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A Database Model for Environmental Impact Assessment of External Wall Construction Techniques

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ABSTRACT

Sustainability assessment tools and certification systems generally assess environmental impacts of buildings in use phase. Nevertheless, the tools and systems often ignored the interaction between building construction process and the environment. However, we should take environmental impacts of buildings into account during design process not only considering use phase but also by making decisions related to construction activities. In this study, the author introduces an approach for external wall systems, which aims to reduce environmental impacts of construction process by taking decisions in design process. Within the scope of the method, the author developed a database based on a proposed assessment system for selecting and comparing construction techniques of external walls to reduce environmental impacts of construction process.

1. Introduction

We can achieve sustainable buildings by considering environmental impacts in each phase of

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the building life cycle. Decisions taken at design stage, building material selection, construction and operation phases are effective on environmental impacts of buildings throughout their life cycles (Metin, 2010). However, optimization of material and component production and a reduction in the amount the energy used by a building at the serviceability stage do not exhaust the problems associated with a building's entire life cycle (Pollo and Rivotti, 2004). Cyclic approach is the basis for sustainability and the construction industry should consider each phase of the building life cycle according to the sustainability principles (Metin and Tavil, 2010). The assessment must necessarily refer to the entire life cycle of a building and cannot be limited to the stage of off-site production of the materials and components, as is often the case when dealing with an industrial product characterized by a shorter life cycle (Pollo and Rivotti, 2004). Since the challenge is to designate sustainability at all phases of the building life cycle, studies should analyze environmental affects for each of the phases individually (Metin and Tavil, 2010). Although there are previous and ongoing studies which ascertain the relationships between the building design/operations and the environment, the interaction between the building construction process and the environment is still largely unknown (Metin and Tavil, 2010). We often overlooked on-site construction phase when considering the entire life cycle, leading to a gap in understanding the whole spectrum and possible sources of environmental impacts on the built environment (Bilec, 2007).

Ensuring environmental sustainability in the construction process will be possible by controlling energy and resource use, emissions and wastes in each phase of the construction process. Therefore, criteria affecting the environmental sustainability of construction process should be set for each phase of the construction process (Metin, 2010). However, assessing environmental impacts of construction process is difficult owing the fact that construction process consist of many sub-processes and there is no recorded data about energy use, emissions and construction wastes (Bilec, 2007). Construction techniques are one of the factors affecting environmental impacts of buildings. Construction techniques designates construction inputs like material, equipment, labor and these inputs affect the amount of energy use, emissions and construction wastes that cause environmental impacts. Therefore analyzing construction process depending on construction techniques is important for defining the environmental impacts of construction process (Metin, 2010).

Architects play an important role by taking decisions about construction process at design phase aiming reduction in environmental impacts. However, architects need some systems to assist him during the design process. Architects need an assessment system to assess and compare different construction techniques that can be appropriate for their designs. For this purpose, the study aimed to develop an assessment system to use in building element design process. First, the author selected external wall systems to study. Innovation in the building material industry and technological developments has led to a widening of external wall cladding material and construction techniques options. Therefore, external wall system selection is one of the complicated stages of the building envelope design, since there are many options depending on the material and construction technique. Therefore, assessing different construction techniques of external wall systems is important for understanding the sustainability level of the construction process that can assist the decision makers at design phase. Because of these cases, external wall systems, which were composed of different external wall cladding materials commonly used for facades in Turkey, were chosen as the study area to assess the effect of construction techniques on environmental sustainability of construction process and an assessment method was developed (Metin, 2010). Finally, the study developed a database, which provided results of different external wall systems based on the developed assessment method for easy selection and comparison in terms of their construction techniques in the context of environmental sustainability of construction process.

2. Methodology

The study depends on two basic steps. First step, the study developed an assessment method in the context of a master thesis (Metin, 2010). Then the study developed a computer-based database including data on different construction techniques of external wall systems.

2.1 Developed Assessment Method

In the first step, the study developed an assessment method, which aims to assess construction techniques of external wall systems in the context of environmental impacts of construction process. For this purpose, the study followed four sub-steps to develop the assessment method (Figure 1).

