Advantages of using virtual reality and building information modelling when assessing suitability of various heat sources, including renewable energy sources

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Abstract. The pace of changes in the construction industry is constantly accelerating. It includes 3D modeling, utilization of drones, 3D printing and virtual or augmented reality. Augmented reality combines something real, such as existing buildings, with expanded 2D or 3D digital information about individual technologies or planned changes, and the actual projection of individual elements into a given (even hidden) space. It can be a key for improving project engineering processes, subsequent maintenance or more efficient renovation procedures. Virtual and augmented realities need 3D building models, i.e. incorporation of building information modelling. Building information modelling (BIM) is a modern and efficient solution process that incorporates the entire building life cycle, based on a realistic model and information. Individual building technical equipment, i.e. including heat sources, to a certain extent influence the internal structure of individual buildings, particularly in the case of a more complex structures. The article describes some of the modern technologies that can be applied to the administration, maintenance and implementation of building technical equipment. Such technologies can also help when deciding about the most suitable heat source for a given building. The article points out the benefits of incorporating these modern technologies.

1. Introduction
The everyday progress in the field of information technologies allow project engineers to utilize modern technologies that make human activities easier or of a higher quality. They can also prevent problems thanks to timely analyses. Modern technologies play a decisive role in the Industry 4.0 revolution. The use of modern technologies is accompanied by many benefits, such as lower cost, lower risks, faster processes, better quality of individual proposals and improved efficiency [1, 2]. In many fields, virtual and augmented realities often represent a welcome aid. Industrial revolution, objective of which is to fully digitalize the construction industry and to expand application of building information modelling in this sector, offers many new opportunities when it comes to applying and utilizing these realities in the work of project engineers. Augmented reality has a great potential to be one of the leading factors of the revolution of the existing user interface. It is because it can offer a unique quality, which provides a direct link between reality and virtual information about this reality. Our entire world can this become a user interface [3].
2. Virtual reality and its degrees
Virtual reality, used and discussed so much these days, allows its users to submerge into artificial worlds and to create visual, auditory and tactile experience, which arouse subjective impressions, using only a computer or a special helmet or goggles. One can also focus on the given user interface that provides a combination of virtual reality and reality, thus providing information about small and, at the same time, easily understandable parts. Virtual reality has come to a point where virtual images are often indistinguishable from the real world. It means that basically anything is possible without almost any limitation [3].

Users submerged into virtual reality perceive only virtual impulses, for example, inside of a room with walls that allow for stereoscopic projections or while wearing enclosed virtual reality goggles. The space between reality and virtual reality, which allows us to combine both of them to various degrees, is called mixed reality. One of the degrees of mixed reality is extended reality, where the number of real elements is greater than the number of virtual ones.

The term extended reality is used for creating direct, automatic and operational relations between the physical, real world and electronical, added information that includes digital objects created by a computer. We could say that it is a somehow improved reality, when users can see the real world, however, with added, computer-generated images, objects or information. This view can be generated using special goggles or using a tablet or a smartphone. Added information, which will be displayed as a part of the extended reality, is always supposed to help the given users to conduct their activities, to better imagine certain space with new or hidden elements, or to display relevant information about real elements in the real world [4].

2.1. Usage possibilities of virtual reality in the construction industry
All technological equipment as well as construction details have been getting ever more complicated, which has a great impact on their planning, implementation and operation. Architectural buildings, infrastructure as well as technological support facilities of the buildings are designed using numerous software applications. Various project changes have to be usually incorporated during the implementation process. It does not matter if they are just small changes or relatively extensive interventions. It is no problem to incorporate them back into the given model and to create an easy and transparent as-built documentation of the given construction. However the current or past practices have not been working this way so far and the changes are usually not incorporated back to the drawing documentation in a good way. That causes problems later, for example, during renovations or defect situations, in relation to individual structures, technologies or, more generally, facility management practices.

Virtual reality can be also used in architecture, when engineers can go through proposed constructions and assess if the given buildings are typologically in good order and if individual building areas comply with the given functional as well as operational requirements. They can also assesses aesthetics of corresponding interiors.

Thanks to virtual reality, we can control static and structural proposals, particularly locations and connections of individual elements, since it is easier to locate components that are incorrectly placed when we are fully submerged in the 3D environment. These elements cannot be, so far, corrected directly in the virtual reality environment. The corresponding changes have to be adopted subsequently, using the software application, in which the model was created. Nevertheless, considering the speed of the development in this area, we can expect that even this problem will be solved in a near future and individual element will not be only static, which will allow us to work with them directly in the virtual reality environment.

