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Original Research Article

ANALYSIS OF THE POSSIBILITY OF DEVELOPING "EARTHSHIP" AUTONOMOUS BUILDINGS

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A b s t r a c t

This paper presents a general technical characteristics of autonomous buildings - earthship, an analysis of the results of surveys of the public's knowledge and perception of this construction technology compared to the studies presented in the literature, and the development of a SWOT matrix and its analysis in the context of the development and dissemination of the construction of autonomous buildings. The results show that this idea, in light of its drawbacks and the threats in the surroundings, is not able to gain a large number of customers and survive in its classical form. However, it was found that this technology is a possibility for proponents of living in harmony with nature and unusual architectural and technological solutions.

Keywords: autonomous buildings, earthship, sustainability, waste management

1. INTRODUCTION

The construction industry is one of the economic sectors with the highest environmental impact. Reports made, among others, by the EU on this subject are not optimistic, because the construction industry [1, 8]:

- consumes 1.8 billion tons of primary raw materials, i.e., uses 25% of the total demand for these raw materials,

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- generates annually about 0.6 billion tons of waste, which gives 36% of the total amount of waste,
- uses (mainly during the use of buildings) about 40% of the generated energy [11],
- within the energy demand of the building industry generates approx. 36% of total CO2 emissions.

So, it can be noticed that the production and exploitation of building structures is material-intensive, energy-intensive, transportation-intensive, cost-intensive and generates a lot of waste and pollutants. Therefore, methods of eliminating these drawbacks involving construction with local materials, reusable (not only materials but also water) and recyclable and low embodied energy. Today we observe an increased trend to implement the principles of sustainable development and circular building (in accordance with the circular economy) in building practice. Passive [21, 29] , green [28, 45], sustainable [35], smart [36], circular [8], etc. buildings are being developed.

One of the ideas for an autonomous building was the realization in the 1970s of the house named earthship by the architect M. Reynolds [12, 41]. It has found a lot of followers. Although in Poland and in the world, there are many anonymous realizations of buildings built earlier, which to a greater or lesser extent meet the above criteria.

In its general assumption, the earthship is an autonomous building with sustainable architecture, made of recycled materials and local raw materials. It meets six basic requirements for (ecological) living: shelter, energy, waste management, water, and food (Fig. 1) [27].

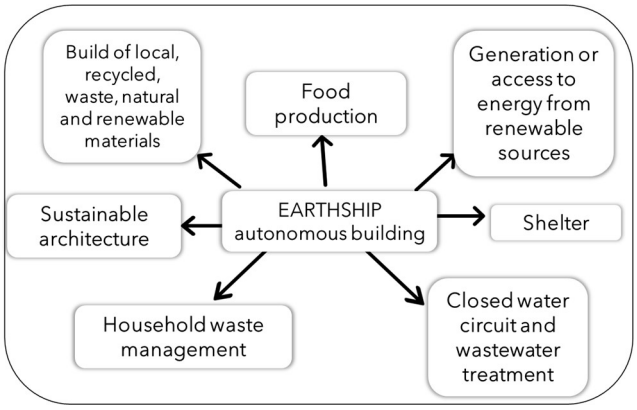

Fig. 1. Basic features of earthships
Source: own elaboration

In Poland, the knowledge about earthships is not widespread. Therefore, the aim of the article is to analyse the possibility of development of this type of

buildings. The paper includes their general technical characteristics, analysis of the results of surveys of the public's knowledge and perception of this construction technology in comparison with presented studies in the literature, and development of a SWOT matrix and its analysis (based on the SWOT/TOWS method) in the context of the development and dissemination of the construction of autonomous buildings.

2. EARTHSHIP - STATE OF THE ART

Figures 2 and 3 show examples of built earthships.

Fig. 2. Example of Erathship - Brighton Earthship [3]

Fig. 3. Example of Erathship [42]

Earthships are located in more than 40 countries and are located across all the climatic zones [7]. Their purpose ranges from residential buildings or schools to hotels or museums.