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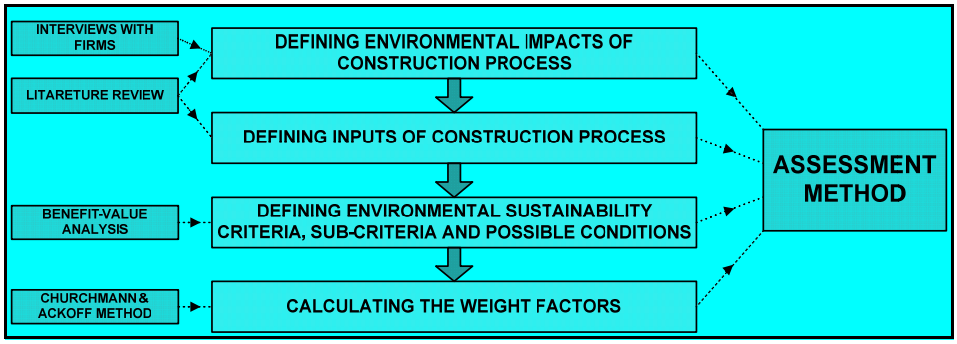

Figure 1: Development of Assessment Method.

Firstly, the author examined through literature review, the relation between the construction industry and environmental sustainability and designated environmental impacts of the construction process. Afterwards, the he analyzed the external wall systems. In this process, he analyzed different external wall systems constructed using different materials and construction techniques with queries applied to cladding firms, review of the firms' catalogues, websites and literature. At the end of this study, he defined inputs of construction process according to the different external wall systems. Finally, the study proposed an assessment method for assessing the effect of the construction techniques of the external wall systems on the environmental sustainability of construction process. Because of the lack of the quantitative data related to construction process, the study based the quantitative assessment method on subjective data, which allows the comparison of the different construction techniques. After analyzing the assessment methods by literature review, the study selected the "Benefit-Value Analysis" method and "Churchmann and Ackoff Method" to calculate the weight factors of the possible conditions (Tapan, 2004). According to the acquired data from the previous steps, criteria, sub-criteria and possible conditions, which affect the environmental impacts of construction process, were determined by following "Benefit-Value Analysis" method. The study specified the criteria as resource use, energy use, and human health and construction wastes.

The building industry should control the resource and energy use during construction process for it to be able to reduce environmental impacts. The construction industry consumed around 50% of all global resources (Edwards and Hyett, 2001, cited in Sev). All building activities involve the use, redistribution and concentration of some components of the earth's resources, such as water, energy and materials (Sev, 2008). In the construction process of external wall systems, resource and energy use relates with type of the construction and equipment; finishing level of the fixings and external wall system; labor training. Energy use relates also with material handling at

construction site (Metin, 2010). Type of the construction increases the amount of assembly by affecting the amount of work, material and energy spent. Type of equipment affects natural resource consumption. For instance, technological equipment causes more environmental damages and emissions by fuel-oil consumption. Type and finishing level of the fixings affects the resource used for preparing it. Anchorages can be used without need any extra preparation; however water and energy are used for preparing fixing components. Type of the fixings also affects the length of the installation time. Finishing level of the external wall system affects the amount of work. In case of the necessity of any extra application such as painting, sealing etc., the amount of work and installation time increase. Labor training directly relates to time, quality, energy and resource use. If we train workers for a specific installation and gain experience, the same job from trained worker will result in level that is more qualified in shorter time compared with an unskilled worker. This also prevents improper use of resource and energy. Material handling affects the use of resource by consuming or not consuming fuel oil according to the type of the equipment. Obviously, it is related with the dimensions and unit weight of the materials (Metin and Tavil, 2010).

Another issue is that the diverse environmental impacts during construction process can damage human health. Construction site conditions are important for the labors. Type of the fixing method affects the labors health directly. Fixing components can consist of dust, VOCs and other chemical components, which cause hazardous emissions and contamination. Noise control is another important problem of the construction sites, which also affects human health. Noise is not only affects the labor health but it also affects the people living in the neighborhood. Technological equipment increases the amount of noise while conventional equipment can decrease the amount of noise created (Metin and Tavil, 2010).

Wastes are one of the important problems of the environmental sustainability. The construction industry is facing a challenging problem of looking for landfill sites for construction and demolition waste (Peng *et al.*, 1997). However, in the context of the sustainability management of the construction wastes, reuse, remanufacturing and recycling should be the major concerns for the construction industry. Management of the construction wastes involves managing the works

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Table 1: Assessment table for construction techniques of external wall systems.

