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Development of Prefabricated Modular Retrofitting Solution for Post-World War II Buildings

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Abstract. Residential and public buildings are one of the essential energy consumers. The majority of European buildings were constructed within the period from mid-1950ies to the late 1990ies. Currently the retrofitting process is too slow. The main barriers are complicated retrofitting process, variety of available technologies as well as precision of estimated energy savings calculations. This paper is prepared in scope of work done within the European Regional Development Fund project "NEARLY ZERO ENERGY SOLUTIONS FOR UNCLASSIFIED BUILDINGS". The main aim of this study is to develop full modular retrofitting process based on 3D laser scanning minimizing time consumed for architectural project development, on-site construction works as well as to ensure correct energy simulation. Paper presents results of Latvian case building 3D scanning results, architectural project development specifics as well as selection of optimal thermal insulation layout and energy simulations. Study analyses main barriers for wide implementation of prefabricated panels.

Keywords: modular retrofitting, 3D scanning and BIM.

Conference topic: Energy for Buildings.

Introduction

Retrofitting of building stock has become an important issue in Europe since early 1990ies. Nowadays the deep retrofitting target is set in Europe to reach EU20 and EU30 goals. The average heat consumption for Latvian post-World War II buildings varies from 160 till 250 kWh/m^2 with a maximum heat consumption up to 350 kWh/m^2. Even buildings built after 1990is require urgent deep retrofitting of external building envelope (Korniyenko *et al.* 2016). The main reason is poor thermal properties of building envelope and unsatisfactory technical conditions of heating, ventilation and hot water systems. There are several already well known and widely used retrofitting solutions. The classic rendered facades with application of mineral wool or expanded polystyrene are the most popular on the market. The installation of mechanical ventilation with centralized heat recovery, which could noticeably improve energy efficiency in buildings, however is not common due to high installation costs, lack of space and low awareness.

Typical retrofitting package of external building envelope allows reduction of thermal losses up to 60%. Undoubtedly the final reduction of energy consumption strongly depends in tenants (Martinaitis *et al.* 2015). This study takes into account only theoretical reduction based on technical measures. As it was mentioned rendered facades are among the most cost efficient solutions. However, it should be mentioned that retrofitting rate is very slow across all the Europe. Currently there are only less than 2% of all apartment buildings renovated in Latvia. The main reason for such slow retrofitting rate is low interest from house owners, bad understanding of financing options, disbelief in results as well as limited capacity of construction companies. The typical façade retrofitting solutions require high amount of on-site works and skilled craftsmanship. Also very actual issue is quality of construction works, compliances with manufacturer requirements and estimation of material specifications. In addition, utilization of construction waste also is an important issue to minimize environmental impact of retrofitting process. In order to reduce construction time and to ensure high quality of retrofitting process as well as to minimize environmental impact new solutions should be established and promoted on the market. Latest EU projects such as MORE-CONNECT, Ri.Fa.Re, RENEWSchool, ANNEX etc. are focused on development of modular retrofitting solutions. Such technologies have several benefits in "development to installation" chain and combined with precise measurement, production and installation process can greatly improve the results. Precise initial data calculation (technical and financial) is very important for owners, contractors and energy auditors. The implementation of prefabricated panels fulfills all the major requirements of involved stakeholders. The prefabricated panels mainly are frame constructions or Structural Insulated Panels (SIPs). Study (Lupisek *et al.* 2015) presents a methodology for deep energy retrofitting of post-war residential buildings with use of prefabricated panels. While author (Op't Veld 2015) provides extensive overview of modular retrofitting solution benefits and positive experience in Netherlands and Denmark. Positive effect of application of prefabricated panel for apartment building retrofitting already was proven in Nordic climate (Sandberg *et al.* 2016).

