

OPTIMIZATION OF FACADE WALL BUILDING SYSTEMS IN WALLOON REGION

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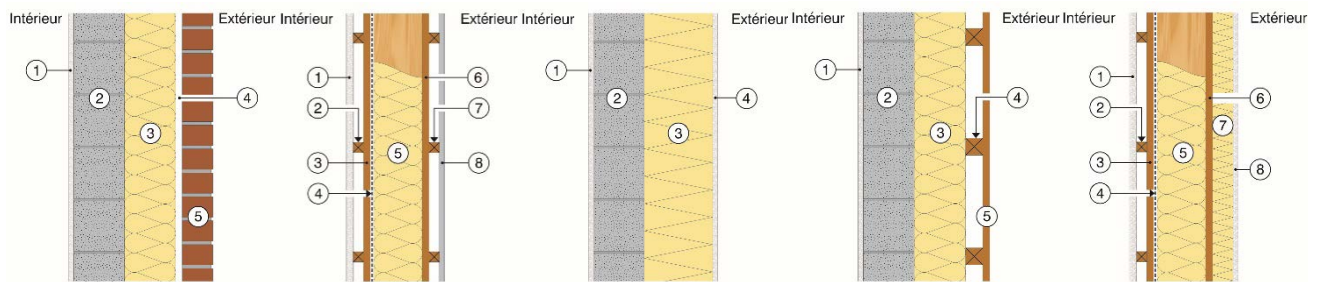


Fig 1: Detail drawings of analysed facade wall building systems

DESIGN FOR AFFORDABILITY AND MARKET APPEAL

DESIGN SAFE, COMFORTABLE AND HEALTHY ENVIRONMENT

DESIGN FOR DURABILITY AND FLEXIBILITY

Research summary

As our society experiences a significant demographic expansion, 350 000 new households in Wallonia will need to be erected by 2040. However, the Belgian index of construction costs is constantly increasing due to building lots scarcity and high requirements in terms of energy efficiency. A funding problem appears as the Walloon average income has not improved, hence the need to control building costs in order to offer quality accommodation for everyone. This two year research aims to create a support tool reducing costs of new buildings without jeopardizing comfort, structure or durability. Three action plans are set in order to achieve this goal: the optimization of wall building systems, the development of more efficient habitation practices and the restructuration of the organizational model of building companies. The present paper states the first action plan of the study, namely the optimization of the wall building systems. The final objective of this first step is to highlight the factors impacting significantly on wall prices and to offer more economical or ecological solutions. During this first step, the authors defined the most used building systems for each type of wall. They determined some relevant variants of the reference building system and established their price and environmental performances. At the present time, the research compared only facade wall building systems. As of yet, the results are not extensive enough to draw definitive conclusions. However, preferential choices are presented providing relatively good environmental and economical performances. More general findings have also been highlighted but still require verification; for instance, the larger the amount of different layers that are assembled in a building system, the higher its price will be. Additional analyses are needed to extract aspects that will have a decisive role in the optimization task.

Keywords: optimization, comparative analysis, building systems, environmental and economic characteristics, façade wall

1. Introduction

The Walloon region is affected by demographic growth: its population will reach 4 million people by 2040. Hence the need to develop housing quickly in order to fulfill the demand of the 350,000 additional households. (Duyck et al, 2014)

However, housing prices are constantly increasing. On the one hand, building lots scarcity is responsible for the high land prices and on the other hand, construction costs tend to grow due to stricter energy regulations. Building techniques become increasingly difficult to implement, impacting significantly on prices. According to CSTC sources, this impact is about 10% of the total building cost.

Therefore, building new housing becomes a challenge for households whose income does not follow the curve of construction price inflation. SPF economy information sources establish that the average income for a household is € 6,000 gross per month. This monthly salary allows to fund, via a loan, an amount of around € 200,000 in 20 years. If we deduct the price of the land plot, VAT, architect's fees, etc., the available amount for the building costs arises to around € 110,000. Besides the need for providing own funds, this amount does not suffice in order to build a new housing project in the Walloon region. This trend is confirmed for the Flemish region. (Albrecht and van Hoofstat, 2011).

This situation could have a short term impact on the activity of construction companies which are already under great pressure. If the first reason of this pressure is the economic crisis, Belgian companies are also facing competition from Eastern European and South American companies, which benefit from much

lower labor costs and higher productivity. Belgian companies counterbalanced low productivity by cutting profit margins, but since 2012, employment rate is the next on the list.