C	SC	PC	WF	T
I. RU	**A. Type of the construction**	I. No core	**0.51**	1
		II. Core (cast-in/masonry/frame)	**0.26**	
		III. Core + Sub-construction (vertical or horizontal)	**0.15**	
		IV. Core + Sub-construction (vertical and horizontal)	**0.08**	
	B. Finishing level of the fixing	I. Anchorage	**0.52**	1
		II. Fixing component	**0.30**	
		III. Anchorage + Fixing component	**0.18**	
	C. Finishing level of the cladding system	I. No extra application (joint sealant, painting etc.)	**0.77**	1
		II. Extra application (joint sealant, painting etc.)	**0.23**	
	D. Labor training	I. Trained labor	**0.77**	1
		II. Unskilled labor	**0.23**	
	E. Type of the equipment	I. Hand tools	**0.52**	1
		II. Hand tools + Electrical hand tools	**0.30**	
		III. Hand tools + Electrical hand tool + Engineering vehicle	**0.18**	
II. EU	**A. Type of the construction**	I. No core	**0.51**	1
		II. Core (cast-in/masonry/frame)	**0.26**	
		III. Core + Sub-construction (vertical or horizontal)	**0.15**	
		IV. Core + Sub-construction (vertical and horizontal)	**0.08**	
	B. Type of the fixing	I. Anchorage	**0.52**	1
		II. Fixing component	**0.30**	
		III. Anchorage + Fixing component	**0.18**	
	C. Finishing level of the cladding system	I. No extra application (joint sealant, painting etc.)	**0.77**	1
		II. Extra application (joint sealant, painting etc.)	**0.23**	
	D. Labor training	I. Trained labor	**0.77**	1
		II. Unskilled labor	**0.23**	
	E. Material handling at construction site	I. Conventional equipment / Manpower	**0.77**	1
		II. Electrical equipment / Engineering vehicles	**0.23**	
	F. Type of the equipment	I. Hand tools	**0.52**	1
		II. Hand tools + Electrical hand tools	**0.30**	
		III. Hand tools + Electrical hand tool + Engineering vehicle	**0.18**	
III. HH	**A. Labor health**	I. No emissions to the air (VOC, dust, etc.)	**0.77**	1
		II. Emissions to the air (VOC, dust, etc.)	**0.23**	
	B. Noise control	I. No engineering vehicle usage	**0.77**	1
		II. Engineering vehicle usage	**0.23**	
IV. CW	**A. Waste management**	I. Waste management plan	**0.77**	1
		II. Lack of waste management plan	**0.23**	
	B. Reuse	I. Appropriate construction technique for reusability	**0.77**	1
		II. Inappropriate construction technique for reusability	**0.23**	
	C. Recycling	I. Appropriate construction technique for recycling	**0.77**	1
		II. Inappropriate construction technique for recycling	**0.23**	
	D. Remanufacturing	I. Appropriate construction technique for remanufacturing	**0.77**	1
		II. Inappropriate construction technique for remanufacturing	**0.23**	

RU: Resource Use **EU:** Energy Use **HH:** Human Health **CW:** Construction Wastes
C: Criteria **SC:** Sub-Criteria **PC:** Possible Conditions **WF:** Weight Factor **T:** Total

of recycling, remanufacturing and reusing. The basic issues of management are the development of a site-specific waste management plan to include in the contract documents (Peng *et al.*, 1997). Reuse is associated with the reusability capacity of the materials. It is affected by the construction techniques of the external wall system. If the construction techniques cause less damage at the demolition phase, the materials and the fixings can be reused for another system. Recycling is also affected by the construction technique and the components of the external wall system. It is associated with recycling the materials, construction frames and connectors after the end of their useful life. Remanufacturing has the same purpose with recycling. However, it differs from recycling, since it means remanufacturing for the same function (Metin and Tavil, 2010).

After defining criteria, sub-criteria and possible conditions, weight factors of the possible conditions were calculated by using "Churchmann and Ackoff Method" which is recommended for the weight of individual preferences. Finally, assessment method consist of criteria, sub criteria, possible conditions and weight factors were composed (Table 1).