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Structural Insulated Panels are formed of an insulating foam core sandwiched between two layers of board, typically OSB (orientated strand board). These can be used for walls, floors and roofs. Frame constructions or Structural Insulated Panels are manufactured under factory controlled conditions and can be fabricated to fit nearly all building designs. With a pre-manufactured frame and pre-manufactured SIPs panels building can be made watertight in a matter of 5–6 weeks reducing labor costs and the time lost due to bad weather. In addition, ventilation ducts can be easily integrated into prefabricated panel with thickness of 200 mm (Zemitis *et al.* 2016), which allows installation of mechanical ventilation systems with heat recovery.

Currently 3D laser scanning technologies in combination of building information modelling (BIM) allows precise building measurements and development of prefabricated thermal insulation modules. In scope of this study 2-story brick building was chosen for test application of prefabricated panels. Whole process from scanning till design was evaluated. The selected building has a special bomb shelter with ventilation shaft.

Description of retrofitting process

The success of use of prefabricate modular solutions is based on precise on-site building measurements and panel manufacturing. The existing studies (CZ) have shown ability of various technologies available for precise building 3D scanning. According to before mentioned studies photogrammetric and laser scanning methods can be used for 3D measuring. However, use of ground control points is strongly recommended for higher accuracy demands (<5 mm) and for large buildings (Faltýnová *et al.* 2016). In general, development of prefabricated modular solutions can be expressed as shown in Figure 1.

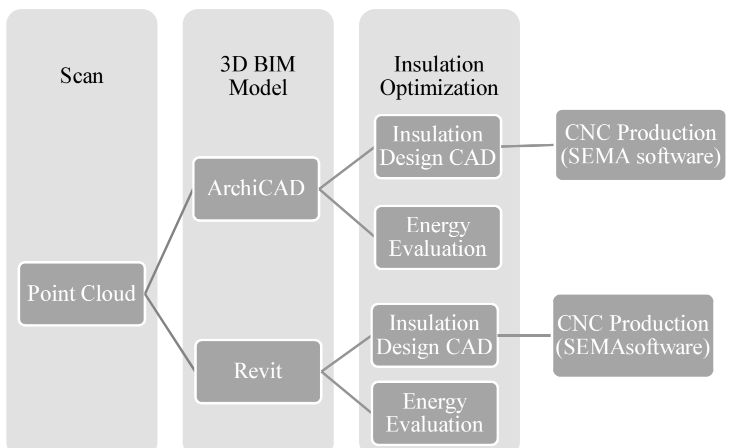


Fig. 1. Optimization of BIM Workflow

As it can be seen from Figure 1, there are two critical steps in estimation of building dimensions: creation of point cloud and development of 3D building model.

Laser scanning and data pre-processing

3D laser scanning techniques have been developed since the end of 1990s for 3D digital measurements, documentation and visualization in many fields, including geospatial and survey industries, architecture, processing and mining industries, building infrastructure, archaeology, and etc. (Feng, Röshoff 2015). 3D scanning already has proven its indispensability for heritage restoration (Seduikyte *et al.* 2016). Nowadays a 3D laser scanning is the fastest and most convenient method of data capture compared to the traditional geometry documentation methods used before. Basic parameters which must be considered and correctly selected for different applications are as follows:

- Scanning resolution;
- Scanning range;
- Position of each scanning;
- Number and location of reference targets.

In addition, some scanning systems are also sensitive to the environment, such as temperature, moisture, density of particles in the air, and even the reflectivity of the object. These parameters and factors must be carefully considered in order to obtain good quality scanned data.

