation results for EIA are as shown in the Fig. 4.

2.2.2 Inventory Construction for EIA of the Composite Small Craft Building Step

The basic data used for performing EIA is similar to the LCI information that is generally used in LCA. The process proposed by this study uses EIA values quantified according to the material used in creating unit members that make up the composite product. Here, the user can define the EIA factors to be applied. Although the values provided by various database can be used as the quantified value, the present study used the evaluation results of the “Green Guide in the Composite Report” written by BRE.

The relevant report defines 12 EIA factors and uses the assessment results by dividing them into different steps (A-E), according to the composite material combinations and manufacturing processes of the composite product. Meanwhile, the weighted value of the EIA factors also provide the summary results by using the data collected by BRE. Finally, the EIA results are provided according to the manufacturing process and composite material combinations used to create single-skin and sandwich structure products.

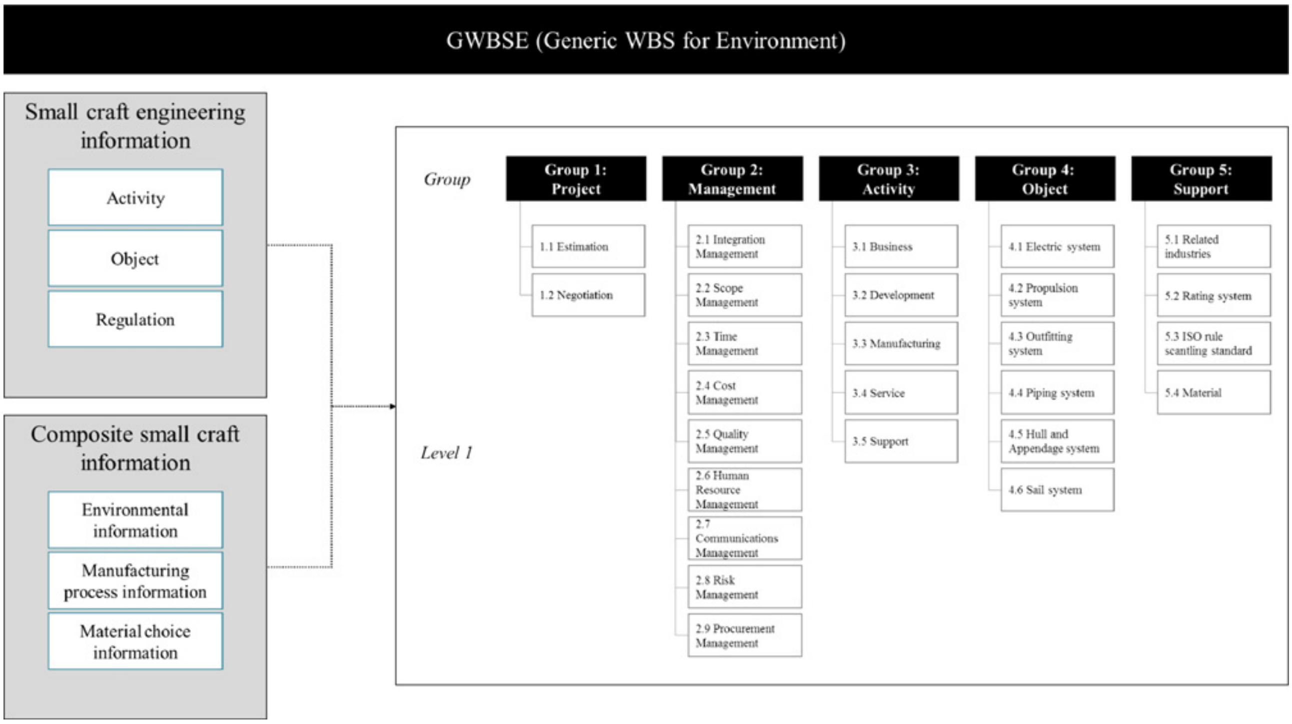

Fig. 4 GWBSE implementation results for the EIA

Table 1 Combination of manufacturing process, material, and environmental indicator

Manufacturing process	Material choice	Environmental indicator			
		$l = 1$	$l = 2$	$l = 3$	$l = 4$
$j = 1$	$k = 1$	p_{i111}	p_{i112}	p_{i113}	p_{i114}
	$k = 2$	p_{i121}	p_{i122}	p_{i123}	p_{i124}
	$k = 3$	p_{i131}	p_{i132}	p_{i133}	p_{i134}
$j = 2$	$k = 1$	p_{i211}	p_{i212}	p_{i213}	p_{i214}
	$k = 2$	p_{i221}	p_{i222}	p_{i223}	p_{i224}
	$k = 3$	p_{i231}	p_{i232}	p_{i233}	p_{i234}
$j = 3$	$k = 1$	p_{i311}	p_{i312}	p_{i313}	p_{i314}

Among the various processes involved in building composite small craft, the hull-building process is that which actually uses composite materials. This study performed EIA for the hull-building process by dividing the relevant products into single-skin and sandwich structure and using the value proposed by the BRE report as the basic value.

