Mobile Tiny Houses – Sustainable and Affordable?

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Abstract. The topic of „affordable accommodations" has affected the construction industry and the politics for many years, not least due to sharply rising real estate prices. Building plots in good locations are just as prohibitively expensive for young people as larger apartments in urban areas, especially in big cities. This raises the question: How much does a person need to live? Energy efficiency, sustainability and regionality are as equally important as coziness, which decisively defines the quality of life of the residents. As part of the "klimaaktiv" regional partnership, the Upper Austria University of Applied Sciences has carried out several research projects concerning the topic of small sustainable homes. In cooperation with an Upper Austrian prefabricated house company, a building technology concept for an innovative modular construction system was devised. The aim here was the development of an innovative, high-quality and inexpensive modular system that does not exclude increased ecological standards. As part of an interdisciplinary project, a group of students developed an energy self-sufficient cabin for almost every kind of application. Based on extensive research on existing building systems, a variety of topics were examined. The focus here was on mobility, modular assembly, ecological materials, self-sufficiency, energy efficiency and the water cycle. In the end, a single-family house, which considers most of the aforementioned aspects, was built.

1. Background & State of the Art

The statements and findings of this publication are largely based on bachelor and master theses of students at the Upper Austria University of Applied Sciences. The main focus was on the master thesis of Lukas Krainz [1] – Development of a building technology concept for an innovative modular construction system – and an interdisciplinary project from the "Eco-Energy Engineering" bachelor's degree programme [2]. Furthermore, research into the topics of small houses ("Micro homes", "Tiny homes"), modular construction, mobility of buildings and urban development was carried out. The cooperation with Wolfthal Zimmerei GmbH during the completion of a bachelor thesis provided important insights into wood-based module construction [3]. Additionally, alternative building concepts of well-known Austrian module construction companies, like "Wohnwagon" [4] and "Genböck's microHOME" were considered [5].

1.1 Mobility of Buildings

The longing for change, flexibility and freedom often makes people dream of mobile micro homes. This longing presents a variety of challenges for architects, civil engineers and technicians. One of these challenges is the balancing act between cost-effective industrial prefabrication and the mobility of the individual building modules. In Austria, the transport of building modules is regulated in the Special Transport Order (SOTRA - Gesamterlass). Depending on dimensions and weight, these transports are classified into four special transport levels with individual legal requirements (see Table 1). Maximum size and weight of a module are dependent on the existing infrastructure and road conditions e.g. road width, load capacity of bridges or height of underpasses [6].

Table. 1: Special Transport Levels and legal requirements for Federal Highways [6]

	Level 1	**Level 2**	**Level 3**	**Level 4**
Width	3,01 – 3,20m	3,21 – 4,50m	4,51 – 5,00m	from 5,01
Height	-	from 4,31m	-	-
Length	22,01 – 25,00m	25,01 – 40,00m	from 40,01m	-
Weight	individual (depending on weight, axle load and requirements of the expert opinion of the road administration)			from 140,01t
Legal Requirements	self-accompaniment	1 Vehicle incl. 1 sworn road supervisory authority	2 Vehicles incl. 2 sworn road supervisory authorities	min. 3 Vehicles incl. min. 3 sworn road supervisory authorities

The single building modules, which are described in the master thesis of Lukas Krainz have a dimension of 18,00 x 5,50m and a maximum weight of 75t (see Figure 1). According to SOTRA, dimensions of this kind would represent a Level 4 Special Transport which requires a minimum of three vehicles including three road supervisory authorities. By combining the single modules, entire single-family houses can be built effortlessly. Mobile buildings in modular construction are usually mounted on screw foundations, which do not negatively influence the soil of the building ground. This guarantees the preservation of the property value and offers the possibility of removing the modules anytime [1].

