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Review

The Role of Buildings in Rural Areas: Trends, Challenges, and Innovations for Sustainable Development

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Abstract: Rural buildings represent the functional relationship between rural communities and agricultural land. Therefore, research on rural buildings has practical repercussions on environmental and socio-economic sustainability. Comprehensive state-of-the-art research on rural buildings may address research activities. We present a systematic review of the scientific research between 2000 and 2022 based on the PRISMA protocol. Five main topics were identified. The results showed that the primary research focus was production (25.1%) and environmental management issues (23.2%). However, construction and efficiency are rapidly taking centre stage (20.6%). Regarding sustainability (20.8%), life cycle assessment, green buildings, recycling and global warming should be the future research focus. Energy efficiency will benefit from studies on thermal energy. More research on engineering and technologies (10.3%), specifically remote and automatic detection and transport in rural areas, will increase cost efficiency. The results may help improve the global efficiency of rural buildings in a modern farming system.

Keywords: rural development; farm building; sustainable construction; smart technologies

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1. Introduction

Born to meet the need to connect the agricultural activity of product manipulation to the production environment, rural buildings represent the intimate bond between man and the rural environment. Although an official categorisation is not available, rural buildings can be classified into three major categories, i.e., production, residential and cultural. According to Picuno [1], the production buildings can be further divided into three sub-categories, designed for animal breeding, crop production and agro-food.

Over time, priorities of the production buildings planning focused on four essential topics. One first issue is the mitigation of the environmental impact. The first works aimed at assessing the environmental pollution of rural buildings. For example, in 2009, van der Werf et al. [2] proposed an operational method based on the life cycle assessment (LCA) concept for evaluating the environmental impact of dairy barns. In 2005, Basset-Mens and van der Werf [3] compared the environmental impact of different pig production systems and used their findings to provide practical recommendations for improving farm practices in the three scenarios. According to the authors, building characteristics could be the most effective solution to reduce NH_3 emissions in the long term. More recently, research suggested solutions to reduce the environmental impact of rural buildings. For example, a recent literature review [4] demonstrated that adopting smart tools can potentially reduce polluting gas emissions and soil and water contamination. Moreover, the concept of "green building" has been developed. A green building is built with local and environmentally friendly materials and ensures the conservation of natural resources [5]. However, implementing green agricultural buildings still needs to be improved [5,6].

The second major topic related to production buildings is indoor environment control. Several researchers designed specific models for monitoring indoor climate control. For example, Schauberger et al. [7] proposed a steady-state balance model and assessed the influence of building characteristics on indoor conditions, such as the number of wet surfaces. Xie et al. [8] evaluated a dynamic thermal exchange model for swine buildings using the energy balance equation under three ventilation modes. The simulated values highly correlated with the actual values (R^2 = 0.945). Additionally, studies on hygiene and biomonitoring of indoor environments were carried out [9,10].

Such studies introduce the third essential research topic related to the production buildings: animals' and workers' welfare. Nowadays, the concept of one health highlights that human health is not isolated but connected to the health of animals and environments [11–13]. Therefore, considerable research has been yielded on space allowance, floor type and monitoring sensing technologies [14–16]. Moreover, the workers' welfare has also been examined by several studies. For example, works analysing Sick Building Syndrome, a non-specific syndrome affecting agricultural workers caused by mycotoxins, aim to propose some solutions in the building design stage [17,18]. The last primary topic is energy efficiency. Pan and Mei [19] provided an overview of the energy consumption of rural buildings in severe cold regions. The authors analysed the functional structures of rural buildings, such as windows, roofs, walls, and their effects on energy consumption. Based on their findings, they designed a demonstration building ensuring energy saving. Moreover, several authors worked on photovoltaic and solar systems for energy efficiency [20,21].

The goals under the Kyoto Protocol and the Paris Agreement promoted deep decarbonisation in the building sector [22]. Concurrently, the minimum requirements dictated by the international treaties for animal protection (e.g., EU 2008 Council directives [23,24]) have imposed a redesign of stables.

Rural residential buildings' characteristics differ depending on the country's development [25]. There is no sharp distinction between rural and urban houses in developed countries. The comfort level of residential houses is a primary objective for rural communities and their policymakers. For example, the European Union enacted the Energy Performance of Building Directive (EPBD) to address the energy consumption issue of the building sector in 2010. However, energy-saving policies in developing countries are hindered by increasing social development [26]. Therefore, several rural residential building improvements, such as environmental impact mitigation and increased thermal-energetic efficiency technology, are more critical in developing countries [25,27,28].

The cultural buildings include traditional, heritage and rural public buildings. The role of cultural buildings is to promote and preserve the territory. Their conservation creates a sense of belonging, strengthening the relationship between rural communities and territory [29]. Moreover, they can promote rural and environmentally friendly tourism [30]. Tools such as Geographical Information Systems (GIS) were used to support the spatio-temporal analysis of traditional rural buildings with an efficient approach [31,32].

Analysing the picture of research related to rural buildings allows for understanding the path taken by scientific research and identifying the tendencies and the research gaps that need to be filled. Several studies aimed at providing a literature review on rural buildings have been published in past years. Recently, Picuno [1] contributed a literature review on the types of rural buildings and their role as drivers of the rural environment. This paper accurately describes features, materials, and indoor and outdoor environmental conditions. Previously, Barnwell [33] focused on historic rural buildings and their connection with agricultural history. Several reviews have been yielded on specific aspects of the rural construction sector. Švajlenka, et al. [34] proposed a detailed investigation of monitoring methods of indoor environments [34–36] and building materials [37,38]. Maraveas and Bartzanas [36] reviewed all the sensing tools and technologies available for farm structural health monitoring. In their work, the authors highlighted the benefits and constraints of using different sensors, providing an exhaustive examination of the state-of-the-art.

Other reviews focused on building materials. For example, Maraveas [38] examined the effects of corrosion-inducing chemicals contained in animal manure on concrete and metals. Picuno [37] retraced the history of traditional building materials stressing their current utilisation opportunities for sustainable buildings. However, a comprehensive review allowing the analysis of the long-term evolution of research on the rural buildings sector critically and systematically is missing.

This paper represents a systematic review of the research literature from 2000 to 2022 in the rural building sector. The objectives of this work are to (*i*) highlight the research tendencies, (*ii*) analyse the evolution over time of the leading research topics, and (*iii*) identify research gaps to address future developments.

2. Materials and Methods

We analysed the research on rural buildings through a systematic review considering the papers published between 2000 and 2022. Systematic reviews allow us to identify research trends, tendencies and gaps, thus, providing a comprehensive overview of the research topic from a theoretical and methodological point of view [39].