For the construction of earthships, materials are obtained from the immediate environment (e.g., soil from a from lot) or waste materials such as vehicle tires, metal cans, or glass bottles are used [12, 41]. The tires are filled with compacted soil (from the plot) or rubble and form retaining walls [16]. Such a structure is separated from the outside by a layer of vapour barrier foil (protection against external factors), while from the inside it is covered with a mixture of chaff, straw, and mud (filling gaps and irregularities) and a layer of plaster. The use of cans and bottles is not necessary, but they often give a unique character to such an object, creating walls resembling stained glass. All other elements of the building, not only the structural ones (window and door frames, glazing or equipment) are also very often made of recover materials.

The energy efficiency of earthship and the solutions used in this regard depend mainly on the climate in which the building is located [11]. The primary source of energy is the sun, often with buildings located in areas with less sunlight, wind is used as an alternative energy source. The demand for electricity is estimated at the design stage. Because the building usually does not require the use of non-renewable energy sources, the annual cost of energy used is close to zero.

Tires filled with earth are responsible for accumulating heat in the earthship. Tire walls (in buildings in the northern hemisphere) are laid on the north, east and west sides. This design provides the facility with the ability to accumulate thermal energy [15]. This means that the walls heat up during the day, and in the evening (when the temperature inside the building drops below that of the walls) the heat is released and warms the interior. The southern part of the building is usually a fully glazed wall. Its purpose is to provide adequate lighting and to capture heat energy to warm the floors and walls. The wall is inclined perpendicularly to the sun's rays falling in the winter. Such solution causes that in winter (when the building needs as much heat as possible) the exposure to sun rays is the biggest and in summer (in order to avoid heat) - the smallest. The disadvantage of such a wall layout is the lack of discretion in form the layout of the rooms. For this reason, operable walls are most often formed into a U-shape [41]. Earthship in summer does not need to be air-conditioned, thanks to cooling from the ground. Additional cooling in some buildings is supported by installed the earth tubes which are natural ventilation. Warm air entering the tubes is cooled by the surrounding earth. The air, due to the convection phenomenon, continuously flows into the building and escapes through the skylights mounted on the roof [40]. This article presents the results of a study on the effective use of this technology to provide an optimum temperature in the building, both in summer and winter.

In earthships the outer wall is inclined at a suitable angle, while the inner wall forms a corridor to the entrance of the building and is where the plants are grown. The owners can grow all kinds of plants here: herbs, tomatoes, or bananas.

Water is obtained from rain or snowfall. The sloping roof ensures that it drains to the rear of the building. The used water is treated and reused. It is divided into grey water (coming from sinks or showers) and black water (coming from toilets). Gray water used for watering edible plants and excess water used for flushing toilets. Black water is treated for particulate matter and used for watering non-edible plants [37]. For water to be potable it requires passing through a bacterial purification device and proper treatment. The collected water is used up to four times, so the house can function without taking additional water from the ground or the water pipe.

The concept of building earthships is in line with the principles of sustainable development and current standards of EU policy aiming to reduce energy consumption and maximize the use of renewable energy in the building sector [11, 34, 35]. Figure 4 shows the layout of an example eartship.

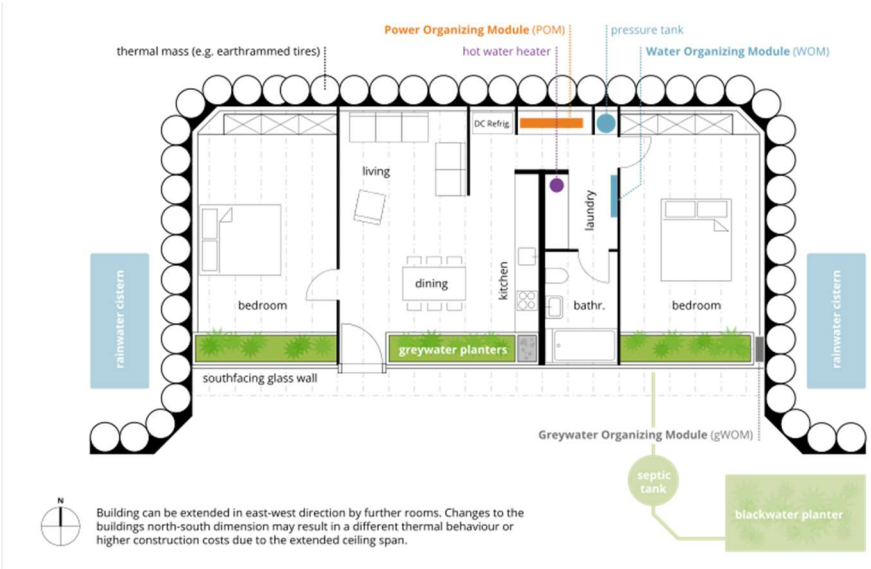

Fig. 4. Typical floorplan [31]