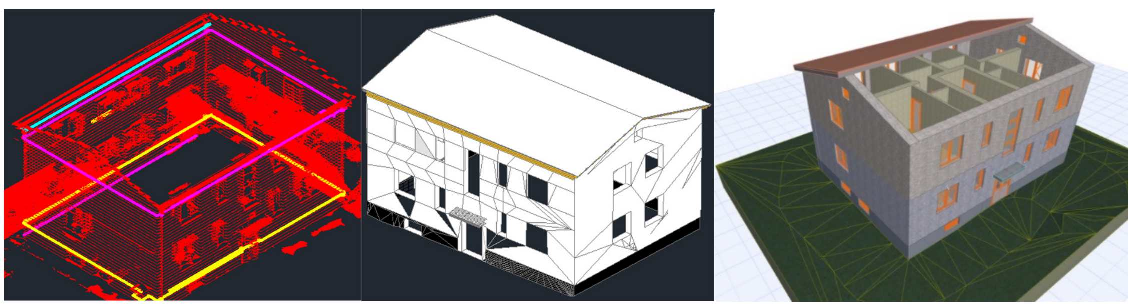
BIM

Effective implementation of BIM can be achieved only in cases if it was applied right from the initial stage of a retrofitting project (Fig. 2).

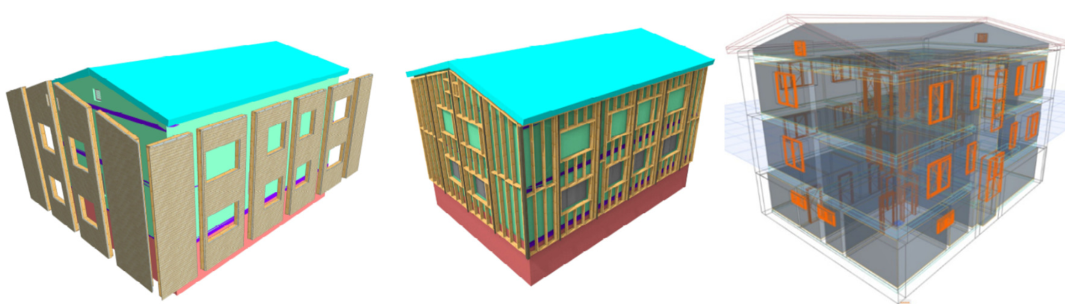
MANUAL	SEMIMANUAL	AUTOMATICAL	FROM PHOTOS (automatically)
• From seperate points • Create object (walls, windows, doors)	• From cross sections • Create mesh, smartsurface or solid elements • Convert to object (walls, windows, doors)	• Create mesh • Correcting the mesh • Convert to object	• Create mesh • Divide mesh to seperate • Correcting the mesh • Convert to object
• Average time consumption, easy but does not reflect real situation	• fast, easy, shows real situation, convertations problems	• fast, but needs a lot of work for correcting the mesh and to divide into seperate object types • Shows real situation	• VERY complicate, a lot of photos and correction works are needed

Fig. 2. Different types of BIM creation models based on the point cloud method

The 3D building model provides all involved parties with correct data on building measurements. The data can be easily imported in CNC production and energy simulation. For panel design SEMA software is widely used across the Europe. It allows data import from .DWG, .DWX, .3DS, .SHP and other formats. Extra extensions allow direct .IFC import. IFC format also can be used in most popular independent dynamic energy simulation software such as IDA-ICE, RIUSKA and IESVE. However, the embedded energy simulation modules in REVIT, ArchiCAD and AutoCAD allow easier energy analysis while minimizing errors due to data transfer and conversion. The retrofitting process development is shown in Figure 3.



