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A Concept to Assess the Economic Importance of the On-Site Activities of ETICS

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***Abstract*—**Construction technology and on-site construction activities have a direct influence on the life cycle costs of energy efficiently renovated apartment buildings. The systematic inadequacies of the External Thermal Insulation Composite System (ETICS) which occur during the construction phase increase the risk for all stakeholders, reduce mechanical durability and increase the life cycle costs of the building. The economic effect of these shortcomings can be minimised if the risk of the most significant on-site activities is recognised. The objective of the presented ETICS economic assessment concept is to evaluate the economic influence of on-site shortcomings and reveal their significance to the foreseeable future repair costs. The model assembles repair techniques, discusses their direct cost calculation methods, argues over the proper usage of net present value over the life cycle of the building, and proposes a simulation tool to evaluate the risk of on-site activities. As the technique is dependent on the selected real interest rate, a sensitivity analysis is anticipated to determine the validity of the recommendations. After the verification of the model on the sample buildings by the industry, it is expected to increase economic rationality of resource allocation and reduce high-risk systematic shortcomings during the construction process of ETICS.

***Keywords*—**Activity-based cost estimating, Cost estimation, ETICS, Life cycle costing.

I. Introduction

THE construction industry is described with high uncertainty which influences the decisions of each stakeholder during the life cycle of the building. The risk is directly linked to the costs of the project, which is increasing with higher uncertainty. Building lifecycle expenses are influenced by the quality of on-site building process [1]. The repair costs of the shortcomings take more effort and resources in comparison to their avoidance during the primary installation process. Due to this snowballing economic effect, it is relevant to specify which activities have high impact to the owner of the building and how to conduct the tradeoff between the future repair costs and increase quality cost in the early construction phase. By revealing the economic significance, the resources can be allocated to the high-risk activities.

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II. Life Cycle Costing

Life cycle costing (LCC) approach origins from normative neoclassical economic theory and is developed due to deficiencies in the process of cost management [2], [3]. It aims to optimize the value for money by considering different cost factors which are present during the operational life of the building. The theory seeks the most economical investment program with multiple factors [3]. The smart trade-off between relevant factors can provide minimum cost of the asset.

LCC is a process beginning with the first considerations of the capital investment and is continuous until disposal of the life cycle (Fig. 1). It aims to optimize the cost for purchase, building, operating and wasting of the asset by revealing and quantifying significant cost factors [4]. The present value method enables to reveal optimal configuration of the trade-off elements, which can ensure optimum outcome.

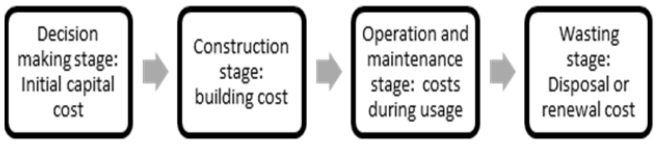

Fig. 1 Project structure diagram of the life cycle costs

In principle, LCC reflects various expenses in each phase of the building, considering the discount rate to reveal net present value during the estimated lifetime [3]. Mathematically it is expressed in (1):

$$LLC_j = C_0 + C_c + C_M + C_D \qquad (1)$$

LLC_j – Initial function of the life cycle costs, C_0 – Decision making cost, C_c – Construction cost, C_M – Maintenance and operation cost, C_D – Wasting cost or selling price

One of the fundamental philosophies of LCC analysis is that initial capital can be traded off against subsequent savings. Woodward [4] has argued that the capital increase reduces costs during maintenance and operational phase. Skitmore and Martson [5] have stated more clearly that construction technology and quality are in correlation to cost. It can be concluded that focused resource allocation increases the common value. The optimum is achieved when the factor expenditure has the lowest value.

The usage of the LCC concept in the construction industry is limited due to a significant amount of uncertainty. The usefulness of rational decision making is decreased as the uncertainty increases, and the concept is, therefore, oversimplified. The historic or predicted data reliability, complexity of building process and economic and political changes during the life cycle are the reason for these doubts. Value maximization is highly dependable from the availability and reliability of the information. Glunch and Baumann [2] have argued that individuals do not make rational decisions under uncertainty and complex conditions. However, there are still benefits which have an influence on better decision-making outcome in the case of reduced amount of factors. To appreciate enhanced quality decisions the LCC approach is still recommended [4].

III. Trade-Off between Quality and Cost

The traditional trade-off in project management concerns time and cost [6]. Babu and Suresh [7] have argued that quality problems need to be taken into account to achieve a project's success for the stakeholder. The limited amount of achievement criteria in "The Iron Triangle" model is the trade-off basis which can be optimized to maximize value to the owner. The minimum principle of the alternatives is considered when deciding resource allocation.