To carry out the systematic review, we used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Diagram [40], revised to be adapted to agricultural research [41]. According to this modified diagram, the steps for conducting a systematic review of agricultural literature are (*i*) Scoping, (*ii*) Planning, (*iii*) Identification/Search, (*iv*) Screening, (*v*) Eligibility/Assessment, and (*vi*) Presentation of the results.

2.1. Scoping

Scoping is the initial step which allows for addressing the review process. This phase consists of setting up the review protocol and prior systematic reviews on the same topic. After identifying the papers published from 2000 to 2022, all prior reviews on rural buildings were examined. This analysis allowed excluding previous similar research and determining the issues related to rural buildings that guided the research interest so far. A total of 50 previous reviews were found and investigated by classifying the critical research questions.

2.2. Planning

Planning involves establishing the criteria for extracting the papers to include in the systematic review. The database must be configured in this step, including the scientific literature and the search query.

According to Pranckutė [42], Scopus is a database containing broader and more inclusive content. Therefore, for the current review, we extracted papers from Scopus. We built a custom string with a combination of keywords and Boolean arguments. Then, we typed it in the Scopus advanced search tool, limiting the search to "Title, Abstract and Keywords" of papers written in English, published in Journals and classified as papers or reviews (Table 1). The string included synonyms commonly used to designate rural buildings.

Table 1. The search string used for document extraction (ar = article; re = review, j = journal).

Database	Search Query
SCOPUS	(TITLE-ABS-KEY ("agricultural building") OR TITLE-ABS-KEY ("rural building") OR TITLE-ABS-KEY ("rural buildings") OR TITLE-ABS-KEY ("agricultural buildings") OR TITLE-ABS-KEY ("farm building") OR TITLE-ABS-KEY ("farm buildings")) AND PUBYEAR > 1999 AND PUBYEAR < 2023 AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re"))

2.3. Screening

This phase includes the string execution and preliminary examination of the extracted papers. The string was executed in Scopus, and the results were exported as comma-separated values (.csv) document. All data included in the csv were revised, and duplicates were removed. Then, the papers were imported in Mendeley Desktop v. 1.19.8.

2.4. Eligibility/Assessment

This step is necessary to establish the papers' inclusion and exclusion criteria in the systematic review. First, we followed the eligibility criteria proposed by Koutsos et al. [41], who classify the strength of evidence of research papers based on their type. Based on such classification, only "articles" and "reviews" were considered, while opinion papers, conference papers and workshops were excluded. After exporting the papers from Scopus, all the abstracts were carefully examined to decide whether to include or exclude the papers in the systematic review.

2.5. Presentation/Interpretation

This final step consists of presenting and discussing the findings. To reach this stage, however, the words contained in the selected papers were previously managed with a text-mining technique. Text mining allows transforming unstructured text into a structured format to identify meaningful patterns and new insights.

Specifically, all the words contained in titles, abstracts and keywords of the selected papers were extracted in an Excel spreadsheet and pre-processed to reduce redundancy and exclude meaningless information. The pre-process consisted of joining compound words (e.g., thermal performance), removing meaningless items (e.g., symbols), deleting low-frequency words (i.e., words appearing one or two times), and disambiguating the sense of some words (e.g., to elucidate the ambiguity of acronyms). A detailed explanation of the text mining process adopted in this review can be found in Cogato et al. [13]. Finally, using the wordStem command in R statistical software (Version 4.4.2, RStudio Version 2022.12.0+353), a stemming algorithm was applied to the final list of words and word stems were obtained. Although stemming and the identification of similar terms can be performed manually, software-guided stemming has the advantage of assuring higher replicability of the results.

Based on the analysis of previous reviews on rural buildings, five broad topics were identified. Each stem obtained from the pre-processing of words was then assigned to one of five clusters, depending on which of the five topics it was more akin to. Furthermore, sub-clusters were identified within each cluster, and a similar stem-subcluster assignment was performed.

The pre-processing of words and the allocation of stems in clusters and sub-clusters were followed by the preparation of the bibliographic database. The database contained the year of publication of each bibliographic entry and a textual field obtained by pasting its title, abstract and keywords. The words contained in this textual field were converted into stems, and only stems that were part of the list obtained from the words pre-processed were retained.

Given the stem cluster assignments, we computed in R the importance of each cluster in the whole corpus of documents calculating, in the textual field of the bibliographic database, the relative frequency of stems pertaining to the cluster, as detailed in (1):

$$s_i = \frac{n_i}{N} \tag{1}$$

where s_i is the share of cluster i, n_i is the count of stems that are part of cluster i (where the assignment of stems to clusters was performed as described above), and N is the total number of stems in the documents.

To introduce a time component in the analysis, the 23 years were divided into five four-year periods and one three-year period (2020–2022), and the share of each cluster was computed within each period. The frequency formula is reported in (2), where the t subscript is added to denote the time period:

$$s_{it} = \frac{n_{it}}{N_t} \tag{2}$$

The same analyses were conducted at the sub-cluster level. In this case, however, the relative frequency of each sub-cluster was computed within the cluster they pertained.

A final analysis was conducted to provide a global overview of topic co-correlation. This analysis was performed by counting the number of co-occurrences of stems within the same document (i.e., Title, Abstract and Keywords). The graphical representation of the intercorrelations between the stems was created with Gephi 0.10.1 (Gephi® Consortium, Compiegne, France).

3. Results

3.1. Overview of the Scientific Literature

The papers extracted from SCOPUS with the search query were 1492; however, after checking for duplicates, three records were removed. Therefore, 1489 papers were considered for this systematic review.

The preliminary analysis was the objective investigation of published reviews on rural buildings. According to the classification provided by SCOPUS, 50 out of 1489 extracted publications were reviews. However, after their examination, only 41 were considered as reviews in this study.

In order to better understand the different research approaches, we identified five main topics related to the literature on rural buildings (Table 2). Thus, we attempted to classify the five topics by attributing them to a name as descriptive as possible. The first topic, "*Construction and efficiency*", refers to building materials, strategies and planning/design. The second topic is "*Engineering and technologies*", involving technologies, systems and tools for handling and monitoring building responses and performances. Then, we identified the topic "*Environmental control and impacts*" associated with the indoor and outdoor conditions survey to ensure health, hygiene, and environmental protection. The fourth topic is "*Productions*", i.e., the intended use of rural buildings (e.g., crop or animal production). The final topic we identified concerns environmental and socio-economic "*Sustainability*".

Table 2. Synthesis of previous reviews involving some aspects of rural buildings. The reviews were classified into five major topics.