2.2.3Assessment Method and Formula Definition for Quantitative EIA of the Composite Small Craft Building Step

The unit members of the composite product have different EIA assessment values, depending on the combination of the environmental impact indicator l, the material choice k and the manufacturing process j (Table 1). Here, a total environmental impact score (EI_{jk}) of the target product can be derived by Eq. (1) considering the weighted value of each environmental impact indicator (w_l). The value proposed by the BRE was used as the preset weighted value.

$$EI_{jk} = \sum_{i=1}^{I}\left(r_i \sum_{l=1}^{L}(wlp_{ijkl})\right) \tag{1}$$

In the next step, the applicable target product information is defined by utilizing the previously designed GWBSE, and EIA is performed through this. Because the GWBSE has a hierarchical structure, it can be used to define a systematic product structure. Therefore, it begins with the unit product, which composes the subject product, then defines the products of higher rank. At this time, the unit product must define the ratio of single-skin to sandwich structure for the final composite products.

2.2.4 Quantitative EIA Execution of Composite Small Craft Using GWBSE

The composition ratio of the final product structure is also defined, based on the relevant information, and finally the composition ratio of single-skin to sandwich ofthe entire product is utilized. Then, the EIA scores are quantified according to the combination of manufacturing processes andmaterials for each unit product. The users are allowed to determinethe weighted value, because of the variety of EIA factors. Finally, Fig. 5 shows a three-dimensional graph of the results. The EIA composition ratio of the sub-product was established during the selection of the top structure products.

An advantage of carrying out the EIA is that the assessment model can be easily recycled using the series of steps described above. Also, once the GWBSE has been built through the existing WBS information, it is also possible to perform EIA with other quantified environmental impact scores provided by various databasesas well as BRE.

3. Case Study

An EIA was conducted for the manufacturing process of the composite small craft based on the proposed method in this paper. To this end, the existing constructed Generic-YWBS was extended to

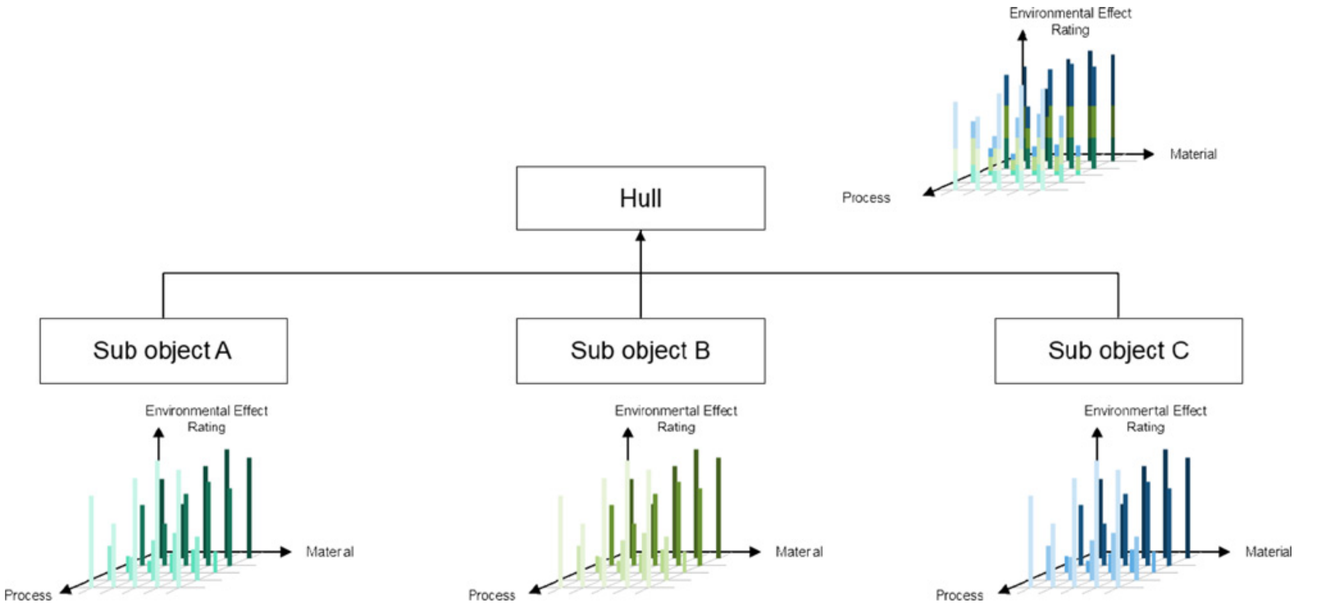

Fig. 5 Sample of EIA result

GWBSE that includes EIA items and the product structure of the target craft was expressed by items with a hierarchy structure by analyzing the product structure. Because the EIA model proposed in this study is for composite products, not all of the product structures of the craft were regarded as being the target. Only structures such as the hull, bulkhead, deck, superstructure, and others, which were constructed using composites, were considered as the target. In addition to the items that define the product structure, GWBSE includes material information for creating composite products and the manufacturing process for the composite product. The EIA model proposed in this study derived the assessment results according to the manufacturing process and material choice of the composite product.