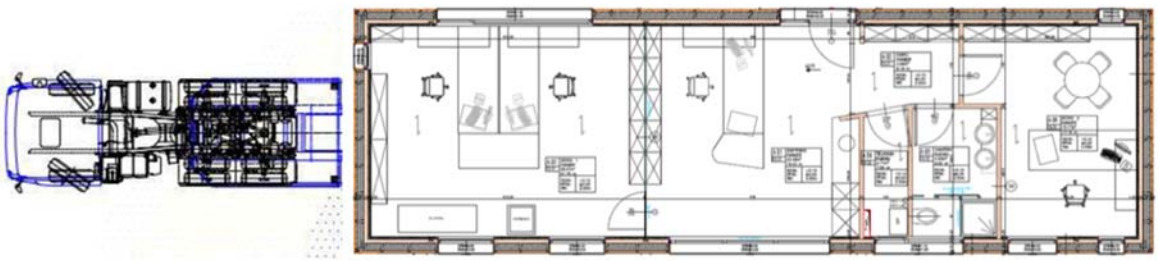

Figure 1. Building in modular design [18,00 x 5,50m] on a truck [1]

1.2 Infrared Heating Systems

For a long period of time, infrared technology was not suitable for use as the main heating system in buildings. This was due to the fact that high-quality energy (electrical energy) is converted into low-quality energy (thermal energy). Due to highly energy-efficient building concepts and the associated low heating requirements, infrared heating systems for buildings can make sense under certain conditions [1].

The most important advantage of this technology lies in the low investment and maintenance costs as well as in the very short heating and cooling phases. These are essential arguments, especially for holiday houses or small rooms that are rarely used. Another advantage is the high proportion of radiant heat, which many people find very pleasant. The high operating costs for buildings with a heating requirement above the passive house standard still represents the most important disadvantage [3].

1.3 klimaaktiv

“klimaaktiv” is the climate protection initiative of the Austrian Federal Ministry for Sustainability and Tourism, which is essentially divided into four main areas - Building & Renovation, Energy Saving, Renewable Energies and Mobility. klimaaktiv Building & Renovation stands for energy efficiency, ecological quality, comfort and execution quality. In order to be able to compare buildings with regard to these criteria, the klimaaktiv building standard was developed. New construction and renovation projects that meet the strict requirements in terms of location & quality assurance, energy & supply, building materials & construction, as well as comfort & indoor air quality are awarded such a designation. A building is assessed for all fulfilled and proven requirements with up to 1000 points, whereby three different quality levels (gold, silver and bronze) can be achieved. In order to ensure a meaningful comparison, a distinction is made between residential buildings and service buildings [3].

2. Implementation & Results

This chapter presents the results of a master thesis and an interdisciplinary project on the topic of "Mobile Micro Homes" written by students of the Upper Austrian University of Applied Sciences. In the end, a single-family house, which considers most of the aforementioned aspects, was built.

2.1 Development of a Building Technology Concept in Modular Design

The construction industry still has high potential in terms of efficiency in the construction of buildings on site. Despite the fact that the average Austrian household size is currently only 2.2 persons, the desire for home ownership is greater than ever. This poses entirely new challenges to the flexibility of the industry. The master thesis entitled “Development of a building technology concept for an innovative modular construction system” was prepared in cooperation with an Upper Austrian prefabricated house company and had the following objectives [1]:

- Preparation of building technology concepts from low to high-tech
- Implementation of a klimaaktiv building declaration for an office building
- Preparation of a building technology document (focus on heating & ventilation)
- Implementation of a photovoltaic simulation

2.1.1 Heating & Ventilation

As already described in the Chapter 1, infrared heating systems only can be economically operated in a building with passive house components. In the context of the master thesis, a modular design based lightweight construction building was considered. The annual heating requirement is 38,1 kWh/m^2a, which is equivalent to a low-energy house.

The annual heating costs with an installed capacity of 70W/m^2 (empirical value) would be € 1993.67 and therefore far above the average heating costs of a water-based heating system. Nevertheless, the implementation of a photovoltaic system (130m^2, 21,6 kWp), which covers nearly 75 percent of the electricity required for infrared heating, significantly reduces the heating costs. By signing a green electricity contract, the ecological aspect is taken into account as well [1].

In accordance with §10 of the "Upper Austrian Air Pollution Control and Energy Technology Law" (From the German "Oö. Luftreinhalte- und Energietechnikgesetzes"), in the state of Upper Austria, electrical resistance heaters may not be used as the main heating system in new buildings, except in justified exceptional cases [3].