Topic	Summary of Reviews	Year	Reference
Construction and efficiency	Durability of timber structures	2000	[43]
	Durability of metal structures	2000	[44]
	Snow load requirements of rural buildings	2002	[45]
	Pole building construction in the farm sector	2004	[46]
	Energy use and reduction in the building sector	2010	[47]
	Economic convenience of photovoltaic systems in Italian farm buildings	2013	[48]
	Sheep wool fibers as building components	2020	[49]
	Investigation on durability and corrosion of materials for farm buildings	2020	[38]
	Thermal and acoustic insulation panels	2021	[50]

Table 2. *Cont.*

Topic	Summary of Reviews	Year	Reference
Engineering and technologies	Solid-state NMR spectroscopy	2008	[51]
	Formation of the stable cluster phase in colloidal suspensions	2009	[52]
	Numerical methods to solve engineering problems	2015	[53]
	Cost-benefits of sensors used for structural health monitoring	2021	[36]
Environmental control and impacts	Improving fire protection in agricultural buildings	2003	[54]
	Ventilation design of agricultural buildings	2004	[55]
	Grazing management to reduce the potential for badger cattle contact	2010	[56]
	Particulate matter in livestock production systems	2010	[57]
	Volatile organic compounds in swine buildings	2012	[58]
	Air pollutants in swine buildings	2012	[59]
	Indoor environment monitoring	2018	[34]
	Passive cooling systems for livestock buildings	2019	[35]
	Meta-analysis of measured ammonia and methane emissions from dairy barns	2021	[60]
	Effects of climate control on intensive livestock farming	2021	[61]
	Computational Fluid Dynamics (CFD) studies applied to greenhouses and livestock buildings	2022	[62]
Productions	Rural buildings as a source of historical evidence	2005	[33]
	Investigation of archaeological Australian rural buildings	2008	[63]
	Alpine summer farms as an element of cultural heritage	2010	[64]
	Anaerobic digestion in Indian farm buildings	2010	[65]
	Architectural details of vernacular buildings	2012	[66]
	Most used methods to quantify ammonia emissions from fertilisers	2020	[67]
	Analysis of different typologies of rural buildings	2022	[1]
Sustainability	Sustainable reuse of derelict rural buildings	2004	[68]
	Gasifiers functionality	2008	[69]
	Lean methane combustion	2008	[70]
	Stable water isotope simulation in reservoirs	2009	[71]
	Impact of climate change on intensively housed livestock	2011	[72]
	Flood damage to agriculture, including buildings	2013	[73]
	Barn owl behaviour in a rural environment	2015	[74]
	Traditional materials in farm buildings to increase sustainability	2016	[37]
	Ecological surveys for badger activity monitoring	2017	[75]
	Adsorptive desulfurisation of liquid fuels and regeneration attempts	2022	[76]

The documents were analysed over five four-year periods (2000–2003; 2004–2007; 2008–2011; 2012–2015; 2016–2019) and one last three-year period (2020–2022). The course of scientific publications on rural buildings over time is reported in Figure 1. The number of documents reported in Figure 1 is normalised based on the total amount of papers published in the subject area "Agricultural and Biological Sciences" in the same period. The normalisation allowed us to evaluate the actual trend of the topic without confusing it with the constantly growing trend of publications in the agricultural and biological sciences.

The trend shows a sharp increase in the four years 2008–2011; then, the published papers decreased, although showing a growing trend from 2012 to 2022.

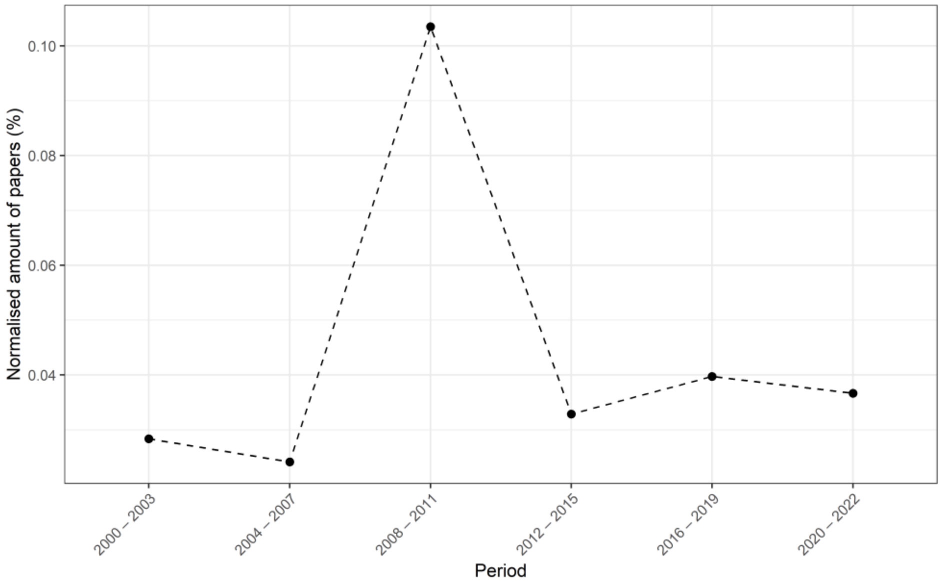

Figure 1. The trend of publications on rural buildings from 2000 to 2022. The number of documents was normalised based on the totality of documents in subject area "Agricultural and Biological Sciences".

Using the geographical classification provided by Scopus, the trend of published papers in the first five contributor countries (US, China, Italy, UK, and Canada) is reported in Figure 2. The US prevailed throughout the observed period, whereas China showed a rapid increase starting from 2008–2011 and currently ranks second. Similarly, the contribution of Italian authors increased over time, and to date, Italy is the third contributor country (Figure 2).

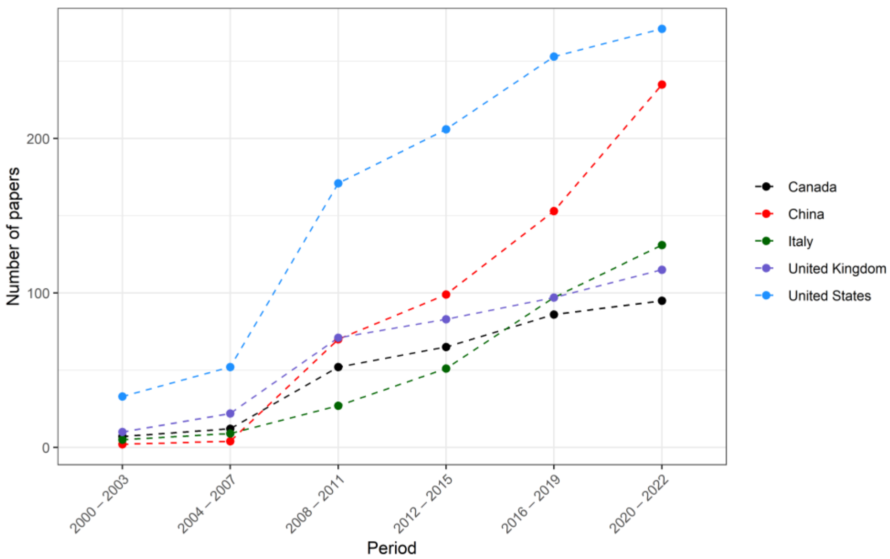

Figure 2. Cumulated number of papers of top five country contributors over the observed period.