The EIA assessment score was defined based on the unit product. This section defines the single-skin and sandwich products by unit product based on the results of the study conducted by BRE. The unit product has an EIA assessment score for each unit area based on the materials and manufacturing processes used. The method proposed in this study used the BRE study results as preset information; Table A-1 in the appendix part of this paper, lists the detailed values. The environmental indicator and weight of each indicator used the values presented in the BRE report.[17]

Fig. 6 illustrates the rating criteria, where ratings A to E are assigned according to the range of the environmental impacts. In this study, numerical values were assigned to each rating, based on a ten-point scale to analyze the results quantitatively. The unit product assessment score and the weight of the environmental indicator can be edited according to the user's needs. Hereafter, the attributes are determined based on the lowest items of the target product and the area is defined according to the attribute value. The attribute of the target product represents the classification of the relevant unit product. The single-skin and sandwich products in the present case correspond to this. The area corresponding to the attribute value can be calculated using actual design data and EIA is performed based on this area. Fig. 7 shows the detailed order of the application method of the EIA model using GWBSE.

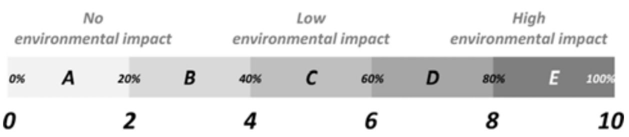

Fig. 6 Ten-Point scale of the environmental rating criteria

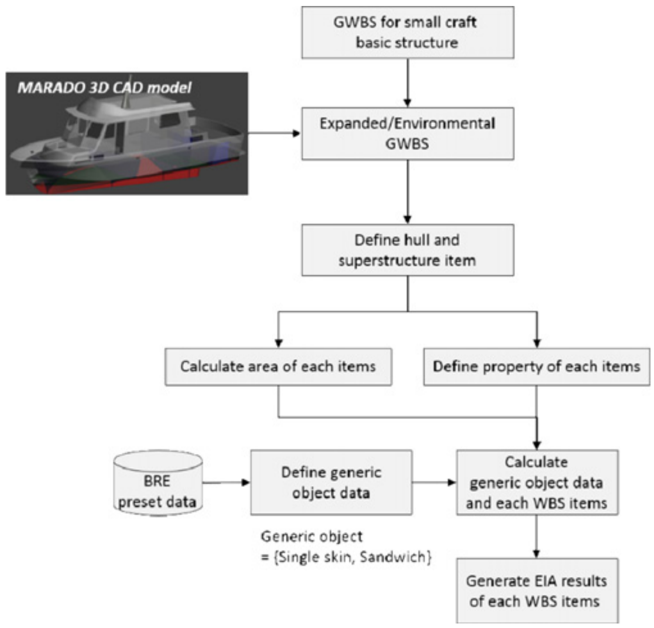

Fig. 7 Basic implementation process of the EIA

A case study was conducted based on actual craft information in order to verify the efficacy of the EIA method for composite small craft proposed by this study. The target craft of this study is a small fishing craft (MARADO). The length, beam, and depth of the craft are 16.40, 4.50, and 1.90 m, respectively. It is a small FRP craft built for leisure use in inland or coastal waters. A 3D CAD model at a 1:1 scale was analyzed to define the product structure of the target craft. The surface area of the product structure and each item of the target craft was

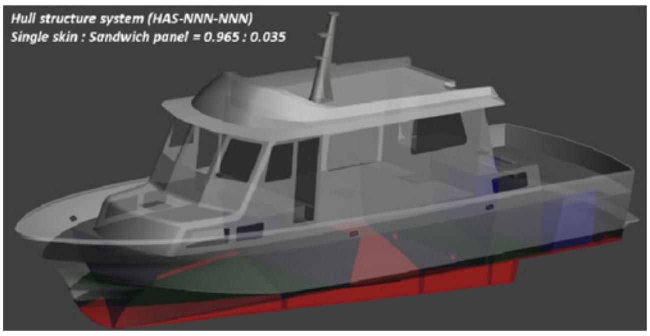

Fig. 8 3D CAD model of the target craft (MARADO)

Table 2 Laminate stacking sequence of small fishing boat

Product	Work order	Laminate stacking sequence	Manufacturing process	Material density (g/m^2)
Hull surface	1st	SM+M	Hand lay-up	M300
	2nd	M+R+M	Hand lay-up	M380 R570
	3rd	M+R+M+R+M	Hand lay-up	M380 R570
Bulkhead	-	UF+MRM×3+M	-	M300 R570
Deck / Superstructure	1st	SM+M	Hand lay-up	M300
	2nd	M+R+M	Hand lay-up	M380 R570
	3rd	Partial UF+ M+R+M+R+M	Hand lay-up	M380 R570

SM: Surface mat / M: Chopped stand mat / R: Woven roving cloth / UF: Polyurethane foam

calculated using 3D CAD software. The product structure of the target craft can be broken down into the hull structure, propulsion system, and outfitting. However, this study limited the GWBSE items to the hull structure because it focuses on the composite product. The hull structure can be broken down into the hull surface, bulkhead, deck, and superstructure. Each element has a corresponding code. This code is used to express the structural information of the GWBSE item. Thus, GWBSE items can be conveniently managed. Fig. 8 shows the code and the sub-items constituting the hull structure.