The advanced model of this research aims to reveal the economic potential of construction activities of ETICS which could be allocated to increased quality assurance while enhancing economic value. The focus is set on the trade-off between construction quality and future repair costs during operational phase (Fig. 2). With this simplification, the element of time is not taken into account.

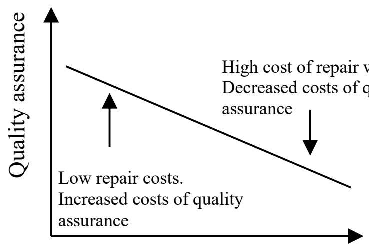

Fig. 2 Structure diagram of the trade-off components

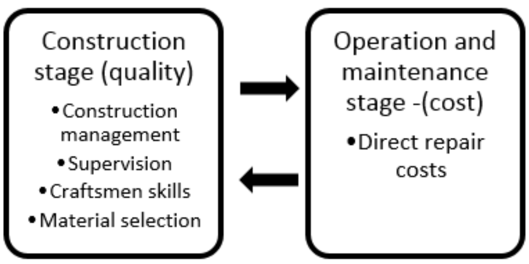

Fig. 3 Trade-off relationship between cost and quality

The quality element is defined as the cost of measures which can decrease or increase the appearance of degradations after the construction phase. The knowledge enables to quantify the efficiency of control. The measures can be smarter construction management, improved craftsmen skills, better material selection or increased supervision during application.

The cost element can be transformed into monetary units by the removal of degradations. The economic value of each repair activity (cost element) is related to the shortcoming during the construction phase (quality element) (Fig. 3). To avoid future degradations resources (quality element) can be applied to the high-risk activities if they are known.

IV. The Trade-Off in the Economic Assessment Model

To reveal the optimum value a procedure to establish the life cycle costing formula is proposed by Harvey [8]. The general procedures of the LCC technique (Fig. 4) divides the costs into cost elements, organizes the cost structure, defines critical cost relationships and proposes an economic evaluation formulation. The relationships of the trade-off elements reveal optimized LCC calculation method.

Fig. 4 Harvey's [8] life cycle costing procedure

The two cost elements are, as previously described, the cost of repair and quality assurance. The complexity of the model lies in the specific determination of the cost structure of repair methods which can be traded off to achieve optimum LCC.

V. Cost Elements of Repair Costs

A. Description of Cost Elements

Cost elements are the cash flow items that occur and are relevant for the results of the study. The construction cost is a function of numerous variables. The independent variables are measurable and define each new construction activity.

Each task has specific requirements on the resources, and the costs are shown as direct costs. The sequenced individual tasks with the durations and resources give the project needs for the resources. To complete a task estimated resources must be allocated. The duration of individual tasks is based on assumed equipment and labor productivity rates.

The cost of each task is a composition of direct and indirect costs. The indirect costs are the expenses which have no specific physical activity and the expenses which cannot be linked to a specific project [9]. Due to the aim of the research only direct costs, which are traceable to the action in an economical method, are used. If the specific activity is not performed, the costs are not seen as direct costs. Therefore the direct expenses of the project, which would not have been occurring if the project were not active, are considered as an indirect cost. Small costs which cannot be traced to specific activity are estimated as a percentage of the direct costs or a cost per unit.

Construction direct costs and the trade-off elements are equipment, labor, and materials.

B. Components Explosion

The comparison between the on-site building and repair process has an end product which is described and structured as a collection of tasks, composed by elements or additional sub-tasks (Fig. 5). The research design is basing on the bill of quantities method, which enables to include information like individual rates of items, overall costs with single price methods for approximate estimation (per unit) or costs based on a basic price list if available.

The major costs and the sources of uncertainty need to be identified. The objective of the estimation is to ensure that the right components - materials, equipment, and labor, are accurately applied and in right quantities. Therefore, characteristics and the amount of the components must be determined.

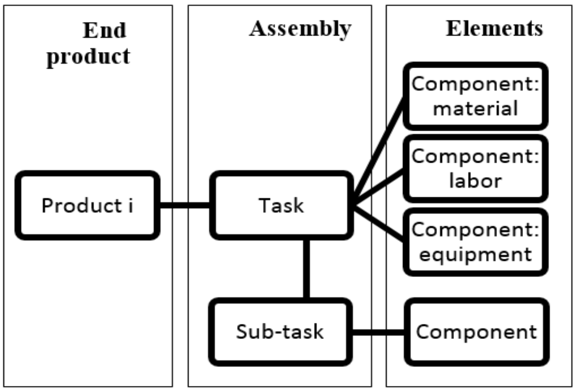

Fig. 5 Construction structure of an end product

Construction planning must address assemblies (tasks), and components to be delivered. Components can be purchased or constructed. Assemblies are made eventually from components, and as all required assemblies are done, the end product is complete (Fig. 6). To divide cost elements in a structured way the "components explosion" is conducted [10].