An incentive to build such a building is certainly the reduction or complete elimination bills. This is possible due to the autonomy of the building, grid-off and other elements of technical infrastructure. This has been confirmed by studies of operational earthships located in different cities (Paris, Albacete, Seville, Valladolid, and London). They prove that additional heating or air conditioning

systems are only necessary for buildings in extreme conditions (in areas with high sunlight or cloud cover) [7, 23].

The methods used to build earthships are considered to be low-tech and uncomplicated making them easy to learn by people outside the construction industry. Despite their low level of sophistication and simplicity, are relatively labour intensive compared to, for example, a frame house. The use of recycled materials reduces construction costs, but can increase labor time, which is common in self-erected and minimal environmental impact buildings [13] .

The use of waste or recycled materials reduces the cost of building construction. The construction of earthships requires about 20% less investment resources compared to a passive house [39]. However, you should expect higher initial costs for earthships, up to 20% more than for a standard building [4].

The use of renewable energy sources can reduce construction costs, as there are often opportunities to obtain various types of subsidies and grants resulting from EU policies.

The basic building materials used in earthship construction are mostly available locally, and their use contributes to reducing waste. Sourcing materials from the close vicinity also contributes to reducing transportation and CO_2 emissions. Additionally, earth materials used for e.g., wall plastering as shown by papers [2, 10] are able to ensure appropriate humidity for health (especially in hot climates) preventing the development of harmful bacteria or fungi. These materials also show the ability to absorb unpleasant odours [5].

Depending on the choice of the construction of the building, the plot of land on which it will be built must also be properly selected. When filling the structure with earth, a better choice will be a flat area. With the method based on digging into the slope and then securing it from the inside (by means of tire constructions), a plot of land with an appropriate slope is necessary. Attention should be paid to the appropriate type of soil, suitable for growing plants, as well as for use in the construction of the building. The aforementioned issues mean that the choice of plot cannot be random. It is necessary to take into account the impossibility of erecting a building in a dream location, as well as difficulties in finding a suitably adapted place. Additionally, such buildings will work best in suburbs, and not necessarily in the center of cities due to their design and size [39].

Since the building is located in the ground, there are also often dark spaces, creating difficulties in air circulation and problems with adequate lighting. Furthermore, darkened spaces can adversely affect the well-being of the occupants [4, 30, 43]. People oriented towards typical/standard architecture and solutions may have problems adapting in earthship.

It is necessary to adapt the building to the given location. When constructing a building in a given place, the surrounding environment, insolation, topography, frost line and groundwater level must be evaluated. These aspects

guide the designer's choices and result in solutions that will vary from project to project. For example, in climates with long winters, more heat is needed, so glazing will be placed on the south façade to maximize sunlight. In contrast, a region with hotter summers will likely have northern glazing to reduce heat access [1].

It is worth noting that earthship is a great option for those interested in unusual architecture. Each building is unique and unusual, and thanks to the use of recycled furnishings that are unique.

People who choose to live in an Earthship must be aware of the need for rational and economical use of utilities and limited access to amenities that users of typical buildings can enjoy. However, increasingly communities in countries around the world are aware of the need to protect the environment, reduce consumer lifestyles, and agree with the need to implement sustainable development and a circular economy. They are interested in an ecological and nature-conscious lifestyle. The research presented in [7] shows that environmental aspects as the main benefits of building earthships outweigh the cost savings of building them. The principles of autonomous lifestyle are considered as stimulants rather than barriers to the establishment of earthships. Therefore, it can be considered that the chances of finding potential investors/owners of this type of buildings increase among people interested in environmental issues and living in accordance with nature. This requires the propagation of information about earthships, their construction technology, etc., resulting in increased demand and interest in them [13].