Due to the fact that costs and flexibility play an important role in the project, it was decided to concentrate on a decentralized ventilation system. In cooperation with a wholesaler for ventilation units, a suitable concept for the modular building system was developed. The chosen ventilation system comes from a German producer which offers certified passive house ventilation units [1].

2.1.2 klimaaktiv Building Declaration

In order to emphasize the energetic, ecological and economic quality of the building, it was subjected to a klimaaktiv building declaration in the planning phase. The innovative building concept covers a wide range of possible applications. Therefore, two different plans were carried out. In the category Service Building, the (theoretical) bronze award was achieved by satisfying all essential criteria (with a total score of 523). Due to the fact that electrical heating and electrical hot water preparation have a negative effect on the primary energy requirement (PEB_{SK}) and on CO2 emissions factor ($CO2_{SK}$), a klimaaktiv declaration for residential buildings was not possible because these values were too high. The difference between green electricity and mixed electricity also has a very strong effect on the building's primary energy requirement, which should be taken into account when operating infrared heating systems or heat pumps [1].

It must be stated that klimaaktiv recommends infrared heating systems only for true passive houses with heating energy demand lower than 10 kWh/m^2a, including a ventilation system with heat recovery [7]. Further research is necessary to determine whether infrared heating systems in combination with low tech renewable heating systems (e.g. one room pellets stove and intelligent air ventilation management) make sense as a backup heating system for bathrooms and toilets when photovoltaic systems and/or other renewal energy are used.

2.2 Energy Self-Sufficient Cabin

Currently, there is an increased demand for mobile micro homes and module based buildings. An interdisciplinary project offered students from the Upper Austria University of Applied Sciences the opportunity to develop an ecological and economically interesting alternative to standard building solutions. The students had to face a variety of challenges especially in terms of renewable energy, ecological construction materials, energy efficiency and mobility. The project had the following objectives [2]:

- Research into the topic of module construction and mobility
- Substitution of expensive and non-ecological components used in the cabin
- Presentation of a building technology concept including CAD plans
- Optimization of the energy concept
- Economic calculations and comparison with other building concepts
- Construction of an exhibition object (sample wall)

2.2.1 Mobility and Ecological Aspects

The basic construction of the cabin is based on an innovative modular design and can be extended as required, depending on the field of application (see Figure 2). The transportability with a conventional truck (no special transport) had to be considered at every stage of the planning. This requirement means that the floor plan of the individual modules is limited to a maximum floor area of $15m^2$ (length: 5.00m; width: 2.50m). All changes to the interior or exterior wall have a direct effect on the already very limited living space. Therefore, a central problem was the ecological energetic optimization of the exterior walls. The students opted for a lightweight wood construction because it is unrivaled concerning ecology and ensures a healthy indoor climate. The thermal insulation consists of a combination of cellulose and soft-fiber boards. The entire wall construction has a thickness of only 32cm and has a heat transfer coefficient of 0.21 W/m^2K [2].

Figure 2. Standard modules for different applications [2]

2.2.2 Building Technology

The self-sufficient cabin contains many innovative ideas, which harmonize in interaction with each other. A well thought out concept that is not only ecological, energy-efficient and practical, but also looks good. Unfortunately, the realization of a 1:1 scale model would have exceeded the time constraints of the project and the budget. A sample wall (see Figure 3) was built, which reflects nearly all aspects of building technology and has already been presented at several internal and public events of the Upper Austria University of Applied Sciences [2].

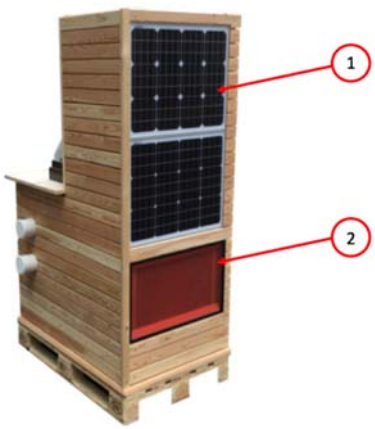

Figure 3. Front view sample wall with PV and cardboard honeycomb insulation [2]