a) 3D point cloud　　b) intermediate 3D building model　　c) final building model



d) development of panel layout　　e) Thermal blocks for energy simulation

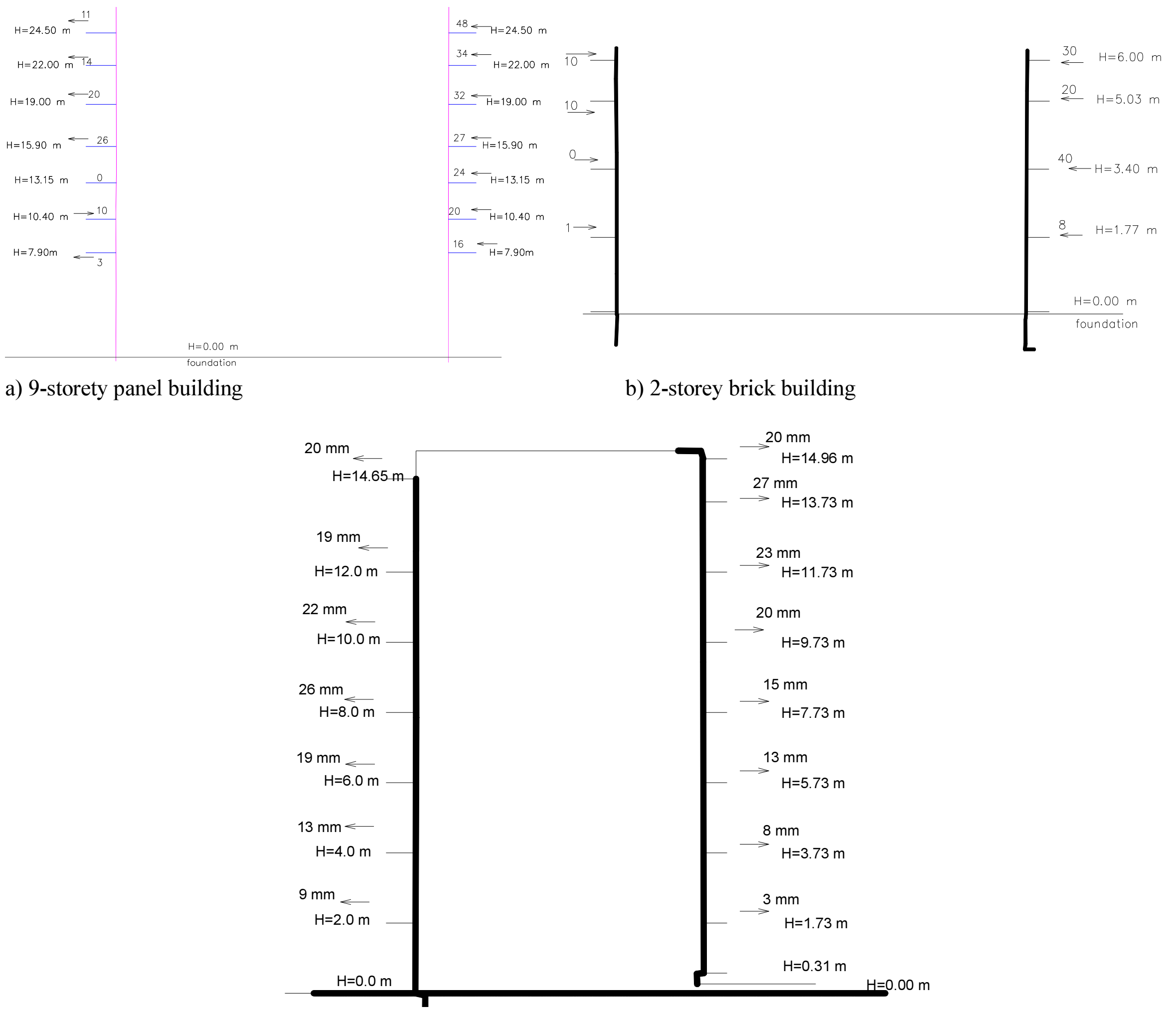
Fig. 3. Application of 3D laser scanning for panel design and energy simulations

The building laser scanning and future BIM creation allows precise building dimensioning. Thus, provides all necessary data for panels manufacturers and energy auditors. Such approach minimizes human error during manual building measurements and use of building old technical documentation. It should be noticed that final building BIM model does not show façade vertical displacement and inaccuracies, which are crucial for panel placement and fixing on the existing facade. Extra attention should be paid to façade vertical displacement during analysis of point cloud.