Designing and building earthships brings many problems. There is a lack of appropriate legal regulations, lack of guidelines, norms and standards for the design and safe use, lack of a system for financing such an investment. In many countries the typical assumptions on which the functionality of earthships is based do not meet the current norms and standards. This is, for example, the lack of foundations (they are replaced by a retaining wall made of tires), minimal lighting (only one glazed wall, often additionally obscured by vegetation) or use of alternative building materials, which lack information about meeting the requirements of safety of users and the environment [13].

It is difficult to find designers who will reconcile the current regulations with the basic requirements to be met by this type of building. There is also a lack of professional construction contractors. Lack of specialists can be a problem also in case of renovation or repair of defects [18].

Although earthships are extremely energy efficient and environmentally friendly, autonomous and can meet basic human needs, there is still a need to improve their design, materials, and technological solutions. Issues to be addressed include increasing the amount of light, improving ventilation, reducing

construction costs, and carefully testing the materials used for durability or impact on the health of building users [13].

3. RESEARCH, ANALYSIS AND EVALUATION OF EARTHSHIP DEVELOPMENT OPPORTUNITIES

3.1. Methology

The SWOT/TOWS method was used to achieve the purpose of the study. SWOT/TOWS analysis is a method of assessing the strategic situation of the object under study (e.g., an enterprise, project, product, etc.) [33]. It is based on the evaluation of both internal and external conditions affecting the object of analysis. The analysis is conducted to determine the current and forecast future position in the market by selecting an appropriate operating strategy [24].

The first step is to determine the opportunities (O) and threats (T) from the object's environment, as well as the weaknesses (W) and strengths (S) that characterize the object of study, and present them in the form of a matrix. The next step is to assign weights to the factors, so that their sum in each category is equal to 1. Then 8 tables comparing the categories should be developed (SWOT analysis: S-O / S-T / W-O / W-T; TOWS analysis: O-S / O-W / T-S / T-W) [33]. Tables in SWOT analysis answer the question of how given internal factors (strengths and weaknesses) interact with external factors (opportunities and threats), while in TOWS analysis how the external environment interacts with the object under study. One way to assess the impact is to identify dependencies in a 0/1/2 system (where 0 - no impact, 1 - low impact, 2 - significant impact). The next step is to count the number of interactions for each row and column separately and add them up for the whole table. After adjusting the results for weights, a weighted number of interactions between the two categories is formed. The SWOT-TOWS analysis is summarized in a table containing the number and weighted number of interactions, which is the sum of SWOT links and TOWS links [24]. The largest weighted value indicates the strategy the company should take. The following strategies are distinguished [20]:

- aggressive strategy (maxi-maxi) – strengths and opportunities prevail,
- conservative strategy (maxi-mini) – weaknesses and opportunities prevail,
- competitive strategy (mini-maxi) – strengths and threats prevail,
- defensive strategy (mini-mini) – weaknesses and threats prevail.

For the purpose of the study objective, a questionnaire-based pilot study on the public's interest in and perception of earthships and an expert survey (conducted in March 2022 and was attended by 17 people involved in sustainable

construction) were conducted to assess the importance of each factor of the SWOT matrix and to conduct a SWOT/TOWS analysis.

To develop the first study - a survey, publications with the results of similar studies [7, 13] conducted in the UK were used. These studies assessed the demand for this type of buildings among future homeowners. The characteristics of the survey, along with a comparison to the aforementioned studies, are shown in Table 1. The pilot survey was conducted with 33 participants. The survey questionnaire was posted on several different websites and shared via email. It consisted of 11 mostly closed questions on the issues listed in Table 2. The survey was conducted in January 2022. Due to the mediocre knowledge of this type of building in Poland, the questions were preceded by a brief description and convention of earthships.

Table 1. Comparison of studies *Source: own elaboration*

Research / **Compared characteristic**	**Own research** on the interest in earthships in Poland.	**Brighton Earthship** – a building built by volunteer workers in the United Kingdom; it serves as a demonstration building, allowing visitors to learn about the concept of earthships, their functioning and construction [14, 19].	**Earthship Fife** – a building constructed for demonstration and research purposes to identify developments and aspects that need to be changed in design/law to popularise the idea of earthships in Scotland [17].
number of respondents	33	31	94
purpose of the study	assessing the public's interest in and perception of earthships	assessing the demand of prospective homeowners; learning about opinions on the pros and cons of earthship	assess demand for renting/buying/building earthships; identify barriers
form of questions	11 mostly closed questions	rating by participants of the listed advantages and disadvantages of earthship on a five-point scale	17 closed questions and a section to add comments
access form /respondents collected	websites, e-mail	visitors to the Brighton Earthship	paper form, websites, e-mail

3.2 Research Findings and Their Analysis

The results of the survey, along with a comparison of information from studies published in the literature [7, 13], are shown in Table 2. Data from the survey and literature review were used to compile a SWOT matrix (Table 3). Table 4 presents a summary of the results of the SWOT/TOWS analysis.