3. Building information modelling
Building information modelling (BIM) provides a tool for preparing complex construction proposals. Visualization via BIM allows us to determine structural discrepancies and to locate problematic spots already during the pre-investment stage. Problem prediction and problem solving already during the planning stage can save us a lot of money during the following implementation stage and, subsequently, during the given building operation. All changes during the construction implementation
process can be easily incorporated into the model, thus allowing us to simultaneously create the corresponding as-built documentation. After the completion of the construction implementation stage, the model should assist the given building operator during the entire building lifespan period [5, 6]. An integral part of every building is formed by the building technical equipment, which can be created using a realistic 3D model. Collisions with other structures or building installations are inspected in a realistic 3D model. Moreover, the model is amended by information about all technologies, pipelines and valves. The data included in the model show the planned state of the given building and thus make the work of people who subsequently take care of the building easier. The information is complex with regard to all applicable technical systems in the given building, including detailed information about heat sources. It can also involve heating systems, water distribution lines or air-conditioning and ventilation systems. Overviews from all technological systems are available. They include lists of individual elements, material prices or other specifications defined individually in advance. Based on such detailed information, we are able to determine real expenses for, for example, a heating system implementation, and to assess multiple options in advance and subsequently select the most convenient one. If we link a BIM model with a CAFM (computer aided facility management) system, it can be used including attached documents and information related to revisions, inspections and, if applicable, repairs. We could also easily find contacts for individual technicians. Moreover, the model carries information about the contractor who is responsible for correct operation of the given system and about warranties and lifespans of individual elements.

4. Heat sources
Regardless of the fact if it is a new building or renovation of an older one, there always are several heat source options to choose from. Heat sources will differ for local and central heating systems. This article addresses only central heating heat sources. There are several options when it comes to central heating as well. Some of them include:

- Radiators;
- Low-temperature heating (floor, wall, ceiling);
- Hot-air heating.

We choose heat sources based on the given system type. From that perspective, we have the following options available to us:

Electric boilers
Electric energy can easily be regulated and small sources can be used, however, it is also the most demanding energy when it comes to its production. That is why it is the most expensive energy source. Since electric energy in the Czech Republic is mostly made in coal power plants, efficiency of which is relatively small and CO₂ emissions of which are high, there is a great pressure to limit the use of electric energy as the main source for heating buildings. Electric energy is usually proposed only as an auxiliary source to, for example, renewable energy sources.

Gas boilers
From the perspective of comfort and price, gas comes second after electric energy. However, the gas distribution network is not as widespread as the electric one. Natural gas heaters are structurally more complex and one must address the issue of where to discharge combustion products and how to ensure operation safety when the flame goes off or when the gas combustion is imperfect. Installation of autonomous sensors, which can detect even very low carbon monoxide concentrations, represents an easy prevention measure against CO leaks.

Solid fuel boilers
Contemporary automatic coal or wood boilers represent yet another heat source that is proposed relatively often these days. And since their service comfort has improved and emissions have been reduced in comparison with the past, solid fuel boilers can sometimes also be a suitable alternative for heating buildings.

Heat pumps
Heat pumps need electric energy for their operation – to drive their compressors. It means that they cannot be used at locations where there is no electric outlet. Heat pumps utilize heat from their surroundings, thus boosting a relatively low operation cost. There are few types of heat pumps, for
example: Air-To-Air, Water-To-Air, Water-To-Water. Each type has different efficiency, but it also varies considerably by the purchase price. Their high acquisition prices represent a big disadvantage though.

**Solar systems**

Solar systems can be designed for water heating purposes and, partially, heating or for the production of electricity - photovoltaic. Their advantage is their wide-spread availability. On the other hand, their big disadvantage is represented by their seasonal and even daily fluctuations. Energy can be, to a certain extent, stored in accumulators. Nevertheless, the relatively high acquisition prices and not a great efficiency of these systems mean that investments in them are economically irretrievable without grants and subsidy programs.

**Wind power plants**

Small wind power plants can be installed even on flat building roofs. They represent clean energy sources, thus contributing to a reduction of CO$_2$ emissions. There are several options when it comes to their configuration. One of them is the island system, when surpluses of the produced energy are stored in accumulators for later use.