3.2. Research Trends Analysis

According to the five topics identified in the analysis of previous reviews, we divided the extracted stems into five clusters and examined their size in the whole corpus of papers (Figure 3). Over the observed period, there was a substantial balance between clusters.

However, there was a slight prevalence of content related to Productions (25.1%), while scientific research on Engineering and technologies was lacking (10.3%).

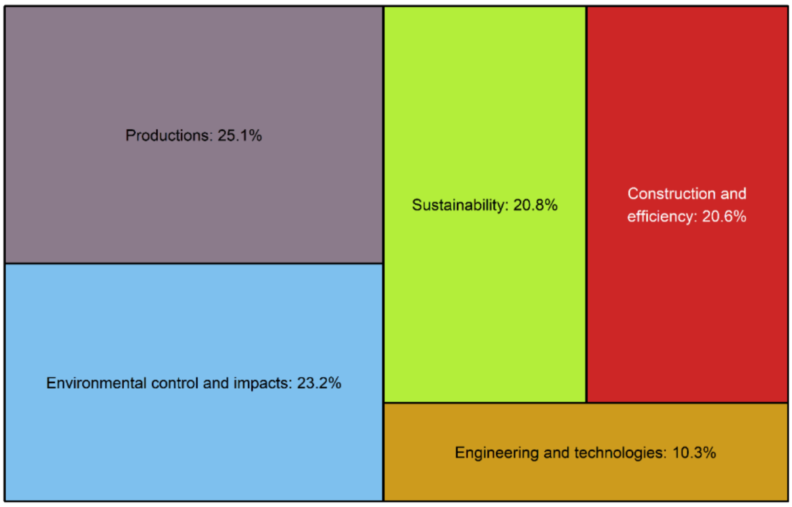

Figure 3. Cluster size: percentages of stems pertaining to the five major clusters over 2000–2022. The area of the rectangles is proportional to the cluster size in terms of percentage of stems included in the cluster.

The following step was to investigate the course of the five clusters over the years (Figure 4). The largest cluster, representing the topic "*Productions*", maintained a constant trend from 2000 to 2019 and then showed a slight decrease in the last three years. The cluster "*Environmental control and impacts*" highlighted a peak in the first four-year period and then decreased until 2011. Afterwards, the interest of the scientific community on this topic was resumed. After a culmination in prevalence in the four-year period 2004–2007, the topic "*Sustainability*" preserved a constant but upward trend. The cluster "*Construction and efficiency*" highlighted a constantly growing tendency from 2000 to 2022. Finally, the smallest cluster, "*Engineering and technologies*", displayed a rather constant trend with a peak in 2008–2011 and another in the last three years.

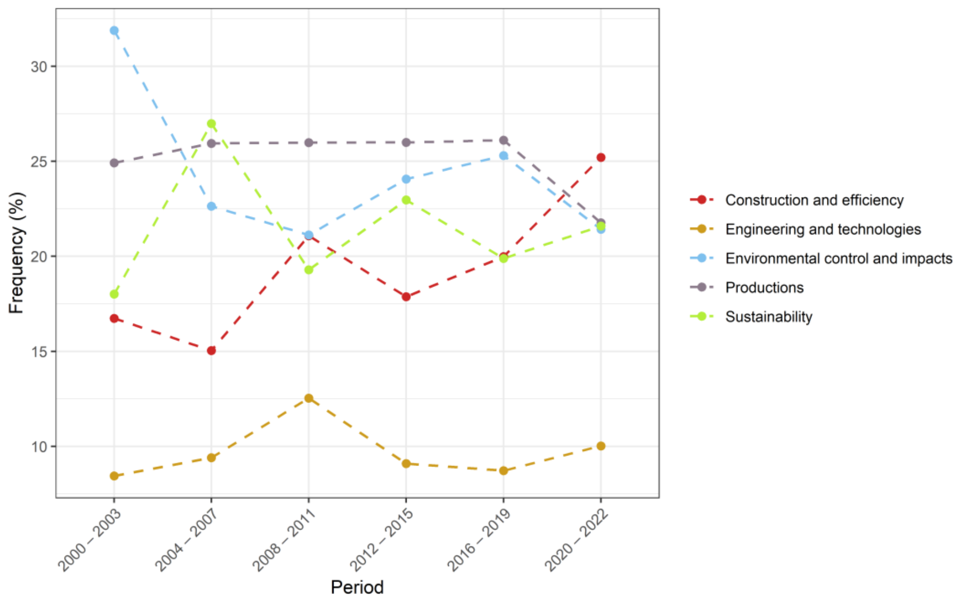

Figure 4. Trend of the five clusters over 2000–2022.

3.3. Research Tendencies and Gaps

To better understand the results obtained, we divided the five clusters into sub-clusters. This analysis was necessary as each cluster contained rather heterogeneous words. The subdivision into sub-clusters provided a comprehensive, detailed overview of the scientific literature on rural buildings. Figure 5 shows the 19 sub-clusters identified and their size.

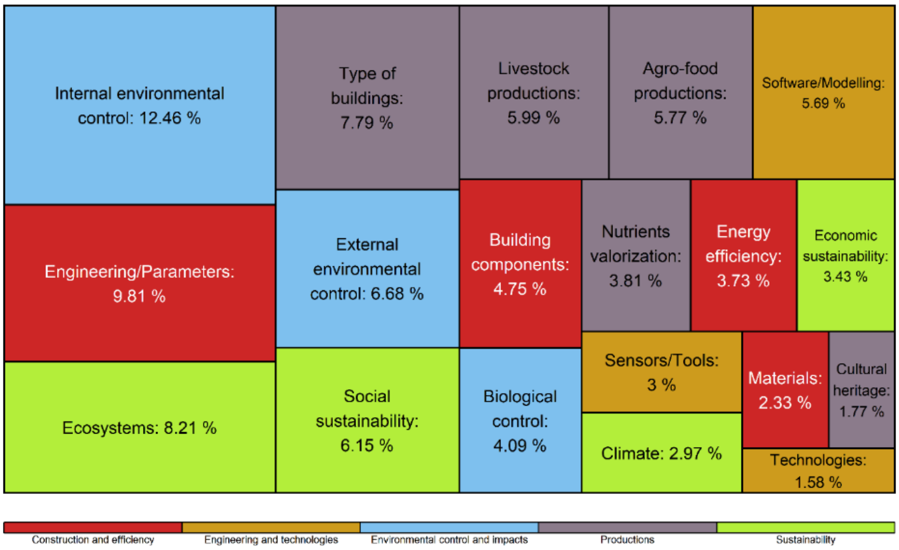

Figure 5. Overview of the 19 subclusters identified in this research. The same colours indicate the inclusion in the same cluster. The area of the rectangles is proportional to the subcluster size in terms of the percentage of stems included in the cluster.