Table 2. The results of the own study along with a comparison to other studies
Source: own elaboration

Id.	Research / Characteristic under study concerning earthships	Results obtained in the study	Comparison to other studies
1	knowledge of the idea	27 %	65 %
2	the most appreciated advantages (among those listed in table 4)	implementation of the principles of sustainable development and circular economy	the same
3	the most troublesome defects (among those listed in Table 4)	– unsuitable technology for densely populated urban areas, – labour intensive building process, – need to adapt the design to the chosen site,	– difficulty in identifying suitable building plots, – unsuitable for densely populated urban areas, – labour intensive building process,
4	appreciation of the green lifestyle offered	80 %	-
5	appreciation of the nature-compatible lifestyle offered	77 %	-
6	difficulties that most discourage construction (among those listed as threats in Table 4)	all listed in the matrix (30%),	obtaining the necessary permits and permissions for planning/building
7	discouraged by construction due to its defects	73 %	-
8	willingness to live	46 %	41 %
9	willingness to live after some barriers/disadvantages have been addressed	62 %	-
10	barriers/disadvantages whose elimination would encourage construction	– formal difficulties, – controlled consumption of utilities, – lack of government support, – improvement of technology, – labor-intensive construction process, – lack of information,	-
11	interest in further development	69 %	73 %

Table 3. SWOT matrix *Source: own elaboration*

Strengths (S)	Weight	Weaknesses (W)	Weight
Reducing building maintenance costs;	0,168	Use of waste materials/ not fully tested building materials;	0,132
Using recycled materials/locally sourced construction material;	0,159	Weak recognition of safety and health aspects at the use stage;	0,125
Lower life cycle costs (LCC) compared to other buildings;	0,145	Unsuitable technology for densely populated urban areas;	0,123
Implementation of the sustainable development and circular economy strategy;	0,140	Utilities dependence on renewable resources and weather conditions;;	0,112
Easy to build('do-it-yourself');	0,137	Difficulty in identifying suitable building plots;	0,110
Integrating the building into the natural landscape;	0,134	Labour intensive building process;	0,107
Unusual/Unique Lifestyle;	0,116	Initial costs greater than ordinary buildings;	0,102
		Need to adapt the design to the location;	0,100
		Futuristic/ Unusual building design;	0,089
Opportunities (O)	**Weight**	**Threats (T)**	**Weight**
The desire to stop environmental degradation;	0,219	No legislation;	0,210
Trend towards sustainable living;	0,207	Lack of technical specifications for earthships;	0,207
Demand for residential buildings;	0,206	Difficulty in obtaining the necessary permits and permissions for planning/building;	0,200
Development of wasteland;	0,192	Deficiency of qualified construction crews and designers;	0,198
Increase education about earthships;	0,176	Difficulty in obtaining financing (high financial risk rating);;	0,185

Table 4. Results of SWOT/TOWS analysis *Source: own elaboration*

Combination	Results of SWOT		Results of TOWS		Sum of SWOT/TOWS	
	Sum of iterations	Sum of products	Sum of iterations	Sum of products	Sum of iterations	Sum of products
S/O	64	11,147	68	11,721	132	22,868
S/T	14	2,339	36	6,084	50	8,422
W/O	52	8,225	40	6,296	92	14,521
W/T	76	11,822	86	13,389	**162**	**25,211**

The SWOT matrix analysis shows that building and living in earthships has many advantages. The most emphasized, also by the survey respondents, is the low environmental impact, with all the related aspects (saving energy, water, etc.). And experts appreciated the fact of eliminating bills for some or all utilities.