2.2 Developed Database

Developed database, named "Construction Technique Assessment (CTA)", is based on the developed assessment method, which aims to assist architects for comparing different construction techniques of external wall systems to be able to select most appropriate one for their design that have less impact on environment during construction process. For this purpose, a computer-based database was constituted by using Microsoft Office Access program. Database was designed by using tables that include data about the assessment method, components of external wall system, and material alternatives for components, construction techniques, external wall system alternatives and weighting factor results of different construction techniques according to each criterion.

3. Implementation of the CTA Database

CTA database allows users to assess the different construction techniques of external wall systems which were proposed in the context of the database to analyze environmental impacts of their construction process by following the forms of the database (Figure 2). In the context of the

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study, results for two of the proposed external wall systems were used to show the design and the use of the database.

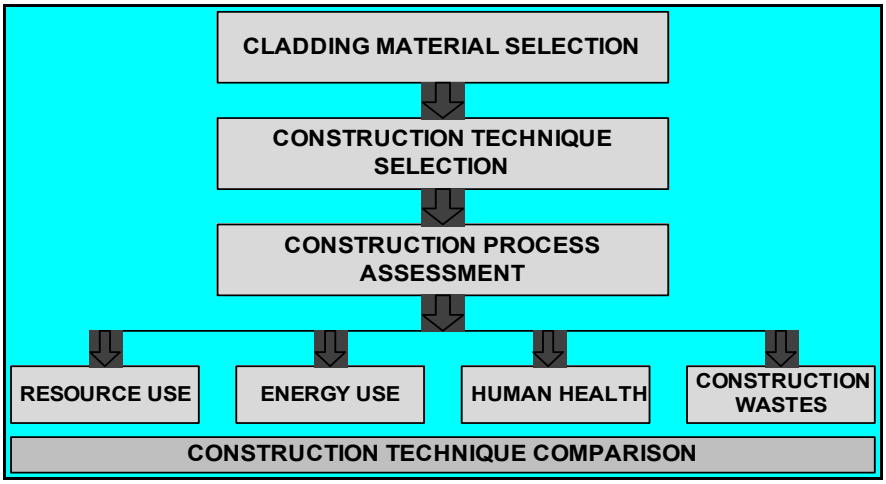

Figure 2: Use of CTA Database.

The CTA database opens through a form, which consists of two buttons as "Construction Technique Assessment 1" and "Construction Technique Assessment 2" to be able to reach the forms, which shows the results, easily (Figure 3).

Figure 3: Construction Technique Assessment (CTA) Database.

"Construction Technique Assessment 1" form was constituted to show the results for each of the external wall system alternatives according to different construction techniques individually (Figure 4). This form shows total weight factor results for each of the criterion according to different construction techniques of different external all system alternatives in one page. This form also shows a figure of relevant external system alternative with all of its layers.

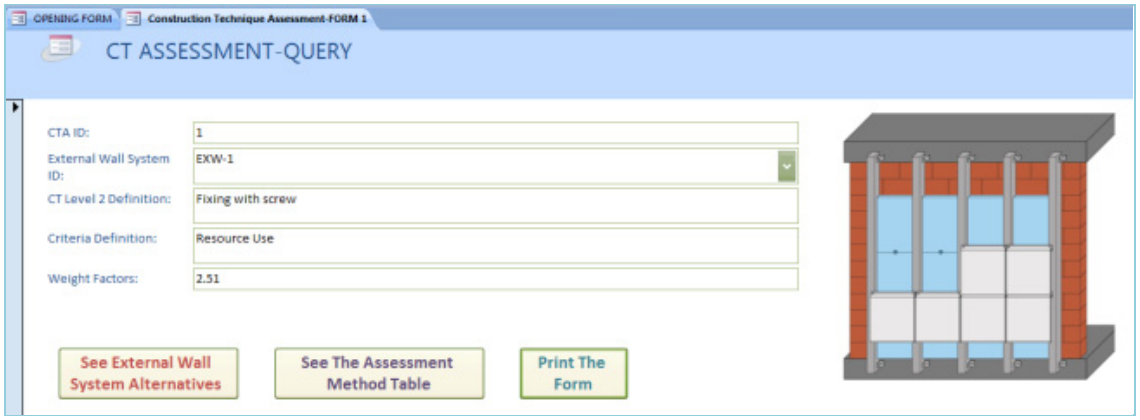

Figure 4: Construction Technique Assessment 1 Form.