For each cluster, we examined the relative relevance of each sub-cluster over time. This analysis allowed us to identify the trend topics and the gaps and provided a picture of the research direction.

The sub-clusters identified within the cluster "*Construction and efficiency*" were Engineering/parameters (indicating the technical characteristics and the parameters to express them), Building components (including structural building parts), Energy efficiency (consisting of terms related to energy sources), and Materials (collecting all different building materials).

The five most frequent stems of each sub-cluster are reported in Table 3. The results highlighted the prevalence of research on engineering issues (46.8%) focusing on design and efficient performance. The less investigated topics were related to building materials (11.8%). Within this sub-cluster, traditional materials, such as concrete and wood, were the most frequent topics. However, a significant occurrence of works on new materials, e.g., polymers, was detected. A similar amount of research was yielded on building components (23.2%) and energy efficiency (18.2%).

Table 3. Sub-clusters of "*Constructions and efficiency*" and the relative frequencies (within sub-cluster) of the first five stems. Words marked with an asterisk are the outcome of the stemming process which allows for including in the dataset all variant forms of the same word (common root) with a single lemma.

Sub-Clusters	Main Stems and Relative Occurrence	Cluster Weight (%)
Engineering/Parameters	design (12.6%); perform * (11.3%): process * (10.1%); monitor * (6.0%); oper * (5.5%)	46.8%
Building components	surfac * (16.3%); storag * (11.2%); local * (10.7%); floor (9.4%); space (6.7%)	23.2%
Energy efficiency	energ * (39.7%); solar (14.2%); power (10.1%); energy consumption (7.7%); insul * (5.6%)	18.2%
Materials	concret * (14.2%); wood (7.6%); polym * (7.0%); steel (6.4%); masonry (5.8%)	11.8%

However, observing the course of each sub-cluster over the period considered (Figure 6), it is evident that research on energy efficiency is growing fast while the topics included in the other sub-clusters are gradually decreasing. Therefore, energy efficiency ranked second within the cluster "*Constructions and efficiency*" in the last three years.

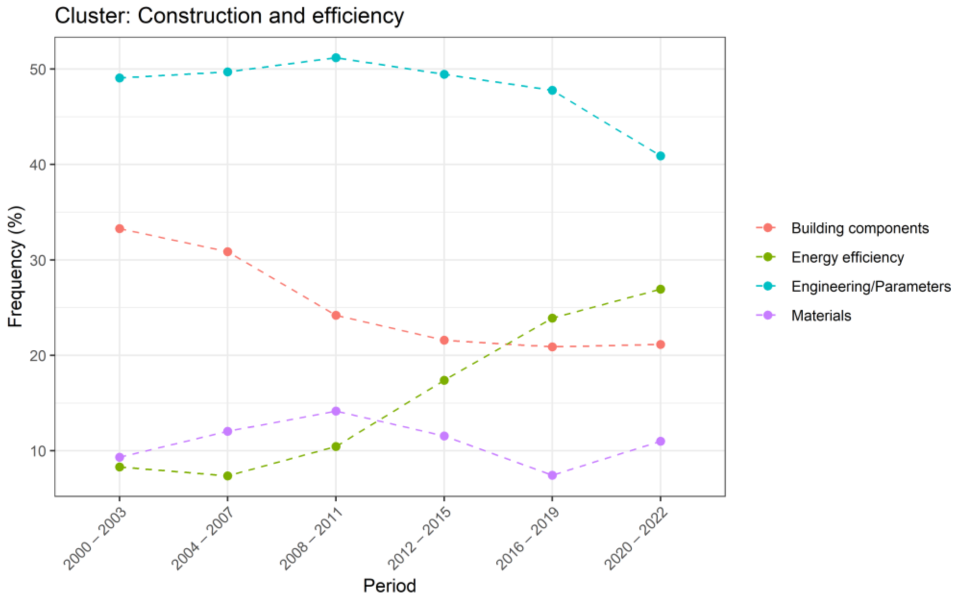

Figure 6. Course of the sub-clusters of "*Construction and efficiency*" from 2000 to 2022. The frequency was calculated as the ratio between the occurrence of stems belonging to a sub-cluster and the total amount of stems in the cluster.

The cluster "*Engineering and technologies*" was subdivided into three sub-clusters. The first sub-cluster was Sensors/Tools, including lemmas indicating sensing technologies and their application. The second one was Software/Modelling containing research topics inherent to computer-based analysis for modelling and predictions. The last sub-cluster was Technologies, where the traditional and new technologies used in farming systems were included.

The results reported in Table 4 show that most research focused on software and modelling issues (55.9%), followed by sensing tools (28.4%) and technologies (15.7%). The most frequent topics of the sub-cluster software/modelling highlighted the relevance of algorithms for spatial modelling. Several devices and techniques were described within the sensors and tools (e.g., positioning and imaging) and their relevance for building decision support systems (DSS). As regards the technologies, electrification was found to be one urgent research topic, along with spectroscopy and filtration.

Table 4. Sub-clusters of "*Engineering and technologies*" and the relative frequencies (within sub-cluster) of the first five stems. Words marked with an asterisk are the outcome of the stemming process which allows for including in the dataset all variant forms of the same word (common root) with a single lemma.

Sub-Clusters	Main Stems and Relative Occurrence	Cluster Weight (%)
Software/Modelling	model * (41.4%); comput * (10.7%); predict * (7.4%); spatial (7.2%); algorithm (6.7%)	55.9%
Sensors/Tools	observ * (17.3%); posit * (12.9%); imag * (11.8%); sensor (11.2%); support (6.7%)	28.4%
Technologies	technolog * (23.4%); electr * (19.0%); spectroscop * (9.8%); airborn (9.3%); filter (8.3%)	15.7%

Figure 7 shows the course of sub-clusters included in cluster "*Engineering and technologies*" over time. The sensors/tools and software/modelling topics displayed a specular trend. However, besides the opposite peaks in 2004–2007, research in such sectors was constant in the last 20 years. Although less popular, the sub-cluster technologies showed a slightly growing trend over the years.