Considering the current and future legislature, when newly built houses will have to boost almost zero energy consumption, it is clear that renewable energy sources will be widely used in the future. The challenge is to find the best alternative for a given building, while taking into account all its characteristics. This process can be relatively complicated since many factors have to be considered.

### 5. Choosing suitable heat sources

Several factors have to be considered when selecting a heat source. No qualified decision can be adopted based only on the current energy prices since these prices always change. The total heating cost can be relatively realistically determined, provided good planning practices are put in place. Prior to adopting a decision about a heat source, it is recommended to assess the following items.

**Construction preparations**

- Financial aspect – gas or electricity connection cost, cost of building a fuel storage space in the case of solid fuel boilers, wellbore prices in the case of heat pumps, etc.
- Time aspect – how long it will take to build the given connections and, if applicable, time needed for the necessary earthworks
- Spatial limitations – necessity of a technical room – it is unavoidable for some heat sources, layout of individual radiators – it is not always possible to install radiators in some rooms; when floor heating is used, a heat source that is compatible with this system has to be selected.

**System acquisition price**

- The acquisition price should include the price of the actual heat source as well as the price of the entire system. The investment cost should include expenses related to the given heat distribution network. It should take into account the material of the lines, insulation, valves, accumulators (if needed), regulation unit, etc.

**Regulation system**

- When the selected system can be well regulated, you can potentially save significant money associated with the cost of heating. Regulation can be manual in individual rooms, or automatic, which is a more expensive option; these expenses have to be also included.

**System operation**

- Operation personnel – will you need any operation personnel to operate the system? Annual or more frequent maintenance, regular cleaning, service, revisions, or will the system be operator and maintenance free? You need to answer also these questions. Should day operation personnel and/or often revisions be needed, you need to expect higher operation cost.
- Operation comfort – will the selected heat source and the entire system be able to achieve the required temperature and to maintain it? There is a risk of room overheating, particularly when a fireplace is additionally used. This has a negative impact on the operation cost [9].
• Operation hygiene - will the selected heat source and the entire system have an impact on the cleanliness and health conditions in individual rooms? For example, more dust or the possibility to eliminate cold floors.

• Operation expenses – actual cost of the used fuel or energy tariffs.

Lifespan

• The lifespan of the entire system, regulations, the actual source, valves, etc. should be assessed.

Using the above mentioned information, we can arrive to general conclusions about a suitable heat source. Nevertheless, some of the items cannot be properly answered when only a 2D drawing is available. For a 3D model prepared using the building information modelling, all lengths and dimensions of individual pipes, number of branches, elbows, distribution line materials, number and types of valves, etc. would be available. An exact appraisal of individual options can be easily prepared based on such very detailed information.

For proposals of renewable energy sources, you also need to consider the particular situation of a given building. It cannot be unambiguously said that a solar system for preparation hot water is suitable for every building since some building roofs can be shaded most of the day due to the surrounding buildings. In that case, the system would lose precious solar yields and its efficiency would decrease. This situation can be prevented by preparing a 3D model of the given building, including the surrounding buildings, and a software simulation - ArchiCad is used here, which clearly shows how shades will move throughout the entire day. Based in this simulation, we can assess if it is suitable to even propose a solar system. If it is, we can see where individual solar collectors should be ideally installed in order to gain the biggest yield possible [7].

*Figure 1:* Simulation of shadows during the day in Archicad software, evaluation of suitable location of solar collectors for prepare hot water

When it comes to a small wind power plant proposal, the situation is similar. We cannot objectively assess the suitability or unsuitability of a wind power plant without knowing the layout of the surrounding buildings and appropriately accurate assessment of the wind flows. When simulation methods are utilized (in this case we use a 3D model created using BIM, which was exported to Ansys), we can professionally determine a suitable location for the given turbine installation based on the simulation results.
Incorporation of virtual reality into project engineering and implementation of technological systems can improve orientation in the project intention, which can be quite difficult in more complex technological systems. In virtual reality, we can walk about an extensive and complex machine room, we can inspect accuracy of all connections and we can also carefully walk through all parts of the given system, while having all relevant information about the given elements available to us. Moreover, we can also assess suitability of individual heating systems for the given space.

**Figure 2:** Wind simulation in Ansys program - wind flow overall situation including surrounding buildings and wind movement on the roof of a particular building
Extended reality has also its place. It can be used as an analysis of discrepancies in, for example, large technological facilities. When inspecting an implemented machine room, you can, for example, control the planned project plan in relation to the already implemented parts on your tablet. Should there be any differences or missing components, you can thus prevent huge problems and financial damages, which could occur upon launching the system.