Users can view details of the external wall system alternatives by clicking "See External Wall System Alternatives" button through this form. This table shows the material used for each of the external wall system alternatives and each of them can be reached by changing record numbers at the end of the page (Figure 5).

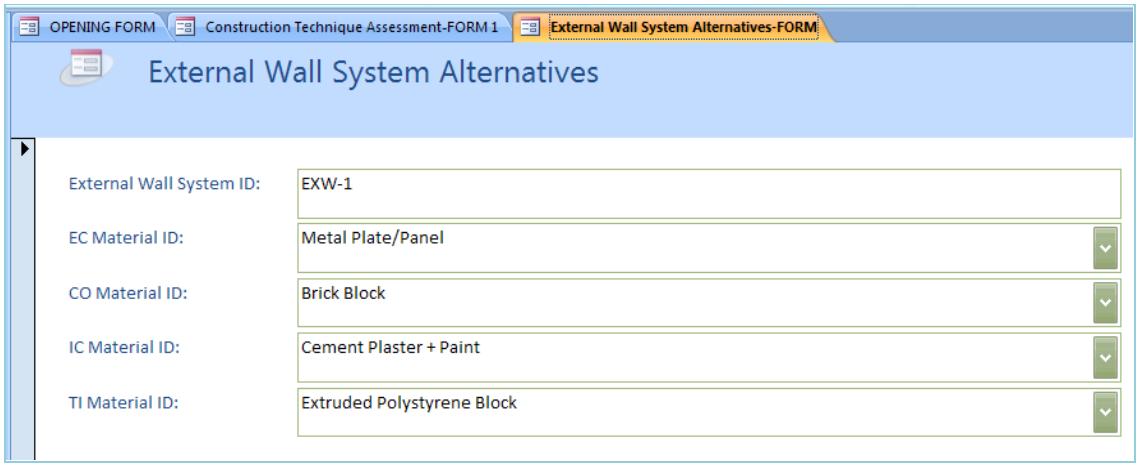

Figure 5: Form for External Wall System Alternatives.

If the user wants to acquire detailed information about the assessment system, she/he can view whole assessment method that consists of criteria, sub-criteria, possible conditions and weight factors, by clicking "See Assessment Method" button (Figure 6).

The second form, which can be reached by clicking the button on the opening form, is "Construction Technique Assessment 2". It was constituted to show all of the results for each of the external wall system alternatives for different construction techniques in one form. This form

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shows total weight factors of proposed external wall systems (Figure 7).

OPENING FORM | Construction Technique Assessment-FORM 1 | Assessment Level 3-Possible Conditions-QUERY