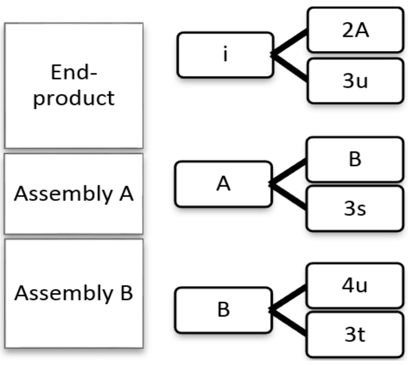

Fig. 6 Sample construction structure of an end product

VI. Economic Evaluation of ETICS

A. Identification of the End-Products

End-product is the final output of the repair activities and is determined by the diagnosis of the occurring degradation. The repair methods can be found in the literature or be defined using actual construction activities. As the methodology is developed for ETICS, the scope of works is specified by the affected layers [11]. German professionals thoroughly describe the repair methods for ETICS [12], and they are reliable for the proposed economic assessment model. The concept for the economic model can be defined if the failing layer, the area size of the defect and layers affected by the repair works are identified.

For the economic assessment model, a distinction is made by the size of occurring problem due to the marginalization of specific elements. The area size of the works can be partial *P* or large *L*. Partial replacements, and specific anomaly eliminations are belong to category *P*. Covering and whole system replacements in category *L*. To reveal the economic effect partial, the size is $1m^2$ or 1m for linearly characterized defects.

The repair methods are dependable from the anomaly occurring layer L_n. The layer description n can be substrate *s*, adhesive *a*, insulation *i*, mechanical fixing *m*, reinforcement *r*, finishing coat *f* or additional details *d*.

The structured ETICS repair methods are additionally described by the layers which are influenced by the proposed repair method. The mark X in Table I presents the defected layer for specific repair method.

TABLE I
Defect Layer and Repair Method Matrix

ID	End-product description	L_s	L_a	L_i	L_m	L_r	L_f	L_d
$R_{L,C1}$	Covering: cleaning, coating						X	
$R_{L,C2}$	Covering: cleaning, disinfection, coating						X	
$R_{L,C3}$	Covering: cleaning, crack filling or crack-bridging coating						X	
$R_{P,R1}$	Partial: render						X	
$R_{P,R2}$	Partial: render, reinforcement				X	X		
$R_{P,R3}$	Partial: render, reinforcement, insulation	X	X	X				
$R_{L,S1}$	System: render						X	
$R_{L,S2}$	System: render, reinforcement				X	X		
$R_{L,S3}$	System: entire system	X	X	X				
$R_{P,A1}$	Specific: additional adhesive		X					
$R_{P,A1}$	Specific: additional anchoring				X			
$R_{P,A1}$	Specific: connections/joints							X
$R_{P,A1}$	Specific: moisture penetration							X

B. Identification of the Assemblies

Each of the repair methods (i.e. end-product) requires specific activities (i.e. assemblies) A_n to be completed. Repair methods are divided into tasks. Table II illustrates the task requirements for repair group R_P. The tasks marked with X are required to be complete the assembly.

C. Element Identification

Assembly is a set of elements which work together in unison to complete the required work. They can be materials $E_{M,n}$, labor $E_{L,n}$ or equipment $E_{E,n}$. Each element has expected consumption rates. The element's list entirety and consumption rates are summarized from various studies in this field. A sample list for the assembly A_6 is shown in Table III.

The validation of the consumption rates will be checked and confirmed by four external experts.

The final element files contain the input data required for the bill of quantity matrix.

TABLE II
ASSEMBLY REQUIREMENTS FOR METHOD END-PRODUCT $R_{L,C}$

ID	Assembly description	$R_{P,R1}$	$R_{P,R2}$	$R_{P,R3}$
A_1	Clear cut through insulation layer and removal of detached area			X
A_2	Clear cut through reinforcement layer and removal of detached block		X	
A_3	Removal of detached plaster, cleaning the surface	X		
A_4	Opening the reinforcement mesh around the cavity ca 10cm		X	X
A_5	Removal of plaster around the revealed mesh - ca 5cm		X	X
A_6	New insulation material application with proper adhesive and anchorage			X
A_7	Filling of the opened joints of insulation plates with PU-Foam (joints up to 10mm) or insulation strips		X	
A_n	Task A_n description	…	…	…

TABLE III
ELEMENTS AND CONSUMPTION RATES FOR ASSEMBLY A_6

ID	Element description	Unit	Quantity
$E_{M,1}$	Insulation Material	m^3	0,24
$E_{M,2P}$	Adhesive for polystyrene	kg/m^2	8
$E_{M,2M}$	Adhesive for mineral wool	kg/m^2	12
$E_{M,3}$	Mechanical anchor	pcs/m^2	8
$E_{L,1}$	Skilled laborer	m^2/h	0.4
$E_{M,n}$	Element $E_{M,n}$	…	…
$E_{L,n}$	Element $E_{L,n}$	…	…
$E_{E,n}$	Element $E_{E,n}$	…	…

D. Relating the Elements with the Bill of Quantity

The elements of each end-product are collected and presented with the bill of quantity method which is expressed by the formula (2). The end product i is defined by the row vector $P^i = (p_{i1}, p_{i2,\ldots,} p_{ij})$. p_{ij} is the number of components of item j required to construct one unit of item i. The column vector of P^i is the bill of quantity matrix.