This paper starts by introducing the general objectives of the research project and its three action plans. Then, it details the method used to tackle the first action plan by which the authors addressed the issue. Finally, results emerging from the first analyses will be presented and discussed to provide a conclusion to the first step of this research.

2. Research objectives

The general task of this research is to provide a design support tool to help reduce construction costs and to write recommendations intended for builders and other construction companies. To achieve this goal, three topics will be studied to provide solutions at various levels.

2.1 Building systems optimization

For the research needs, housing is divided into two types, namely individual and collective housing. Building systems, ways of living, possibilities of scale economies, management, etc., are not similar for both types; it is therefore necessary to address them separately. Several reference cases are established for each type to represent the current state of construction in the Walloon Region.

The economic and environmental impacts of the choice of the building system will be studied through an analysis comparing various building systems to the reference ones. By building system we mean a combination of materials implemented to perform a function.

2.2 Efficient habitation practices

In order to minimize the financial investment needed to build housing, the pooling principle is certainly an element to study because it is currently being developed through concepts such as community land trust, crowdfunding, etc. The authors will therefore analyse the economic impact of scaling factors and opportunities for costs sharing. To do this, they will look at a range of alternatives in terms of space management, equipment and infrastructure sharing and systems operation.

In the end, this task aims to give an overview of feasible pooling gains, depending on the housing type and the project scale.

2.3 Organizational structure of companies

This task is intended first to optimize the management and organization mode of the building process. To get there, a list of hypothetical costs caused by inefficiencies of supply, site preparation, purchase, execution and end site analysis phases has to be defined.

Secondly, the task aims to stimulate another approach of the construction sector business models. Business models from various sectors will be reviewed in order to draw principles applicable to each construction sector.

The proposed solutions should generate new profit margins through innovative ideas and be realistic vis-à-vis the construction sector specificities.

In order to achieve the central objective, the authors started with the first action plan. The following section of the paper describes the method used to tackle building systems optimization. Then, results regarding the optimization of façade walls of individual housing are explained and discussed.

3. Method

To optimize building systems, it was decided to compare the variants of each wall from an economic and an environmental point of view. In this context, "wall" means any flat building component used as a separation between rooms, floors or between inside and outside.

At the comparison basis, reference cases for individual and collective housing are determined. They illustrate the current situation of new housing in Wallonia.

3.1 Definition of reference building systems

The definition of reference cases was not conducted in exactly the same way for both types of housing. In this paper, only the method to define individual housing reference cases is explained since the first analysis focused on this housing type.

First, the authors collected standard specifications of turnkey houses from several companies. The turnkey house is a frequently chosen solution in the Walloon region due to building process efficiency and competitive prices.

Several building systems of turnkey houses have been listed by type of wall: groundfloor slabs, floor slabs, facade walls, structural partition walls, non-structural partition walls, gable roofs and flat roofs. The most recurring building system for each type of wall was used as the reference system for individual housing (see Fig 2).

3.2 Definition of variants

To determine building systems varying from the reference ones, the authors began by creating two categories of building systems: heavy and lightweight structures.

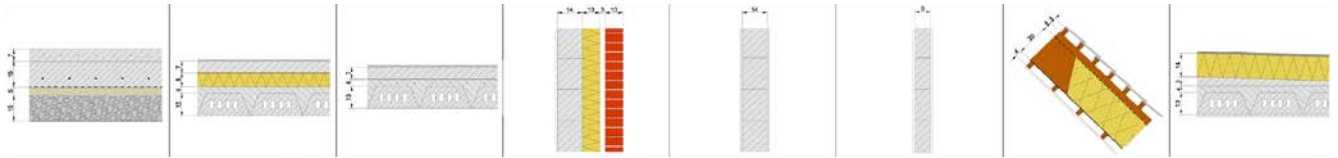


Fig 2: Reference building systems for individual housing

Then they reviewed several possible choices in terms of finishings, facings and insulations. For instance, five kinds of building systems were considered for facade walls (see Fig 1):

- heavy structure + masonry facing;
- heavy structure + cladding;
- heavy structure + external coating;
- lightweight structure + cladding;
- lightweight structure + external coating.

By diversifying materials in the building systems, a significant number of variants for each wall building systems can be achieved for the following comparative analysis.