Two integrated 50W monocrystalline PV modules (see Figure 3, No. 1) were installed for the energy supply. In series, they produce 24V direct current, which operates the floor-integrated infrared heating system without conversion loss. If no electrical current is required, the four gel accumulators (34Ah) monitored by the charge controller are charged. To operate household appliances, an inverter (24V DC to 230V AC) and a socket were installed. The cardboard honeycomb insulation (Figure. 3, No. 2) passively uses the sun's rays to generate heat when the sun is low in winter sky and prevents overheating in summer. The single room ventilation unit with an integrated heat recovery system efficiently exchanges the used, low-oxygen air with the fresh air from outside. Compared to manual ventilation systems, 80 to 90 percent of the heat can be recovered. In order to keep heat losses as low as possible, a passive house window was used [2].

2.2.3 Economics of the Cabin

In addition to the two key factors – comfort and sustainability – the cost-effectiveness of mobile tiny homes also plays a decisive role. The total costs for a ready-to-install standard module of the self-sufficient cabin ($15m^2$) amount to € 21,000 (price per m^2: € 1,400). These modules, which are manufactured by a carpenter in the Upper Austrian Ennstal, are also offered turnkey for approx. € 32,400 (price per m^2: € 2,160). At present, the price level is nearly equal to conventional prefabricated houses. In the long term, the price per m^2should fall due to the possibility of industrial production, continuously improved concepts and the increased use of Building Information Modeling [3].

2.3 From tiny homes to modular construction

Fascinated by the concept of mobile micro homes and their modular construction, in addition to the possibility of erecting a house in one day, the first author realized a small single-family home – an extended microHOME [5] with a modular lightweight wooden construction - near the center of a little community, considering most of the aspects of ecological construction (see Figure 4). The main floor of this building consists of 5 modules, which can be replaced later and built up on another site – perhaps introducing a modern way of living in and recycling a building.

Of course it remains to be discussed whether a single family house can be ecological at all. Therefore the concrete foundation level of this building provides space for the next generation. Additionally, this was the only way to fulfill the klimaaktiv essential criteria for heating energy demand because one of the main problems of micro homes is the very bad surface-to-volume ratio.

While redensification in cities is becoming more and more state of the art (e.g. roof extensions), ecological regional planning in rural zones remains the bigger challenge. New approaches are therefore needed, for example the possibility of packing buildings with higher density (e.g. 3-6 tiny homes per 1.000 m^2) in combination with upgrading the public transport systems.

Figure 4. Transport and construction of a module based home [8]

3. Conclusion

Mobility, sustainability and flexibility with regard to private homes are becoming increasingly important. A large number of construction and carpentry companies in Austria already offer mobile living ideas and concepts with a modular construction. More and more start-up companies have also been successfully founded on this basis, which confirms the trend in this direction. One reason for this development is the steady rise in real estate and building land prices, which is forcing both industry and the politics to search for innovative solutions. Mobile homes offer the possibility of renting land for a temporary period of time, allowing them to be adapted to one one's professional and private life changes. Therefore, this living concept can make an important contribution to the sufficiency of real estate.

Due to the continuous development of new housing concepts and work processes - keyword Building Information Modeling - it can be assumed that the costs for modular based buildings will fall in the near future. Nevertheless, a decrease in quality due to series production must be prevented. The flexible use of small residential modules also offers new possibilities for structural redensification in urban areas (see Figure 5). Combined with the consistent use of vacancy (e.g. rooftops, inner courtyards), mobile tiny homes can make a positive contribution to the economic development and the living quality of our cities.

Figure 5. Module based living concept on a rooftop in Berlin, Germany [9]

In terms of ecology and energy efficiency, today's tiny homes are in no way inferior to conventional single-family homes. However, the prerequisites for these are high-quality planning and execution, the use of sustainable construction materials and the use of energy-efficient building technology. The implementation of an infrared heating system in connection with PV and an electrical storage system represent viable alternatives for such building concepts. All of these projects show that modular based building concepts can be produced and operated in an economical and sustainable way. In the end, every person must decide for themselves, whether this living concept contributes to their personal well-being and corresponds to their way of life.

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