The hull surface of the composite craft is generally formed as a single skin and structures such as reinforcements and the superstructure are formed as sandwich products that include a core. This study defined the attributes of the target product by referring to the layered scheduling information of the FRP craft. Table 2, below, shows the layered scheduling information for a small leisure craft used for fishing. The hull surface did not include the core, and the single-skin and sandwich structures were mixed and used in the deck and for reinforcement. The actual stacking (Layered) area was calculated according to the attribute value and attributes of the hull surface, bulkhead, deck, and superstructure of the target craft. In those instances where a single skin and sandwich are mixed, as in the case of the bulkhead, the actual stacking area was calculated by multiplying the stacking frequency of each unit product and the area of the bulkhead.

The results of these calculations indicated that the area in the total

Table 3 Results of the EIA to the hull structure of the target craft (MARADO)

Process	Material	HUS	BHD	DCK	SST	Total
HLU	CSP	4528.9	1392.9	2064.6	3687.3	11673.6
HLU	WGP	3947.8	1209.0	1795.8	3207.4	10160.0
HLU	HMP	3643.6	1118.7	1659.5	2963.9	9385.7
HLU	CPC	2513.8	771.2	1144.5	2044.1	6473.5
HLU	CPA	4426.6	1357.3	2014.9	3598.6	11397.4
HLU	CLP	4339.4	1334.9	1978.4	3533.4	11186.0
HLU	CLC	2419.1	742.2	1101.4	1967.1	6229.7
HLU	CLA	4331.9	1328.3	1971.8	3521.6	11153.6
HLU	CSE	5169.8	1593.3	2359.2	4213.5	13335.8
SPU	GRP	4409.2	1355.9	2009.9	3589.7	11364.6
SPU	GPC	3608.6	1106.3	1642.4	2933.3	9290.6
SPU	GPA	4426.6	1362.6	2018.8	3605.6	11413.6
SPU	GLP	4314.4	1326.9	1966.8	3512.7	11120.8
SPU	GLC	3513.9	1076.9	1599.0	2855.9	9045.7
SPU	GLA	4331.9	1333.6	1975.7	3528.6	11169.8
VBM	CSP	4528.9	1392.5	2064.3	3686.9	11672.6
VBM	GEP	5391.8	1642.0	2445.8	4368.1	13847.6
VBM	CEP	8628.8	2622.0	3909.8	6982.9	22143.5
VBM	CGP	2950.3	899.1	1338.7	2391.0	7579.0
RTM	WGP	5154.8	1576.2	2343.0	4184.6	13258.7
RTM	HMP	3212.1	982.9	1460.6	2608.5	8264.1
RTM	CBP	7526.5	2290.3	3412.8	6095.2	19324.8
RTM	WPC	3720.9	1142.9	1695.1	3027.4	9586.3
RTM	WPA	4995.2	1523.6	2267.6	4050.0	12836.4
RIF	WGP	4336.9	1326.2	1971.4	3520.8	11155.3
RIF	HMP	3947.8	1213.5	1799.2	3213.3	10173.7
RIF	WGL	4336.9	1325.9	1971.1	3520.4	11154.2
RIF	WGE	4945.4	1513.0	2248.5	4015.7	12722.5
ATM	GEP	4982.8	1518.4	2261.0	4038.1	12800.2
ATM	CEP	7506.6	2282.5	3402.4	6076.7	19268.2
Laminatearea (m^2)		1246.9	414.5	591.6	1056.6	3309.6
Laminate area (%)		37.7%	12.5%	17.9%	31.9%	100.0%

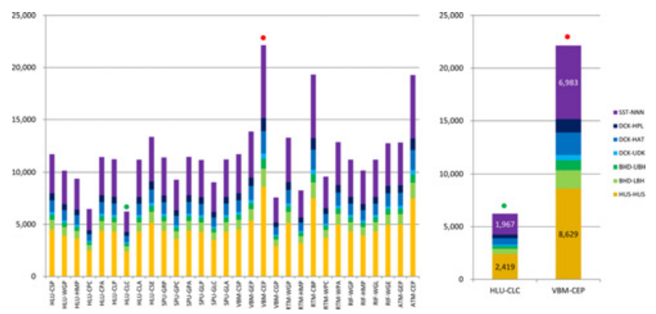

Fig. 9 EIA results of the composite craft manufacturing using the GWBSE

hull structure that used a single-skin was 3,193.45 m^2 and that which used the sandwich was 116.17 m^2. Because the EIA score of the unit product is defined based on the unit area (Single-Skin: 1 m^2, Sandwich: 8 m^2), an EIA for the entire product can be performed based on the area of the target product. The EIA score of each item was derived by multiplying the EIA score of the unit product and the actual stacking area of each item. The EIA score of the unit product is defined based on the manufacturing process and material choices. Table 3 and Fig. 9, below, show the results of applying the EIA model with respect to the

Fig. 10 Prototype UI of the application[18] (Adapted from Ref. 18 on the basis of OA)

hull structure of the target craft. The results derived through the method proposed in this study allow the calculation of the EIA score according to the manufacturing process and material choices, based on the constituent elements of the applicable target product. Therefore, the designer can compare the environmental impacts according to the processes and materials, based on the design and WBS information, before building the craft, formulating strategies to build craft by the combination of process and material with less environmental impact.