Heat sources have to be also designed pursuant to the particular energy demands of the given building, which is a very important and monitored parameter for new as well as existing buildings, which go through a renovation process. Considering the requirements for the lowest possible energy needs of buildings, extended reality has a potential to develop further, with the expectation that emphases will be put on incorporating detailed information directly into the 3D model of the given building [8]. The corresponding model could include information about the heat transfer coefficient of individual structures – the existing ones and those required by the given standard, or the values of individual linear and point heat transfer coefficients. Using a tablet, experts would then be able to immediately see the state of the given building and to modify their heat source selection or to propose structural modification and, subsequently, a heat source.

**Figure 3:** Technological Background of an Experimental House - created 3D model and then showing how it might look like a virtual reality, including element information

**Figure 4:** View detailed information about the existing building
6. Conclusion
The heat source selection process should particularly take into account whatever is available at the given location. Based on the information stated in the article, you can assess the theoretical benefits and negatives of individual heat sources as well as entire systems. Theoretical considerations should be followed by practical simulations and analyses. This particularly applies to proposals of renewable energy sources, when the investment cost for acquiring such systems is relatively high. The investment return period depends on the achieved profits. Incorporation of modern technologies into the decision making process related to suitable heat sources and thus into the entire building proposal, planning and implementation process, can bring many benefits and opportunities for making these procedures more time-efficient, more exact and, most of all, more profitable. It is necessary to admit that only 2D drawings will not soon be sufficient and that the ongoing technological development allows for making project engineering practices more efficient. Project engineers and technician should thus learn how to utilize this potential for their own benefit as well as for the benefit of investors. Should it be the application of the building information modelling, or virtual or extended reality, all of these modern technologies can accelerate and simplify construction processes and all of their parts.

7. References
[1] VERBA, N., CHAO, K.-M., LEWANDOWSKI, J., SHAH, N., JAMES, A., TIAN, F. Modeling industry 4.0 based fog computing environments for application analysis and deployment. In: Future Generation Computer Systems, vol. 91, pp 48-60, 2019.DOI: 10.1016/j.future.2018.08.043.
[2] LU, Y. Industry 4.0: A survey on technologies, applications and open research issues. In: Journal of Industrial Information Integration, vol. 6, pp 1-10, 2017. DOI: 10.1016/j.jii.2017.04.005.
[3] AUKSTAKALNIS, Steve. Practical Augmented Reality: A Guide to the Technologies, Applications, and Human Factors for AR and VR (Usability). Indiana: Addison-Wesley, 2016. ISBN 978-0134094236.
[4] BENFORD, S., GREENHALGH, C., REYNARD, G., BROWN, C., KOLEVA, B. Understanding and Constructing Shared Spaces with Mixed-Reality Boundaries. In: ACM Transactions on Computer-Human Interaction, vol. 5, pp 185-223, 1998. DOI: 10.1145/292834.292836.
[5] BONENBERG, W., WEI, X., ZHOU, M. BIM in prefabrication and modular building. In: Advances in Intelligent Systems and Computing, vol. 788, pp 100-110, 2019. DOI: 10.1007/978-3-319-94199-8_10.
[6] EASTMAN, Ch., TEICHOLZ, P., SACKS, R., LISTON, K. BIM Handbook, A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. New Jersey: John Wiley & Sons, Inc, 2008. ISBN: 978-0-470-18528-5.
[7] SALKUTI, S. R. Day-ahead thermal and renewable power generation scheduling considering uncertainty. In: Renewable Energy, vol. 131, pp 956-965, 2019. DOI: 10.1016/j.renene.2018.07.106.
[8] ZUAZUA-ROS, A., MARTÍN-GÓMEZ, C., IBANEZ-PUY, E., VIDAUARRE-ARBIZU, M., GELBSTEIN, Y. Investigation of the thermoelectric potential for heating, cooling and ventilation in buildings: Characterization options and applications. In: Renewable Energy, vol. 131, pp 229-239, 2019. DOI: 10.1016/j.renene.2018.07.027.
[9] VANUS, J., MARTINEK, R., BILIK, P., ZIDEK, J., SKOTNICOVA, I. Evaluation of thermal comfort of the internal environment in smart home using objective and subjective factors. In: 17th International Scientific Conference on Electric Power Engineering, EPE 2016; Prague; Czech Republic, article number 7521768, 2016. DOI: 10.1109/EPE.2016.7521768.

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