Technical condition of post-World War II building facades

The average heat transfer coefficient of typical homogeneous single layer external wall of Latvian multi apartment building are in rage of 0.85 till 1.20 W/(m^2·K) and for window about 2.6 W/(m^2·K). While low poor thermal properties can be easily improved by application of thermal insulation layer, the poor construction quality and technical conditions of external building envelope requires extra complicated technical solutions. The main problems are air permeability of panel joints, wall vertical displacement, high moisture content and non-uniform properties of building envelope.

Three different apartment buildings were analysis in order to estimate post-World War II buildings' facades vertical displacement. This survey was performer for 2-storey brick building, 5-storey panel/brick building and 9-storey panel building. The Figure 4 shows facades with most critical vertical deviations.



a) 9-storety panel building

b) 2-storey brick building

c) 5-storey brick building

Fig. 4. Vertical deviations of measured 2, 5 and 9 story buildings

The survey of three different buildings showed that the vertical displacement is 40 mm from foundation to top of roof for 2-storey brick building, 48 mm for 9-storey building and 20 mm for 5-storey building. The maximal difference between equal levels is 32 mm.

Technical solution of prefabricated panels

For retrofitting project, several prototypes were developed in order to estimate their total construction costs, materials alternatives etc. (Fig. 5). After various evaluations, the main focus was on selection of optimal external finishing and connection layers between existing wall and panel.

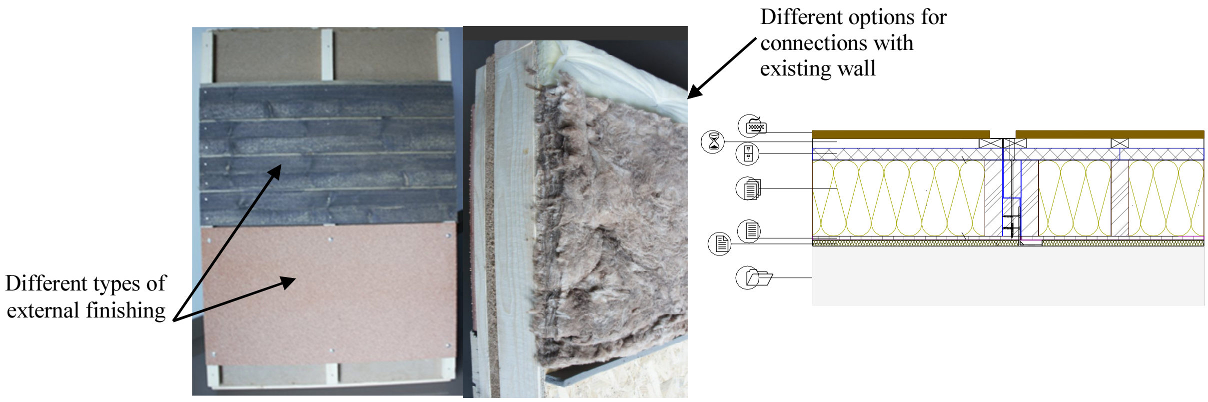


Fig. 5. Thermal insulation panels

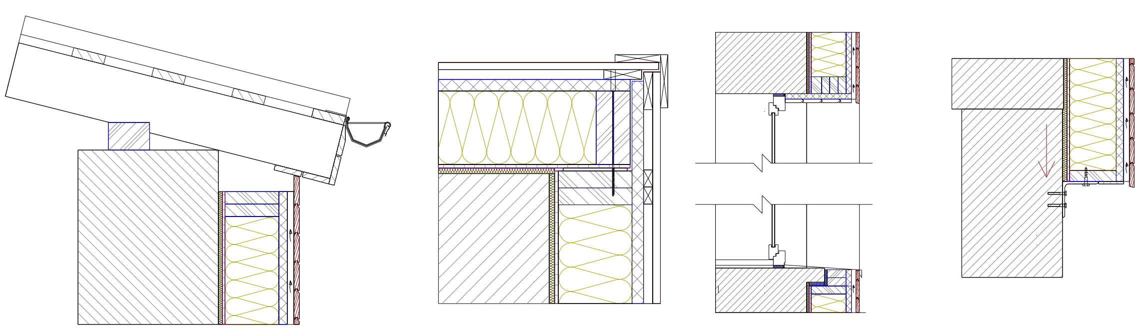
The main disadvantage of wood frame construction is relatively high wood carcass proportion and thermal bridges between panels connection. The wood carcass proportion can be compensated by application of thermal insulation material with lower value of thermal conductivity. Material options for each panel layer are shown in Table 1.