In the case of the target craft, Fig. 9 and Table 3, above, can confirm that the HLU-CLC (Hand Lay-Up + CSM/LS Polyester + 50% CaCO3 Filler, Table A-1) combination is the process-material combination with the least environmental impact. Moreover, the VBM-CEP (Vacuum Bag Molding + Carbon/Epoxy Prepreg, Table A-1) combination is the process-material combination with the highest environmental impact. Furthermore, because the EIA is performed based on the WBS, the assessments of the environmental impacts of each constituent product structure in the final product can be compared. In the case of the VBM-CEP combination, which is derived as the combination with the highest EIA score, it can be confirmed that the EIA score (6982.9) during the manufacture of the superstructure accounts for 31.5% (6982.9/22143.5) of the total EIA score for the manufacture of the entire product. Thus, if the WBS for the EIA is defined and performed using the method proposed in this study, the environmental impact of each constituent element of the final product can be assessed. The EIA can also be performed according to the combination of various processes and materials. This can assist in selecting a process-material combination with the least environmental impact.

4. Application Development

4.1 Prototyping

The EIA model proposed in this study included the process of defining the WBS and repetitive calculation of various numerical values. An application for calculating such a model is required to prevent errors in the repetitive process and confirm the values for various situations. Therefore, this study developed an application that can perform the above functions to increase the effectiveness of the EIA model utilizing GWBSE. This application stores the environmental indicator according to the procedure of the previously defined EIA model and has a function for calculating the assessment results. However, a definition at the user interface (UI) level is required to actually allow the user to use the application in a useful manner. To this end, an UI prototype was designed and detailed functions were implemented. Fig. 10 shows the UI of the application used to implement the EIA model proposed in this study.

The UI of the application for performing the functions proposed in this study is constituted of GWBSE management, environmental indicator attribute management, unit product assessment score input, and assessment result output parts. The program developed in this study should provide useful functions after receiving input information on the environmental indicator, the assessment score of the unit product, and the GWBSE information, either received from the user or recalled from pre-defined information. The application developed in this study defined the LCAX (XML for the LCA) file, based on the XML file format, to effectively express the WBS hierarchical structure. In the same way as for an XML file, the LCAX file basically expresses each piece of information by the items separated by a tag and expresses the hierarchical structure. Figs. A-1 and A-2 in the appendix part shows the sample LCAX file used in this paper.

4.2 Implementation

After defining the input and output file format and the UI of the application, the EIA assessment model implemented within the application should be defined and the architecture of the entire application should be designed. Each function performed by the application is segmented into modules in the process of architecture design. This structure helps to flexibly respond to future changes in the algorithms or requirements, as well as application extension. The following Fig. A-3 shows a component diagram representing the structure of the designed application for each module, by the UML (Unified Modeling Language).

Each component was implemented based on this description and the application was implemented using WPF (Windows Presentation Foundation) and the C# language under Microsoft .NET framework 4.0. The application has an easily extendable structure. Fig. A-4, below, shows the screen from which the application is controlled. Each component can be divided into a part that allows input and management of the assessment score of the unit product, GWBSE information, and environmental indicator information corresponding to the level of the EIA assessment model; the other part outputs the results calculated by applying the EIA assessment model in the form of tables and graphs. The information managed within the application is stored in the LCAX file in xml format as mentioned earlier, and the GWBSE information with the hierarchical structure of the input information is represented by a tree format. The area information of the constituent element is represented by a pie graph format. Finally, the calculated EIA results can be output in the form of a table and 3D graph and/or a text based file (CSV Format or MS Excel File Format).

5. Conclusions

This study proposed an assessment model to perform the EIA of a composite product by utilizing a flexible and extendable GPWBS. The environmental impacts were calculated based on the combination of the manufacturing process, material choice, and product by applying the assessment model to the actual composite small craft data. To increase the utilization of the model, it has to be further developed because the present model requires a repetitive calculation process.

The EIA model that uses the GWBSE proposed in this study has the advantage that it does not require the user to newly define the assessment targets or conditions. It allows EIA through a combination of the items defined in the WBS. As the WBS also includes the product structure of the applicable target product, the sub-item with the highest EIA score in the entire product can be identified. Through this, decision makers can develop products considering the overall environmental impacts.

The proposed method can help in selecting the appropriate manufacturing process and eco-friendly materials for a composite craft based only on WBS and several design information used in the process of developing various products. In our future research, the EIA will be performed for various cases besides composite small crafts.