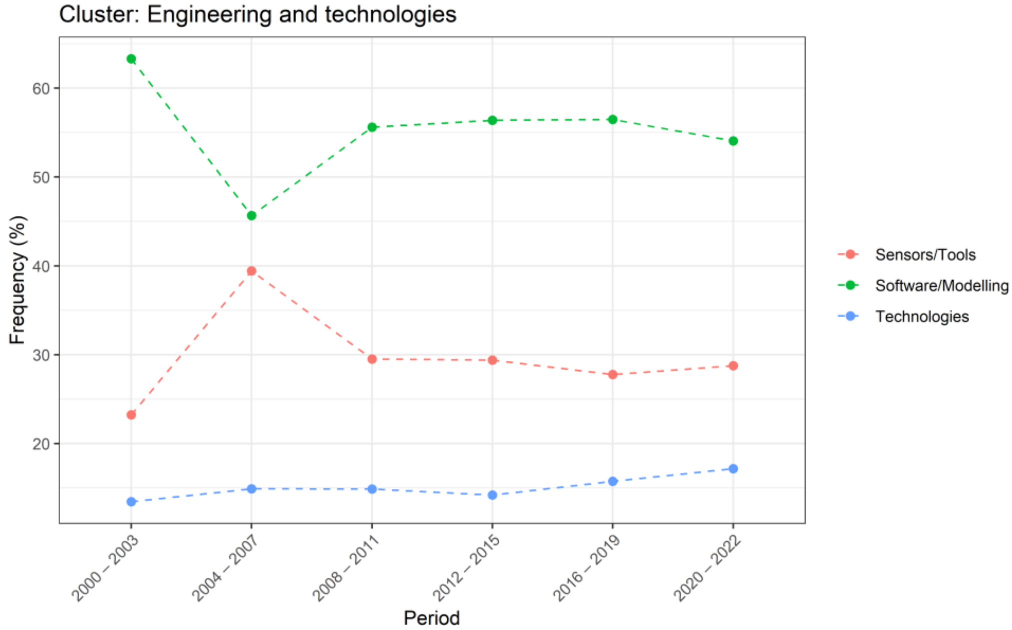

Figure 7. Course of the sub-clusters of "*Engineering and technologies*" from 2000 to 2022. The frequency was calculated as the ratio between the occurrence of stems belonging to a sub-cluster and the total amount of stems in the cluster.

As regards the cluster "*Environmental control and impacts*", we divided it into three sub-clusters. The first one was Indoor environment control, including the parameters to monitor to provide safe and comfortable conditions inside the rural buildings. The second sub-cluster comprised terms concerning External environment control, precisely emissions and pollutants. Finally, the third sub-cluster was defined as Biological control and was related to monitoring and preventing biological risk and ensuring animal welfare. As shown in Table 5, most research focused on internal environmental control (54%), with thermal comfort playing a pivotal role. Regarding external environmental control, its weight was 28.5%, with several papers on gaseous emissions and pollution. Finally, the biological control was the lower frequency (17.4%), focusing on body and stress conditions.

Table 5. Sub-clusters of "*Environmental control and impacts*" and the relative frequencies (within sub-cluster) of the first five stems. Words marked with an asterisk are the outcome of the stemming process which allows for including in the dataset all variant forms of the same word (common root) with a single lemma.

Sub-Clusters	Main Stems and Relative Occurrence	Cluster Weight (%)
Indoor Environmental Control	air (17.1%); temperature (12.7%); heat (11.6%); ventil * (10.9%); thermal (6.9%)	54.0%
External Environmental Control	emiss * (28.8%); pollut * (12.0%); gas (10.2%); impact (8.8%); particl * (7.7%)	28.5%
Biological Control	rate (24.4%); stress (8.8%); diseas * (8.6%); behavior (6.5%); bodi (5.1%)	17.4%

The course of the three sub-clusters of "Environmental control and impacts" over the observed period is displayed in Figure 8. Research related to monitoring the internal and external environment was predominant despite a rather inconstant trend observed. Biological control gathered greater attention in the first period, until 2008–2001 and then slightly decreased.

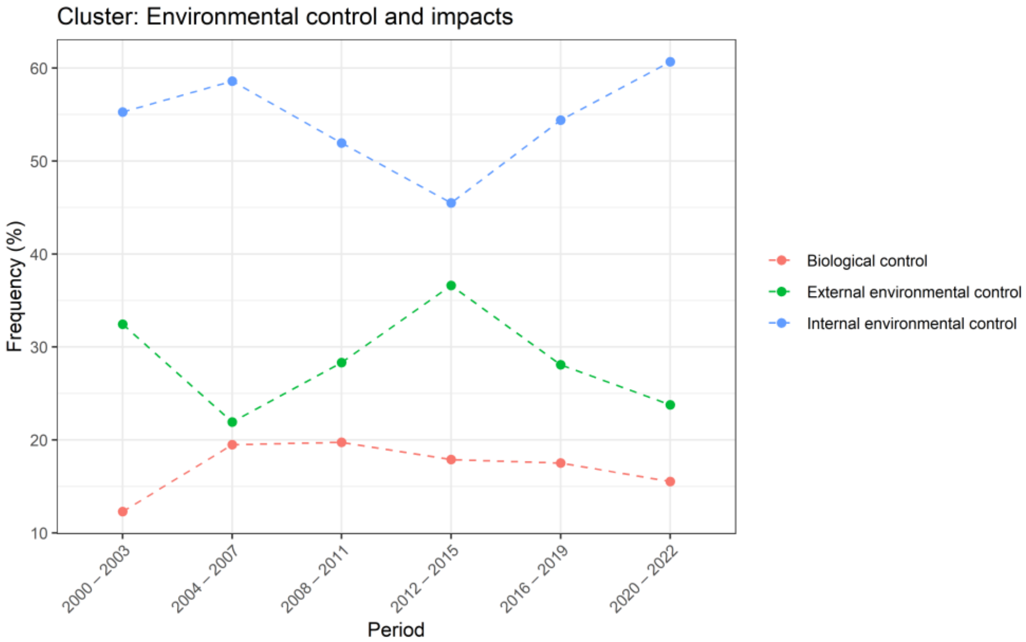

Figure 8. Course of the sub-clusters of "*Environmental control and impacts*" from 2000 to 2022. The frequency was calculated as the ratio between the occurrence of stems belonging to a sub-cluster and the total amount of stems in the cluster.

The cluster "*Productions*" highlighted the highest frequency. Therefore, it was characterised by several lemmas and subdivided into five sub-clusters. Sub-cluster Type of buildings contained general terms indicating the specialisation of the rural buildings. Agro-food production was the second sub-cluster focusing on crop production and the food processing industry. The third sub-cluster was Livestock productions, and the fourth included terms related to Cultural heritage. Finally, the sub-cluster Nutrients valorisation summarised all nutrient cycle and reuse topics.