Table 1. Material options for each panel layer

Layer 1	Layer 2	Layer 3	Layer 4		Layer 5	Layer 6	Layer 7
Existing wall	Connection layer between existing wall and modular panel		Main load bearing and thermal insulation layer				External finishing
	Air gap	Oriented strand board	Steel frame	Mineral wool thermal insulation	Wind protection slab from mineral wool	Ventilated air gap	Wood planks
	Sealing tape	Wood particle board	Food frame	Expanded polystyrene thermal insulation			Fibro-cement board
	Mineral wool		Light steel frame (thermoprofile)	Eco thermal insulation materials			Magnesit e board
	Soft sealing tape (mineral wool)		I-beam				Fibrolite board

Research (Piheloa *et al.* 2016) on evaluation of prefabricated panel moisture regimes have shown that in some cases, especially for Nordic climate, use of water vapor barrier is not recommend since it prevents moisture drying from existing construction.

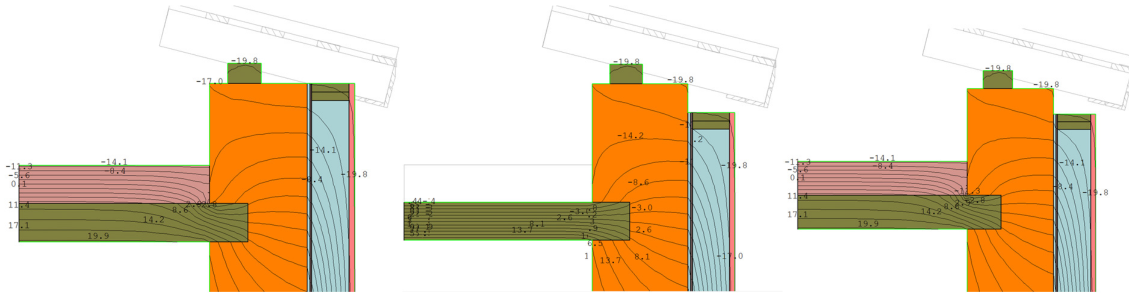
The main problem is relatively high proportion of thermal bridges due to carcass elements. The key elements are roof/fall connection, external corner and windows (Fig. 6).



a) wall/roof b) external corner c) window d) basement

Fig. 6. Critical thermal bridges in case of modular retrofitting

Thickness of thermal insulation panel is up 280 mm which limits thermal insulation of wall upper edge under existing roof construction (Fig. 6a). The upper level can be insulated manually or in case of unheated attic, attic floor should be properly insulated thus minimizing thermal bridge value up to zero. Thermal bridge evaluation at ceiling slab/wall connection is shown in Figure7.



a) Heat flux 7.16 W/m^2 (attic and wall edge insulation)

b) Heat flux 8.90 W/m^2 (current solution with non-insulated attic)

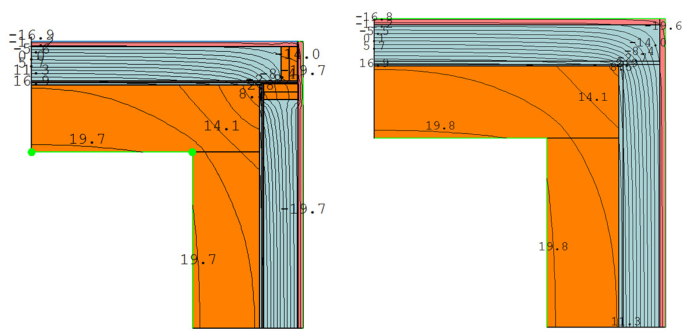
c) Heat flux 7.49W/m^2 (current solution with insulated attic)

Fig. 7. Thermal bridge evaluation at ceiling slab/wall connection

As it can be seen the heat flux in existing retrofitting solution (Fig. 7c) is only by 4.6% higher than in case of additional wall edge thermal insulation (Fig. 7a).