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APPENDIX


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Fig. A-1 Sample data of the LCAX file

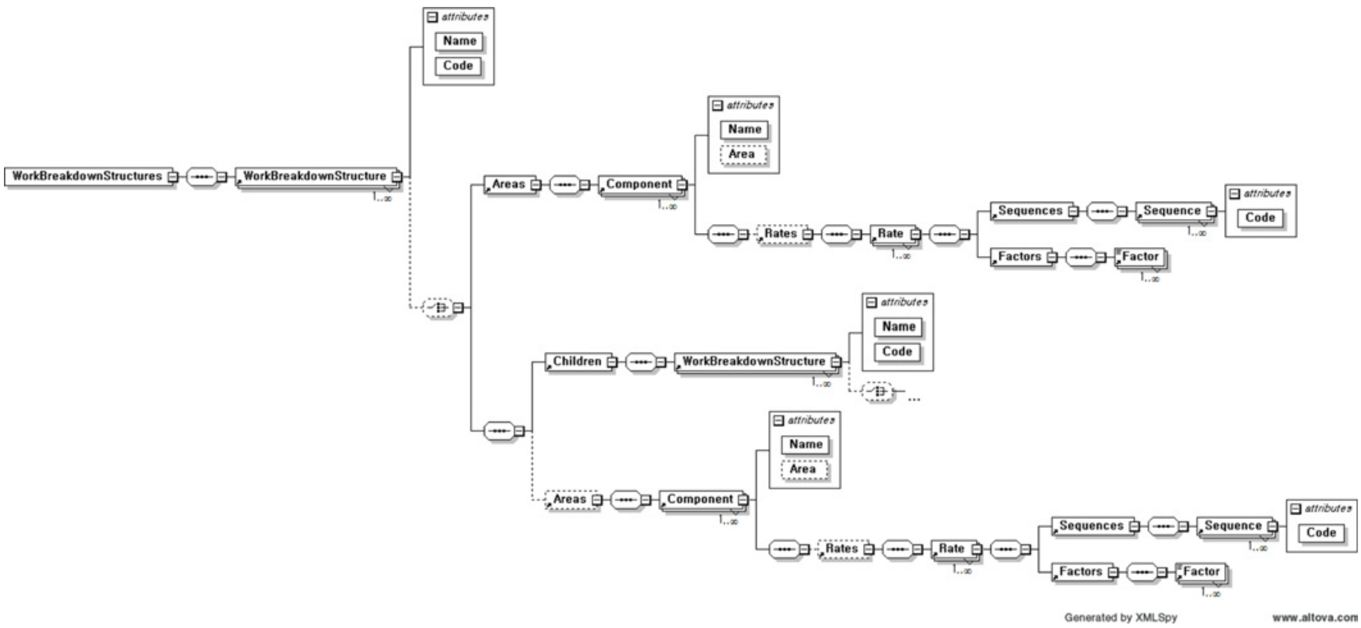

Fig. A-2 Structure of the LCAX file

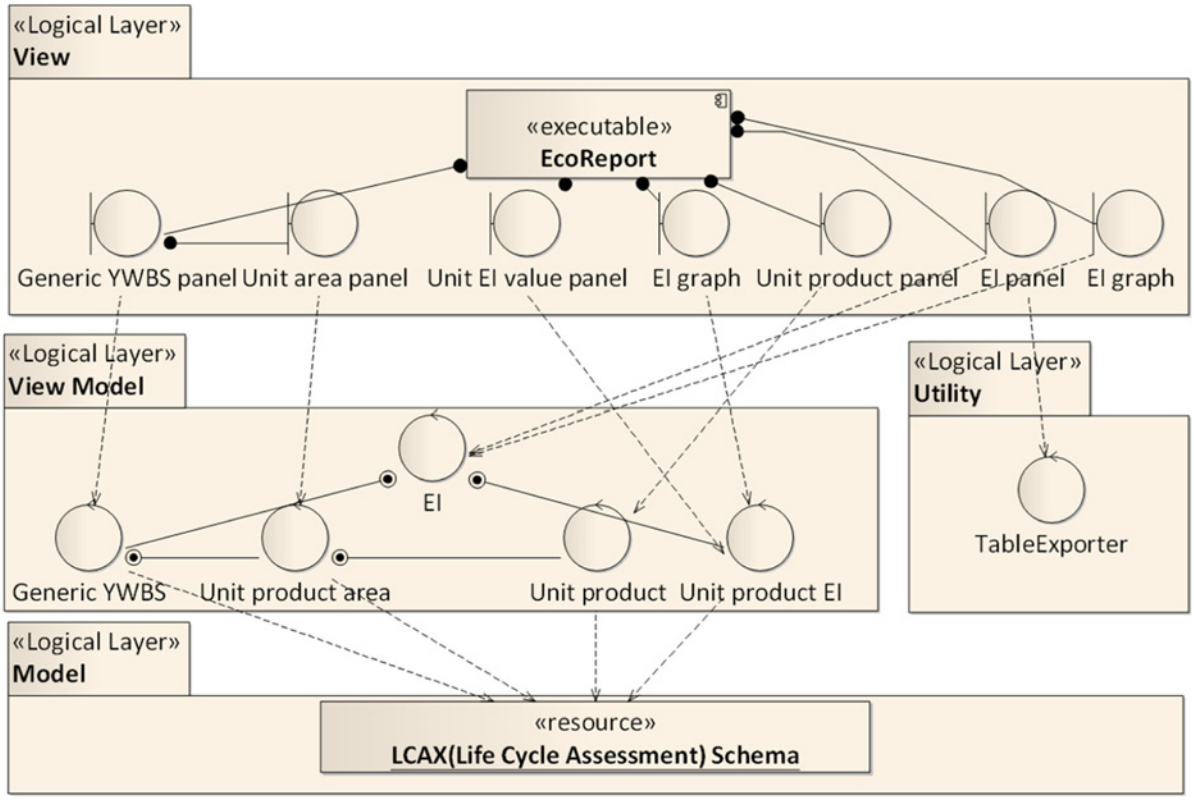