3.3 Evaluation of building system characteristics

The comparison of building systems is based on two main characteristics: the estimated price per square meter of the wall and its ecological performances. To achieve an objective analysis, the authors decided to compare systems that rival in terms of energy performance. The insulation thickness of each system was adjusted so that the heat transfer coefficient was always the same value, namely $U = 0,24 \text{ W/m}^2\text{K}$. All the compared building systems have the same energy performance.

To determine the price per square meter of the various systems, the “Borderau des prix unitaires” (Ketelaer and Ramette, 2013) was used. This reference guide offers price ranges, VAT excluded, for the supplies and the current implementation of common techniques and

materials in Belgium. This way, the authors managed to establish a minimal and maximal price per square meter for each building system.

As regards the definition of the environmental characteristics, the environmental and health assessment tool for building components developed in S. Trachte’s PhD thesis (Trachte, 2012) was used. This tool is based on a global approach of material and system life cycle. It uses databases from other LCA tools such as Ecoinvent, Ecosoft and KBOB to evaluate three main environmental characteristics, namely the environmental performance through quantitative indices such as grey energy [MJ/m^2], greenhouse effect [$\text{kgCO}_2\text{eq./m}^2$], air acidification [$\text{kgSO}_2\text{eq./m}^2$] and ground-level ozone [$\text{kgC}_2\text{H}_2\text{eq./m}^2$]; the resources used and the potential for recycling materials through qualitative indices.

3.4 Comparison

The comparative analysis of wall building systems stands on several quantitative and qualitative criteria. To compare the quantitative criteria such as grey energy, greenhouse effect, air acidification, ground-level ozone, minimum and maximum surface price, the authors developed a formula assigning a score by means of points to each variant by criterion. For each quantitative criterion, the formula sets the average value of the results of all compared building systems as the reference point (0 points) and establishes a scale with points spreading from -5 to +5.

$$P_{ij} = \frac{-5 \left[\left(\frac{x_{ij}}{x_j} * 100 \right) - 100 \right]}{\max_{1 \leq i \leq n} \left[\left(\frac{x_{ij}}{x_j} * 100 \right) - 100 \right]}$$

With :

P_{ij} = amount of points gained by the i^{th} building systems variant for the j^{th} quantitative criterion;

x_{ij} = result for 1 square meter of wall obtained by the i^{th} building system variant for the j^{th} quantitative criterion.

The addition of the points of the different criteria allows defining the ecological and economic performance of each building system on a similar value scale.

Comparison of qualitative criteria such as nature, characteristics and origin of the material resources or recycled content, recyclability, assembly mean and industry situation involves their translation to a quantitative scale. Indeed, the tool developed by S. Trachte provides a color scale composed of six grades going from very bad (red) to very good (green). The authors translated this qualitative scale into a quantitative one with points spreading from -5 to +5, as presented in Fig 3.



Fig 3: Correspondence system between the color scale and the scale of points

4. Results

This section presents the results of the comparative analysis of five building systems of

façade walls for individual housing. The differences between the final score obtained by each variant are explained for both the economic and environmental characteristics. The results are provided in a large table (see Fig 4). For each one of the variants, the table gives physical characteristics (description of the layers, detailed drawing, thickness and amount of material per square meter), environmental characteristics (potential for recycling, resources used and environmental performance) and economic characteristics (price per square meter).

The authors analysed the four variants as well as the reference building system, namely a heavy structure and a masonry facing, separated from the polyurethane insulation layer by a ventilated cavity. The four other systems vary either the structure (timber frame) or the facing (cladding or external coating) or the insulation. These five systems have thicknesses ranging from 29,5cm to 45,5cm. The amount of material used is around 90 kg/m² for a timber frame and between 200 and 350 kg/m² for masonry structures.

4.1 Economic comparison

The first observation is that the lowest surface price is that of the reference building system. This can be explained by the fact that our reference cases are based on "low cost" accommodations with systems specifically developed to achieve the lowest price.

Another reflection deducted from the comparative table establishes that the higher the number of layers composing the wall, the higher its price. Thus, the first variant, composed of over ten different layers, is the most expensive one. While the second variant, composed of about four layers, presents a competitive surface price.