The complete list of the bill of quantity for the final product is a sum of all n-stage requirements. R is the total requirement matrix and R^i is the row vector for requirement i. r_{ij} is the total amount of items j required to create one unit of item i. Both, the units which enter directly and indirectly are considered. If $i = j$, then $r_{ij} = 1$.

$$r_{ij} = \sum_{k=1}^{n} p_{ik} r_{ik} \quad (2)$$

As the structure is ordered, the highest level is the end product. The assemblies and elements are shown in a relationship to the end-product. The level structure projects the bill of quantity matrix [10]. The bill of quantity based on the sample construction structure described in Fig. 6 is shown in Table IV.

The alterations in the economy have a drastic influence on the results of the proposed economic assessment model. To keep the model valid, the price elements and key parameters are changeable by the user. The selected freedom of choice enables to use up to date company specific data.

TABLE IV
BILL OF QUANTITY MATRIX

	i	A	B	u	s	r
i	-	2	-	3	-	-
A	-	-	1	-	3	-
B	-	-	-	4	-	5

E. Cost Estimation by the User of the Model

The practical value is a combination of judgment, professional experience and a matter of relevant data. The information can come from historic data, detailed analysis of the construction process, the user's best guess or a combination of them [9].

To keep the model valid the cost and key parameters are changeable by the user. Key parameters are the quantities specific materials which have proportionally high influence to the results (for example the thickness of insulation material).

The flexibility of cost is required due to a periodic market and the geographical location conditioned particularities. The model is developed with the aim of enhancing decision making to increase the value to the stakeholders. The requirement to compare the results, the estimated costs of the elements contain only the basic cost and the markup, while other possible considerations that are directly not linked to construction activity are not taken into account.

VII. VERIFICATION OF THE ECONOMIC MODEL

The data collection requires validating the end-product to be sure the proposed technologies are used on the market, to verify the assemblies and quantities, and to verify the model to reveal the possible scope of the trade-off.

The end-product is the repair technique used to eliminate degradation cause. As the technologies are described by various authors [13]–[17] additional validation in not required.

The verification of assemblies and quantities has the key influence on the outcome of the model. The applicability of the proposed data is assured by three external experts from the industry. The experts can accept or proposed corrections. The data is considered verified when all three experts confirm that the information applies to the industry.

After the data is proven to be reliable to the industry, two case studies will be conducted to verify the results of the models on two markets. The case study is based on apartment buildings which have signs of degradation. The deterioration of ETICS will be diagnosed and repair technique assigned. Based on the acting company prices, the simulation will be conducted with the proposed economic assessment model and simultaneously by the external expert of the acting company. The model is verified if the difference of the calculation method is less than 10%.

VIII. Limitations

The limitations of the proposed simulation must be taken into account when applying the results during the decision-making process. The model is strictly revealing the costs of further repair activities to enable to simulate the trade-off costs. The suitable quality assurance method shall be decided by the user of the model. The calculated value can be affected by physical, business or environmental uncertainty, and therefore, the outcome can alter in time. To reduce the risk, the costs are changeable by the user. In the case of the emergence of new technologies the assemblies and their elements should be updated. For example, new construction materials may alter the relative significance of the costs.

Although direct costs are taken into account, the overhead costs are excluded, and the prices in the model are basing on the present value. As the capital to eliminate degradation causes are most probably used during the next years, the changes in the value of monetary units can be taken into account by using additional net present value method. The costs inserted by the decision maker need consider the variations of prices depending on the size, type, and the location of the project.

IX. Conclusion

ETICS can be used to modernize and increase the energy efficiency of existing and new buildings. The intensive on-site construction process intensifies the occurrence of minor inadequacies. These inadequacies turn up as degradation signs and require additional resources for their elimination after the completion of construction works.

The proposed economic assessment model describes the concept of a tool which simulates the cost of repair in the operational phase of the building. The result of the simulation enables to enhance rational decision-making for quality assurance during the application process. The proposed resource allocation information supports the decision makers to increases the joint value of the building by maximizing the quality of on-site construction activities and reducing repair costs.

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