However, the disadvantages are equally numerous. In particular, according to the respondents, these are the labour-intensive building process and the need to adapt the design to the chosen location and the use of waste materials/not fully

tested building materials. There are also problems with finding a suitable building plot and the low possibility of building an earthship in a densely populated urban area.

Despite its numerous advantages, it cannot be said that an earthship is a building for everyone, as evidenced by the numerous listed drawbacks, the low declaration of desire to build this type of facility, and the respondents' selection of all of the listed barriers/difficulties as factors that strongly discourage construction. This is also confirmed by the results of the SWOT/TOWS analysis. The SWOT/TOWS analysis showed that the strategic situation of earthships can be described as defensive (mini-mini). This suggests that this idea, in light of its shortcomings and the prevailing threats in the environment, is not able to attract a large number of customers and survive in its classical form (apart from a few cases resulting from interest in this unusual technology).

4. DISCUSSION

Education for sustainable development is promoted as one of the important elements in the pursuit of sustainable development [6] [26] [32]. It is worth emphasizing that the discussed idea of earthships may enjoy greater interest among the society if legal and informational barriers are overcome [7]. Therefore, there is a gap in the number of people who have adequate knowledge and who share information about earthships and help those interested in solving legal or construction (design) problems. Surveys also confirm the poor knowledge of this technology in the society.

The market for recycled materials is strongly influenced by social beliefs, which are driven by social and economic trends and require knowledge and practice in proper waste management. An increase in the aforementioned awareness and a guarantee of the quality of the raw material will lead to a change in requirements and thus an increase in demand for recycled materials [38]. The increase in the level of waste recycling in European countries, confirmed in the work [25], can promote the development of eartships, the assumptions of which are largely based on the reuse of waste.

Complications in building planning and financing are seen as a challenge, regardless of the type of building being built [7]. Thus, it is not surprising that these issues top the list of barriers to earthship construction in the study [22]. Hence, the desire to make this technology more widespread would require the involvement of participants in the construction process in changing the legal approach to facilitate the "path" to earthship construction and ultimately to sustainable living [2]. As an example, it is worth citing again the research, as a case study, of Earthship Fife [13]. Building laws vary from country to country, so such an initiative in countries interested in spreading this idea would help allay

the fears of those interested in building an earthship, show how to modify the design to meet current standards and requirements, or resolve questionable legal issues blocking the construction of such a building.

It cannot be considered that such objects could massively replace the current buildings and living in them would be a standard. The "sustainable" solutions used in earthship construction are now being used in the construction of standard buildings - thus reducing, at least partially, their environmental impact. As already mentioned in the article - saving and using energy from renewable sources, collecting, and using rainwater, using partially or fully recycled materials (e.g., reinforcing steel). In the passive building industry, which has been widely developed for many years and is focused mainly on minimizing energy supplied to the building, solutions leading to the circular building are being researched and introduced. Closed circuits of water, air, energy are used, as well as materials made of recycled construction waste are researched and used for building shells and finishing [34]. Research is also being conducted in terms of autonomous buildings in the broadest sense (not necessarily in every aspect) In particular, there are issues related to energy self-sufficiency [9] or water and sewage self-sufficiency [44].

5. CONCLUSIONS

Taking into account the advantages and disadvantages as well as the opportunities and threats, it can be concluded on the basis of the factors presented in the SWOT matrix and the SWOT/TOWS analysis that there is potential for the development of earthships, although not necessarily in its classic form. Especially in densely populated areas not all of the above mentioned 6 needs of the inhabitants can be met.

Earthship is a very unusual, revealing, and controversial building, but it complies with the idea of sustainable development. It can attract users not only with the guarantee of low maintenance and usage costs, but also, as research shows, with pro-ecological issues.

Given the scarcity and high cost of ordinary buildings, there seems to have never been a greater need for an alternative solution to meet people's housing needs. This technology is an opportunity for proponents of living in harmony with nature, unusual architectural and technological solutions. In addition, the widespread recognition that the world's resources are finite and resource use must be reduced, waste generated must be reduced, positions some of the technologies/solutions used in earthship as alternatives to some traditional methods (e.g., using waste as a construction material). It can also be noted that despite the rapidly developing passive building with sustainable construction and circular economy principles, earthship autonomous buildings, also by providing

food, can complement the construction markets not only its market niche, but also on a larger scale as a market segment, overcoming existing barriers to its development.

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