Table 6 shows the frequency of the sub-clusters. The highest-frequency sub-cluster described the types of buildings, which highlighted significant interest in stables and barns. The lowest-frequency sub-cluster was related to cultural heritage and the importance of traditional buildings (7.2%). The other sub-clusters ranked in the middle, with agro-food productions representing 22.7% of research interest, livestock productions 23.9% and nutrient valorisation 15.1%.

Over time, the different topics of cluster "*Productions*" were rather inconsistent. Figure 9 shows that the interest in livestock production has decreased slightly in the past three years. Moreover, rural buildings representing cultural heritage represented a minor but constantly growing research interest. Finally, nutrient valorisation has regained scientific research interest over the last 15 years.

Table 6. Sub-clusters of "*Productions*" and the relative frequencies (within sub-cluster) of the first five stems. Words marked with an asterisk are the outcome of the stemming process which allows for including in the dataset all variant forms of the same word (common root) with a single lemma.

Sub-Clusters	Main Stems and Relative Occurrence	Cluster Weight (%)
Type of buildings	stabl * (33.5%); barn (28.5%); farm buildings (21.7%); rural buildings (8.9%); resident (2.7%)	31.1%
Livestock productions	livestock (11.9%); swine (10.2%); cow (10.1%); cattl * (9.0%); poultry (6.5%)	23.9%
Agro-food productions	farm (35.2%); dairy (22.4%); field (12.2%); food (5.3%); dri * (4.1%)	22.7%
Nutrients valorisation	manur * (21.6%); ammonia (19.1%); nitrogen (9.5%); sulfur * (5.3%); biofuel (4.7%)	15.1%
Cultural heritage	tradit * (23.2%); cultur * (18.4%); history (14.1%); heritage (11.0%); villag * (10.2%)	7.2%

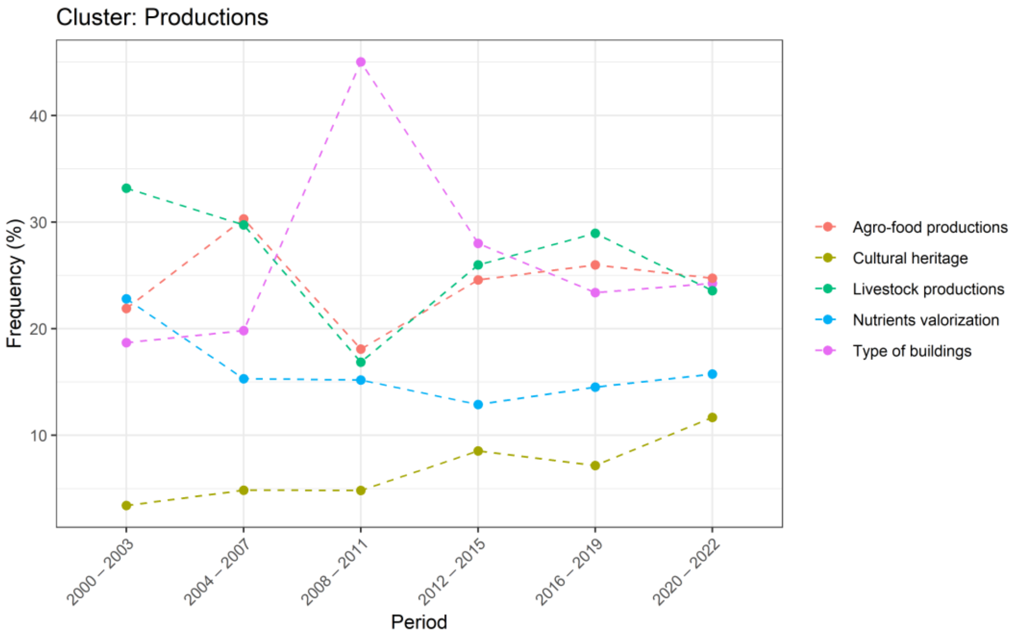

Figure 9. Course of the sub-clusters of "*Productions*" from 2000 to 2022. The frequency was calculated as the ratio between the occurrence of stems belonging to a sub-cluster and the total amount of stems in the cluster.

The last cluster, "*Sustainability*", was further divided into four sub-clusters. The first was Ecosystems, containing terms about biodiversity and environmental protection. Then, we identified the sub-cluster Climate, including all climatic parameters/conditions. The third sub-cluster consisted of Social sustainability; hence, topics like policy-making, land planning, and participation were included. The final sub-cluster regarded Economic sustainability, such as commercial, financial and transport issues.

Table 7 displays the sub-cluster frequencies within cluster Sustainability. The predominant research focus is ecosystems (39.5%), notably water habitats. Another critical role is played by research on social sustainability (30%), while economic sustainability and climate show very similar frequencies, 16.2% and 14.3%, respectively.

The course of sub-clusters reported in Figure 10 highlights a growing interest in issues concerning social sustainability. However, the other topics peaked in the past years, and the scientific community's interest is currently more or less constant.

Table 7. Sub-clusters of "*Sustainability*" and the relative frequencies (within sub-cluster) of the first five stems. Words marked with an asterisk are the outcome of the stemming process which allows for including in the dataset all variant forms of the same word (common root) with a single lemma.

Sub-Clusters	Main Stems and Relative Occurrence	Cluster Weight (%)
Ecosystems	environ * (20.9%); water (14.2%); natur * (7.6%); soil (6.6%); site (5.7%)	39.5%
Social sustainability	landscap * (9.6%); network (8.8%); human (7.4%); organ * (7.3%); urban (7.2%)	30.0%
Economic sustainability	plan (13.7%); econom * (13.0%); risk (11.6%); strateg * (8.6%); damage (8.1%)	16.2%
Climate	wind (23.2%); period (15.2%); climat * (15.1%); season (14.3%); atmosphere (12.4%)	14.3%