Façade wall (U=0,24W/m² K)	Physical characteristics				Economic characteristics				T O T A	
	Description	Detail	Thickness [m]	Quantity of material [kg/m²]	Price					
					min. [€/m²]	max. [€/m²]	Points			
Basic wall	enduit de plâtre monocouche		0,02	24	18,28	194,31	21,23	232,58	4,32	4,32
	blocs de béton d'argex + mortier colle		0,14	169,7	47,01		59,26			
	panneaux rigides en polyuréthane		0,085	3,4	29,36		33,65			
	lame d'air ventilée		0,03	0	0	5	0	3,65		
	bricks de terre cuite + mortier de ciment		0,09	149	99,66		118,44			
Variant 1	panneaux de plâtre cartonné		0,015	13,5	44,07*		61,79*		-5	-5
	lattice		0,06	3,6	*		*			
	panneau OSB		0,018	9	17,29	323,33	25,16	434,02		
	écran pare-vapeur		0,002	1,9	6,49		7,84			
	ossature		0,23	30,36	45,3		53,01			
	laine de roche		0,075	5,85	11,9		15,77			
	panneaux OSB		0,018	9	70,32*		83,71*			
	laine de roche rigide		0,04	4	20,34	-5	28,36	-5		
	membrane pare-pluie		0,002	2,3	*		*			
	lattice		0,06	3,6	*		*			
Variant 2	bardage bois	0,01	6	107,62		158,38				
	enduit de plâtre monocouche		0,02	24	18,28	197,43	21,23	234,99	4,15	4,15
	blocs de béton d'argex + mortier colle		0,14	169,7	47,01		59,26			
	panneaux de polystyrène expansé		0,125	3,75	31,89	4,8	35,1	3,51		
	armature + enduit synthétique		0,01	12	100,25		119,4			
enduit de plâtre monocouche	0,02		24	18,28		21,23				
Variant 3	blocs de béton d'argex + mortier colle		0,14	169,7	47,01	307,74	59,26	344,59	-2,51	-2,5
	chevronnage		0,12	15,84	35,73		39,95			
	polystyrène extrudé		0,12	3,28	31,89		35,1			
	lattice		0,06	3,6	10,6	-3,8	12,69	-1,22		
	bardage tôle de zinc		0,001	7,2	164,23		176,36			
	panneaux de plâtre cartonné		0,015	13,5	44,07*		61,79*			
	lattice		0,06	3,6	*	270,31	*	337,44		
Variant 4	panneau OSB		0,018	9	17,29		25,16		-0,9	-0,9
	écran pare-vapeur		0,002	1,9	6,49		7,84			
	ossature		0,23	30,36	45,3		53,01			
	cellulose insufflée		0,1	2,34	7,74		8,73			
	panneau MDF		0,018	14,4	13,59	-1	16,34	-0,81		
	laine de roche rigide		0,035	3,5	20,34		28,36			
	armature + enduit synthétique		0,01	12	115,49		136,21			
	enduit de plâtre monocouche		0,02	24	18,28		21,23			
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enduit de plâtre monocouche	0,02	24	18,28		21,23					
blocs de béton d'argex + mortier colle	0,14	169,7	47,01		59,26					
panneaux de polystyrène expansé	0,125	3,75	31,89	4,8	35,1	3,51				
armature + enduit synthétique	0,01	12	100,25		119,4					
enduit de plâtre monocouche	0,02	24	18,28		21,23					
blocs de béton d'argex + mortier colle	0,14	169,7	47,01		59,26					
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armature + enduit synthétique										

Façade wall (U=0,24W/m²·K)	Environmental characteristics															T O T A
	Recycling potential					Resources					Environmental performance					
	Recycled content	Recyclability	Assembly	Industry situation	Points	Nature	Characteristics	Origin	Points	[MJ/m²]	[kg CO2 eq/m²]	[kg SO2 eq/m²]	[kg C2H2 eq/m²]	Points		
Basic wall	3	/	5	/	-3	5	1			1802,2	128,4	0,7506	0,0286		1,23	
	3	5	3	5	-1	5	5									
	/	1,3333	/	5	3	3,5	/	5								
	/	/	/	/	/	/	/	/								
Variant 1	-2	5	3	5	-1	5	5			2,6	-4,22	-3,5	1,08		0,97	
	3	/	3	/	-3	1	-1									
	-5	-3	3	/	3	5	3									
	/	/	3	/	3	5	5									
	/	/	3	/	3	5	5									
	-5	-3	3	/	3	5	5									
	-1	5	1	2,0909	-1	0,2727	3,1818	1	1,48	2329,9	-52,08	0,278	0,0377			1,63
	/	/	3	/	3	5	5									
	-1	5	1	-1	-1	5	-1									
	-5	-3	3	/	3	5	5			-2,6	4,84	4	-2,97			
Variant 2	-5	5	3	/	3	5	5								1,75	
	3	/	5	/	-3	5	1									
	3	5	3	5	-1	5	5			1545,3	97,74	0,5435	0,0325			2,29
	-3	-1	-3	2,5	5	2,62	-5	-3	2,3333	5	-2,73	3	-0,68			
Variant 3	/	/	5	/	/	/	/	/							-0,14	
	3	/	5	/	-3	5	5									
	-5	-3	3	/	3	5	5									
	-5	-3	3	3,3333	/	5	5			2440,5	101,87	0,849	0,0197			
	-3	5	3	5	3	-0,333	2,6667	1	1,11	-3,6	-2,93	-5	5			-3,26
Variant 4	3	/	3	/	-3	1	-1								1,67	
	-5	-3	3	/	3	5	5									
	/	/	3	/	3	5	5									
	/	/	3	/	3	5	5									
	-5	-3	3	2,5556	-1	0,39	3	0,25	3,5	2196,6	-54,93	0,2265	0,0363			3,12
	5	/	5	/	-1	5	5									
	5	/	3	/	3	5	5			-1,2	5	4,75	-2,3			
	-1	5	1	-1	-1	5	5									