In many cases old wooden frame windows were replaced by new PVC, the replacement of windows is less cost efficient measure with high negative environmental effect. The existing windows opening should be manually insulated with soft insulation wooden fiberboards or similar material. The thermal bridge at external corner can be minimized using I-beam carcass studs.

The comparison of external corner thermal insulation using prefabricated panels and “classic” rendered facades is shown in Figure 8.



a) heat flux 8.75 W/m^2 (existing solution)

b) heat flux 7.76 W/m^2 (rendered facade)

Fig. 8. Thermal bridge evaluation at ceiling slab/wall

The heat flux at external corner with installed prefabricated panels is by 12% higher in comparison to rendered façade. However, this situation can be improved by use of I-Beams. The presented calculation doesn’t take into account mechanical fasteners. Study (Šadauskienė *et al.* 2015) shows extended evaluation and influence of point thermal bridge in aluminum frames. Wooded frame due to its low thermal conductivity minimizes negative impact off point thermal bridges. The building shape has a strong correlation with heat losses (Szodrai *et al.* 2016). The post war buildings have a very simple form, which makes the retrofitting process more simple and allows lower energy consumption.

Future development of faced retrofitting solutions for unclassified buildings

It is often necessary to foresee special, individually prepared façade construction for unclassified buildings. These façade systems must be made of specific building materials while complying with design rules. Therefore, strict rules, such as constructive strength, heat resistant and fire and blast-proof, must be imposed regarding the multi-active modular façade systems. Also, all the constructive elements must be resistant to extreme weather conditions and intensive vibrations caused by blasts or earthquakes. It must be noted that only materials which are tested for their chemical and mechanical properties in certified independent institution can be used for unclassified buildings. Currently very limited number of studies focuses on thermal performance requirements definition for unclassified buildings. One of the sources (U.S. Army Corps 2012) focuses on specific requirement on air leakage rate.

The prefabricated thermal insulation panels are the most appropriate technology for unclassified buildings since it reduces on-site installation time, minimizes number of involved construction workers and ensures construction quality.

Conclusions

1. Nowadays 3D scanning insures all necessary accuracy of building dimension. Photogrammetric and laser scanning methods can be used for 3D measuring. Use of Ground control points with accuracy less than 5 mm is recommended for large objects such as residential houses, wire houses, offices etc. It is strongly recommended to measure vertical displacement during object laser scanning and data proceeding. This will allow to choose safe carcass solution and fasteners.
2. 3D building model can be created on the basis of point cloud using REVIT or ArchiCAD software. Building model data can be easily exported into energy simulation modules or separate software. In addition, data can be directly used for design and production of prefabricated thermal insulation panels. The most precise is manual creation of BIM model. However, it's time consuming process. Full 3D model which takes into account all vertical displacement requires file size up to 10 GB. Thus, in practice simplified building models without vertical displacements are used.
3. The survey of three different buildings have shown vertical displacement of extremal wall is up to 40 mm from foundation for 2-storey brick building, 48 mm for 9-storey building and 20 mm for 5-storey building. The maximal difference between different levels is 32 mm.
4. Application of prefabricated building modules significantly reduces on-site installation time, allows correct material specification and correct energy simulation due to precise measurements.
5. Thermal insulation using prefabricated building modules, slightly increases share or thermal bridges in comparison to rendered facades. Most critical places are windows, roof/wall and panel joins.
6. Non-insulated wall edge has 4.6% higher heat losses in comparison to insulated edge. However extra construction for on-site insulation should be taken into account.
7. The critical point is external corners where extra losses are by 12% higher in comparison to rendered façade solution.