Fig. A-3 UML component diagram of the application

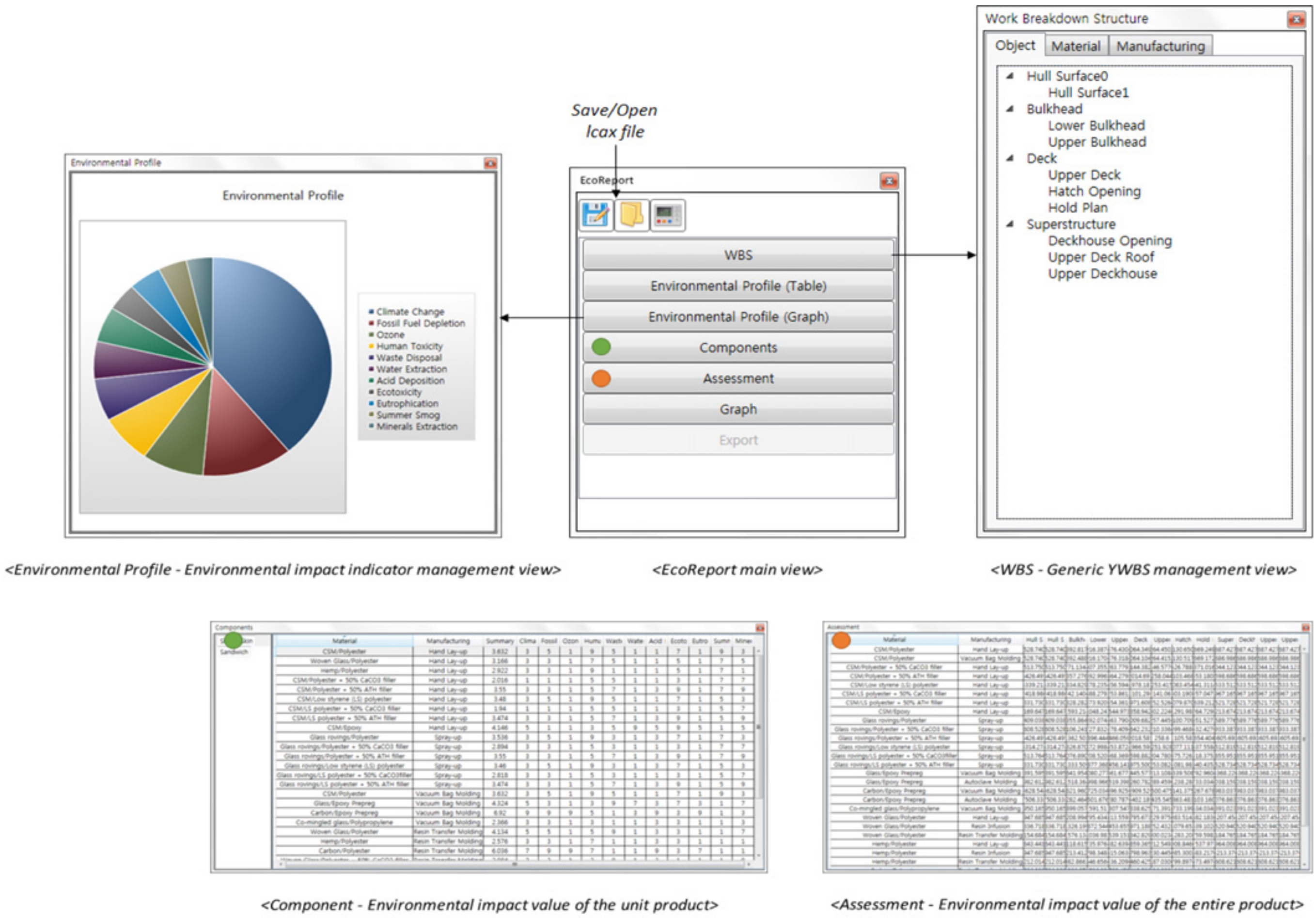

Fig. A-4 EIA application execution results

Table A-1 Environmental rating results of generic composite product in the BRE report (Single-skin/Sandwich)