Possible Conditions ID	Possible Conditions Definition	Weight Factors	Sub-Criteria ID	Criteria ID
1	No core	0.51	Type of the Construction	Resource Use
2	Core (cast-in/masonry/frame)	0.26	Type of the Construction	Resource Use
3	Core + Sub-construction (vertical and horizontal)	0.08	Type of the Construction	Resource Use
4	Core + Sub-construction (vertical or horizontal)	0.15	Type of the Construction	Resource Use
5	Anchorage	0.52	Finishing Level of the Fixing	Resource Use
6	Fixing component	0.3	Finishing Level of the Fixing	Resource Use
7	Anchorage + Fixing component	0.18	Finishing Level of the Fixing	Resource Use
8	No extra application (joint sealant, painting etc.)	0.77	Finishing Level of the Cladding System	Resource Use
9	Extra application (joint sealant, painting etc.)	0.23	Finishing Level of the Cladding System	Resource Use
10	Trained labor	0.77	Labour Training	Resource Use
11	Unskilled labor	0.23	Labour Training	Resource Use
12	Hand tools + Electrical hand tools	0.3	Type of the Equipments	Resource Use
13	Hand tools + Electrical hand tools + Engineering vehicle	0.08	Type of the Equipments	Resource Use
14	Hand tools	0.52	Type of the Equipments	Resource Use
15	Core + Sub-construction (vertical or horizontal)	0.15	Type of the Construction	Energy Use
16	No core	0.51	Type of the Construction	Energy Use
17	Core (cast-in/masonry/frame)	0.26	Type of the Construction	Energy Use
18	Core + Sub-construction (vertical and horizontal)	0.08	Type of the Construction	Energy Use
19	Anchorage + Fixing component	0.18	Type of the Fixing	Energy Use
20	Anchorage	0.52	Type of the Fixing	Energy Use
21	Fixing component	0.3	Type of the Fixing	Energy Use
22	No extra application (joint sealant, painting etc.)	0.77	Finishing Level of the Fixing	Energy Use
23	Extra application (joint sealant, painting etc.)	0.23	Finishing Level of the Fixing	Energy Use
24	Unskilled labor	0.23	Labour Training	Energy Use
25	Trained labor	0.77	Labour Training	Energy Use
26	Conventional equipments / Manpower	0.77	Material Handling at Construction Site	Energy Use
27	Electrical equipments / Engineering vehicles	0.23	Material Handling at Construction Site	Energy Use
28	Hand tools	0.52	Type of the Equipments	Energy Use
29	Hand tools + Electrical hand tools	0.3	Type of the Equipments	Energy Use
30	Hand tools + Electrical hand tools + Engineering vehicle	0.18	Type of the Equipments	Energy Use
31	No emissions to the air (VOC, dust, etc.)	0.77	Labour Health	Human Health
32	Emissions to the air (VOC, dust, etc.)	0.23	Labour Health	Human Health
33	No engineering vehicle usage	0.77	Noise Control	Human Health
34	Engineering vehicle usage	0.23	Noise Control	Human Health
35	Waste management plan	0.77	Waste Management	Construction Wastes
36	Lack of waste management plan	0.23	Waste Management	Construction Wastes
37	Appropriate construction technique for reusability	0.77	Reuse	Construction Wastes
38	Inappropriate construction technique for reusability	0.23	Reuse	Construction Wastes
39	Appropriate construction technique for recycling	0.77	Recycling	Construction Wastes
40	Inappropriate construction technique for recycling	0.23	Recycling	Construction Wastes
41	Appropriate construction technique for remanufacturing	0.77	Remanufacturing	Construction Wastes
42	Inappropriate construction technique for remanufacturing	0.23	Remanufacturing	Construction Wastes
*		0		

Figure 6: Query for Assessment Method.

OPENING FORM | Construction Technique Assessment-FORM 2

CT ASSESSMENT-QUERY

CTA ID	External Wall System ID	CT Level 2 Definition	Criteria Definition	Weight Factors
1	EXW-1	Fixing with screw	Resource Use	2.51
2	EXW-1	Fixing with screw	Energy Use	3.28
3	EXW-1	Fixing with screw	Human Health	1.54
4	EXW-1	Fixing with screw	Construction Wastes	2.54
5	EXW-1	Hanging with special elements	Resource Use	2.66
6	EXW-1	Hanging with special elements	Energy Use	3.21
7	EXW-1	Hanging with special elements	Human Health	1.54
8	EXW-1	Hanging with special elements	Construction Wastes	2.54
9	EXW-2	Fixing with screw	Resource Use	2.51
10	EXW-2	Fixing with screw	Energy Use	3.28
11	EXW-2	Fixing with screw	Human Health	1.54
12	EXW-2	Fixing with screw	Construction Wastes	3.08
13	EXW-2	Adhesive joining	Resource Use	1.63
14	EXW-2	Adhesive joining	Energy Use	2.4
15	EXW-2	Adhesive joining	Human Health	1
16	EXW-2	Adhesive joining	Construction Wastes	2.54
17	EXW-4	Hanging with special elements	Resource Use	2.17
18	EXW-4	Hanging with special elements	Energy Use	3.21
19	EXW-4	Hanging with special elements	Human Health	1.54
20	EXW-4	Hanging with special elements	Construction Wastes	3.08
21	EXW-4	Adhesive joining	Resource Use	1.86
22	EXW-4	Adhesive joining	Energy Use	2.63
23	EXW-4	Adhesive joining	Human Health	1
24	EXW-4	Adhesive joining	Construction Wastes	1.46

Figure 7: Construction Technique Assessment 2.

The main aim of CTA database is to compare different construction techniques during a decision process at design phase. In the context of the CTA database, pivot charts can be used for assessing and comparing different construction techniques, which were previously stored to the CTA database. These charts can be generated by using "Construction Technique Assessment-QUERY" which shows total weight factors for each of the criterion and users can select the external wall systems they want to compare from this query screen. For this purpose, two kinds of charts can be provided. Firstly, same construction technique can be compared for different external wall systems (Figure 8). In addition, different construction techniques of an external wall system can be compared (Figure 9).