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Contribution

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Disclosure statement

Authors of this article don't have any competing financial, professional, or personal interests from other parties.

References

Faltýnová, M.; Matoušková, E.; Šedina, J.; Pavelka, K. 2016. Building facade documentation using laser scanning and photogrammetry and data implementation into BIM, in *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XLI-B3. XXIII ISPRS Congress, 12–19 July 2016. Prague, Czech Republic, 215–220.

Feng, Q.; Röshoff, K. 2015. A Survey of 3D Laser Scanning Techniques for Application to Rock Mechanics and Rock Engineering. 2015, in *The ISRM suggested methods for rock characterization, testing and monitoring*: 2007–2014. R. Ulusay (Ed.). Switzerland, Springer International Publishing: 265–292.

Korniyenko, S. V.; Vatin, N. I.; Gorshkov, A. S. 2016. Thermophysical field testing of residential buildings made of autoclaved aerated concrete blocks, *Magazine of Civil Engineering* 64(4): 10–25. https://doi.org/10.5862/MCE.64.2

Lupisek, A.; Volf, M.; Hejtmanek, P.; Sojkova, K.; Tywoniak, J.; Op't Veld, P. 2016. Introduction of a methodology for deep energy retrofitting of post-war residential buildings in central Europe to zero energy level, *Komunikacie* 18(4): 30–36.

Martinaitis, V.; Zavadskas, E. K.; Motuziene, V.; Vilutiene, T. 2015. Importance of occupancy information when simulating energy demand of energy efficient house: A case study, *Energy and Building* 101: 64–75. https://doi.org/10.1016/j.enbuild.2015.04.031

Op‘t Veld, P. 2015. MORE-CONNECT: Development and advanced prefabrication of innovative, multifunctional building envelope elements for modular retrofitting and smart connections, *Energy Procedia* 78: 1057–1062. https://doi.org/10.1016/j.egypro.2015.11.026

Piheloa, P.; Lelumeesa, M.; Kalamees, T. 2016. Influence of moisture dry-out on hygrothermal performance of prefabricated modular renovation elements, *Energy Procedia* 96: 745–755. https://doi.org/10.1016/j.egypro.2016.09.137

Šadauskienė, J.; Ramanauskas, J.; Šeduikytė, L.; Daukšys, M.; Vasylius, A. 2015. A simplified methodology for evaluating the impact of point thermal bridges on the high-energy performance of a passive house, *Sustainability* (Switzerland) 7(12): 16687–16702. https://doi.org/10.3390/su71215840

Sandberg, K.; Orskaug, T.; Andersson, A. 2016. Prefabricated wood elements for sustainable renovation of residential building façades. Paper presented at the *Energy Procedia* 96*:* 756–767. https://doi.org/10.1016/j.egypro.2016.09.138

Seduikyte, L.; Kylili, A.; Sadauskiene, J.; Fokaides, P. 2016. Preserving and managing heritage buildings in a sustainable way: with integration of BIM-A review, in *28th European Modeling and Simulation Symposium, EMSS* 2016, 183–190.

Szodrai, F.; Lakatos, Á.; Kalmár, F. 2016. Analysis of the change of the specific heat loss coefficient of buildings resulted by the variation of the geometry and the moisture load, *Energy* 115: 820–829. https://doi.org/10.1016/j.energy.2016.09.073

Test Protocol for Building Envelopes. Champaign: U.S. Army Corps of Engineers. U.S. Army Corps of Engineers and Air Barrier Association of America. 2012. U.S. Army Corps of Engineers Air Leakage.

Zemitis, J.; Borodiņecs, A.; Geikins, A.; Kalamees, T.; Kuusk, K. 2016. Ventilation system design in three european geo cluster, *Energy Procedia* 96: 285–293. https://doi.org/10.1016/j.egypro.2016.09.151