Manufacturing process (Code)	Material choice (Code)	Environmental indicators											
		Weight	38.0%	12.0%	8.2%	7.0%	6.1%	5.4%	5.1%	4.0%	4.3%	3.8%	3.5%
		Summary	Climate change	Fossil fuel depletion	Ozone	Human toxicity	Waste disposal	Water extraction	Acid deposition	Eco-toxicity	Eutro-phication	Summer smog	Minerals extraction
Hand lay-up (HLU)	CSM/Polyester (CSP)	E / E	B / C	C / E	A / A	E / E	C / D	A / A	A / B	D / D	A / A	E / E	B / C
	Woven glass/Polyester (WGP)	D / C	B / B	B / C	A / A	D / C	C / D	A / A	A / B	C / C	A / A	D / C	C / C
	Hemp/Polyester (HMP)	D / E	B / B	B / D	A / A	E / E	A / A	A / A	A / B	C / D	A / B	D / E	A / A
	CSM/Polyester+50% CaCO3 filler (CPC)	B / C	A / A	A / B	A / A	C / C	C / D	A / A	A / A	B / B	A / A	D / D	D / E
	CSM/Polyester+50% ATH filler (CPA)	C / D	B / B	B / C	A / B	C / C	D / E	A / A	B / C	E / E	A / A	D / D	E / E
	CSM/Low styrene (LS) polyester (CLP)	D / E	B / C	C / E	A / A	E / E	C / D	A / A	A / B	D / D	A / A	C / C	B / C
	CSM/LS polyester+50% CaCO3 filler (CLC)	B / B	A / A	A / B	A / A	C / C	C / D	A / A	A / A	B / B	A / A	C / C	D / E
	CSM/LS polyester+50% ATH filler (CLA)	C / C	B / B	B / C	A / B	C / C	D / E	A / A	B / C	E / E	A / A	C / C	E / E
	CSM/Epoxy (CSE)	C / C	C / E	A / B	A / A	B / B	C / E	E / E	C / E	E / E	C / E	A / A	C / D
Spray-up (SPU)	Glass rovings/Polyester (GRP)	E / E	B / C	C / E	A / A	E / E	B / C	A / A	B / C	D / D	A / A	D / D	B / B
	Glass rovings/Polyester+50% CaCO3 filler (GPC)	C / C	B / B	B / C	A / A	C / C	B / C	A / A	A / B	B / B	A / A	D / D	D / D
	Glass rovings/Polyester+50% ATH filler (GPA)	C / D	B / C	B / D	A / B	C / C	D / E	A / A	B / D	E / E	A / B	D / C	E / E
	Glass rovings/Low styrene (LS) polyester (GLP)	D / E	B / C	C / E	A / A	E / E	B / C	A / A	B / C	D / D	A / A	C / C	B / B
	Glass rovings/LS polyester+50% CaCO3filler (GLC)	B / C	B / B	B / C	A / A	C / C	B / C	A / A	A / B	B / B	A / A	C / B	D / D
	Glass rovings/LS polyester+50% ATH filler (GLA)	C / C	B / C	B / D	A / B	C / C	D / E	A / A	B / D	E / E	A / B	C / B	E / E
Vacuum bag molding (VBM)	CSM/Polyester (CSP)	E / E	B / C	C / E	A / A	E / E	C / D	A / A	A / B	D / D	A / A	E / E	B / B
	Glass/Epoxy prepreg (GEP)	C / A	C / B	B / A	A / A	B / A	E / D	D / B	B / B	D / C	B / B	A / A	D / C
	Carbon/Epoxy prepreg (CEP)	E / A	E / B	E / B	E / E	C / A	A / A	B / A	E / C	B / B	E / C	A / A	B / A
	Co-mingled glass/Polypropylene (CGP)	A / A	B / A	B / B	A / A	B / B	A / A	A / A	B / B	B / B	A / A	A / A	B / B
RTM (RTM)	Woven glass/Polyester (WGP)	C / B	C / C	C / C	A / A	C / B	E / E	A / A	B / B	B / B	A / A	A / A	D / C
	Hemp/Polyester (HMP)	B / B	B / B	B / B	A / A	D / C	A / A	A / A	B / B	B / C	A / B	A / A	A / A
	Carbon/Polyester (CBP)	D / A	D / B	E / C	E / E	D / B	A / A	A / A	E / C	B / A	D / C	A / A	A / A
	Woven glass/Polyester+50% CaCO3 filler (WPC)	B / B	B / C	B / B	A / A	B / B	E / E	A / A	B / C	A / B	A / A	A / A	E / E
	Woven glass/Polyester+50% ATH filler (WPA)	B / A	C / B	B / B	A / A	B / B	E / E	A / A	C / B	C / B	A / A	A / A	E / D
Resin infusion (RIF)	Woven glass/Polyester (WGP)	D / C	B / B	C / C	A / A	D / C	D / D	A / A	B / B	C / C	A / A	B / B	C / C
	Hemp/Polyester (HMP)	D / D	B / C	C / D	A / A	E / E	A / A	A / A	A / B	D / D	A / B	C / C	A / A
	Woven glass/Low styrene (LS) polyester (WGL)	C / C	B / B	C / C	A / A	D / C	D / D	A / A	B / B	C / C	A / A	B / A	C / C
	Woven glass/Epoxy (WGE)	B / B	C / C	A / A	A / A	A / A	E / E	D / C	C / C	C / C	B / C	A / A	D / D
Autoclave molding (ATM)	Glass/Epoxy prepreg (GEP)	B / A	C / B	B / A	A / A	A / A	E / D	C / B	B / B	C / C	B / B	A / A	D / C
	Carbon/Epoxy prepreg (CEP)	D / A	D / B	E / B	E / E	B / A	A / A	B / A	E / C	B / A	E / C	A / A	B / A