Fig 4: Table of the comparative analysis of facade walls for individual housing

By looking more closely at the prices of the individual components, one can notice that the metal cladding is at least one and a half times more expensive than any other types of cladding. As regards insulation components, the blown cellulose is three times less expensive than polystyrene for an almost identical thermal conductivity.

4.2 Environmental comparison

From the recyclability potential of system components, observation is made that masonry shows better results than wood. This is due to the simplicity of the recycling process: 95% of masonry materials are harvested, crushed and then reinserted in the production chain. While only 50% of the wood used in construction is recycled in Belgium. The steel elements also have a high potential for recycling as they can be reintroduced directly in the production chain without intermediary action.

Going through resources used in component materials of building systems, a noticeable difference between the insulation materials is observed. Polyurethanes and polystyrenes are made of synthetic resources, non-renewable and present in limited quantities on our planet and consequently scored bad points. On the other hand, blown cellulose made of natural, renewable resources and present in large quantities scored relatively good points.

At last, the four environmental performance criteria show that the grey energy required for timber production is substantially larger than that of masonry blocks. However, the timber elements counterbalance partly this negative impact thanks to their CO₂ savings. Furthermore, metal cladding has a very low environmental performance in comparison to other types of cladding.

These findings and reflections help explain the results of the comparative analysis. The second variant shows really good results on both the economic and environmental points of view. Although the resources used in its components are not ecologically optimal, this second variant is found to score the highest number of points when combining this result with its high recyclability potential and environmental performance criteria. On the other hand, the third variant should be avoided. The presence of wood layers and metal cladding within its components brings down considerably its environmental performance and raises its price.

5. Future implementation

To cover the largest possible scope of building systems, it is important to be exhaustive as to the variants of existing building systems. In the coming months, the analysis of facade walls will be completed with other building systems composed of various materials.

The economic analysis of building systems is not conducted with enough detail to identify negative aspects in the need for improvement. The authors are currently in the process of collecting more accurate data for each wall component, namely the material cost, the implementation cost and the equipment required for the implementation cost. By means of this data, they could understand the reasons behind the high prices of some components and find more economical solutions.

Moreover, it is important to mention some limitations that the environmental and health assessment tool still faces.

Indeed, the tool offers only a limited number of wall components for evaluation. Although the list is fairly exhaustive, data relative to new components is probably still missing. As this research wants to tread new ground by offering innovative solutions of wall building systems, lack of component data could be an obstructing factor.

Furthermore, the tool does not take into account all the assembly means. Thus, the glue used to assemble the insulation to the coating is not included in the environmental report. However, a recent report shows that the glue can significantly impact the environmental performances. This observation would most likely lower the second variant's score and possibly even its overall position in the ranking.

It would thus be interesting to continue the development of this tool in order to make balanced analyses for any type of wall, innovative or not.

6. Conclusions

The ultimate objective of this research is to develop a tool reducing building costs. The objective of the first action plan is the optimization of building systems in order to implement these results in the tool. As the method has been established, building system analyses have to be continued in the coming months in order to collect all of the needed information. The comparative analysis of five construction systems described in this article (see Fig 1) is a first step in the advancement of this task but it does not allow drawing definitive conclusions. However, preferential choice orientations are presented, such as the one of the second variant, providing relatively

good environmental and economic performances.

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