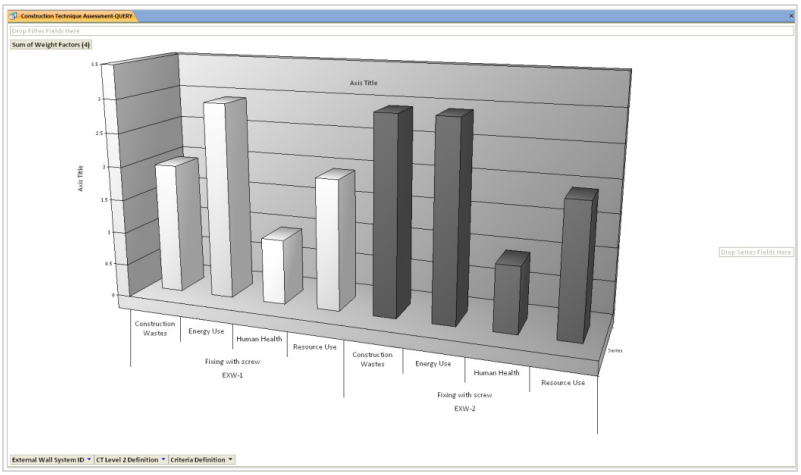

Figure 8: Comparing Same Construction Technique - Fixing with Screw - According to Different External Wall Systems - EXW 1 and EXW 2.

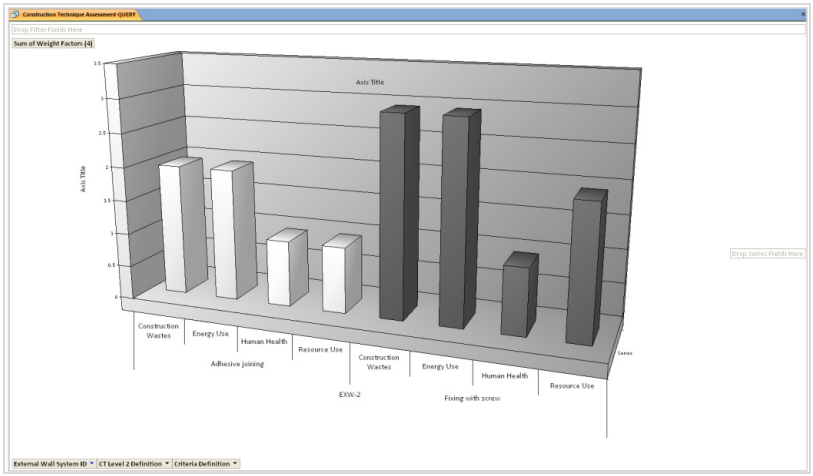

Figure 9: Comparing Different Construction Techniques - Fixing with Screw and Hanging with Special Elements - for EXW 1.

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4. Conclusion

Construction industry started to realize the share of the buildings on environmental problems. Some tools and assessment systems were developed and used for environmental assessment of buildings. Nevertheless, the tools and system generally left out the construction process of the scope and they mostly focus on the use phase of the buildings. Despite the fact that construction process comprises a short time period of the building life cycle, it affects the environment and human. For this reason, the optimum decisions during design process are important to be able to reduce environmental impacts of buildings not only in use phase but also in the construction process. This study presents a database, which was developed based on an assessment method on construction techniques of external wall systems to reduce environmental impacts at construction process. The CTA database was designed to assist architects during design process to assess and compare different construction techniques of external wall systems to reduce environmental impacts of construction process. For this purpose, an assessment method developed in the context of a master thesis was used as the basis of the database. According to this method, effect of external wall systems' construction techniques on environmental impacts of construction process is assessed through four basic criteria, which were defined as resource use, energy use, and human health and construction wastes. The CTA database consists of some proposed external wall system alternatives and their total weight factors as assessment results according to the developed assessment method. By using the CTA database, architects can compare different construction techniques of the proposed external wall system and select the optimum solution for their design.

However, the database should be developed by considering more construction techniques and external wall systems to be used more efficiently. In addition, it should consist of other building elements and their construction techniques for a holistic decision approach. For this purpose, first of all assessment method will be improved concerning other building elements and then database will be developed to be consists of alternatives of building elements and their results of construction techniques according to the assessment method.

5. Acknowledgements

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