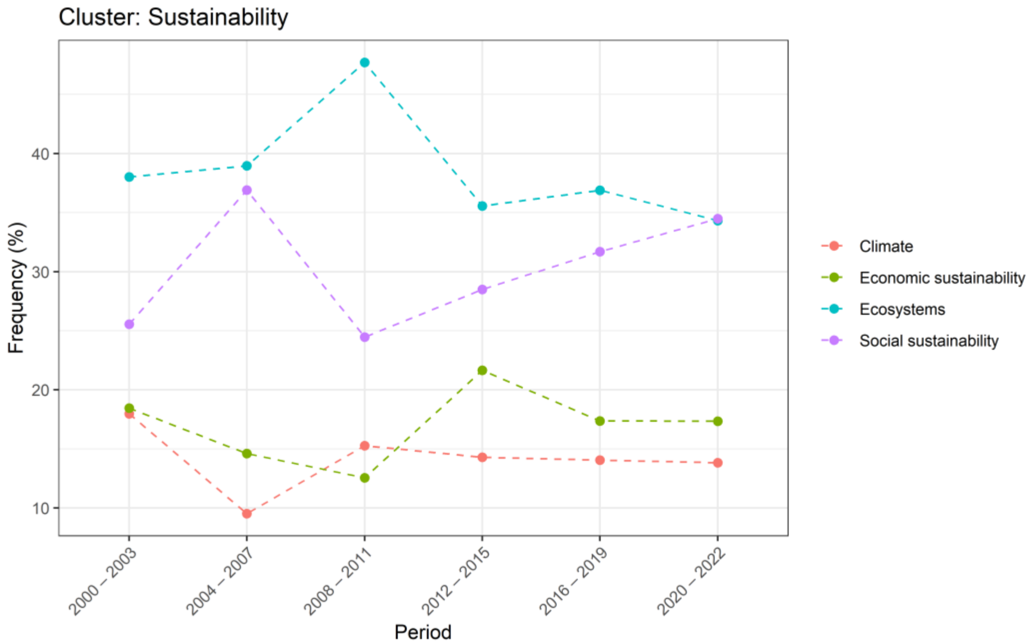

Figure 10. Course of the sub-clusters of "*Sustainability*" from 2000 to 2022. The frequency was calculated as the ratio between the occurrence of stems belonging to a sub-cluster and the total amount of stems in the cluster.

The analysis of the co-correlation of topics (Figure 11) highlighted some crucial interconnections. Specifically, some interconnections referred to barn activities, i.e., barn—emission, barn—ventilation, barn—model, barn—dairy, barn—air. A second group of highly correlated words linked to research on sustainable farming, i.e., emission—pollution, air—emission, barn—pollution, air—pollution, emission—ventilation, emission—model, and barn—manure. Then, several interconnections report exhaustive research on buildings characteristics to ensure animals' welfare, i.e., air—ventilation, model—temperature, heat—temperature, and barn—temperature. Finally, some highly correlated words focus on technological approaches, i.e., model—performance and computer—model.

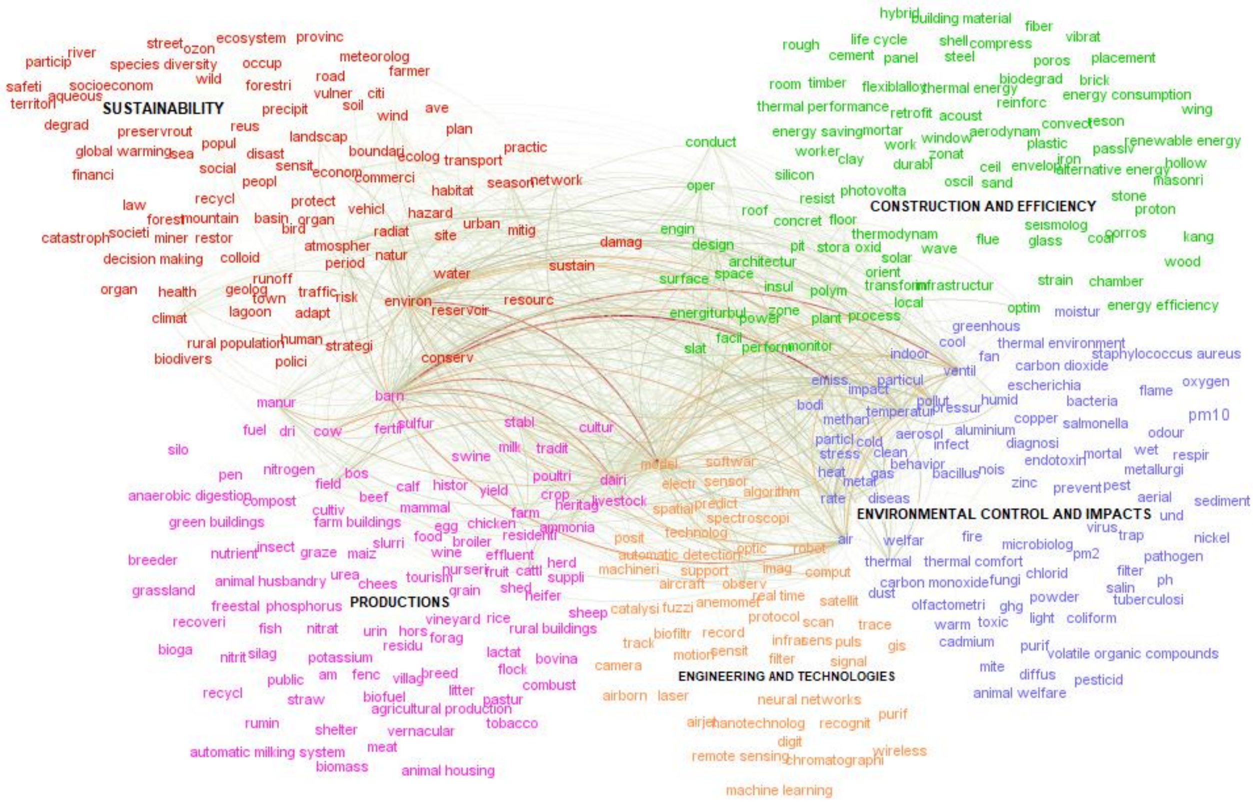

Figure 11. Overview of the stems grouped into clusters. The cluster label size indicates is proportional to its frequency. Different colours represent different clusters. Edges express the co-occurrence of topics. The thickness and darker colour of the edges indicate a higher number of connections.

4. Discussion

The results presented in this paper represent a valuable tool for critically analysing state-of-the-art scientific research on rural buildings. We demonstrated that a comprehensive review of rural buildings needs to be included; however, several reviews were yielded in the past years (Table 1). Most reviews focused on environmental control, intended as indoor and outdoor control and were published after 2010. In the same period, research interest in animal welfare showed a rapid increase [13] as farmers were called to integrate animal welfare, environmental protection and consumer concerns in a rapidly changing economic and social context [12]. The strong drive for animals' well-being and the bustle of agreements and regulations for sustainable rural development [77] might be one of the reasons for the peak of publications in 2008–2011 (Figure 1).

For a deeper knowledge of the topic, we included an analysis of the top five contributors to research activities. Analysing literature with a systematic approach, we determined that environmental control and sustainability are undeniable priorities of scientific research on rural buildings. However, most of the words extracted from papers are attributable to rural productions such as agro-food and livestock products and their consequences regarding the nutrient cycle (Figure 3). We included in this cluster the classification of the types of buildings. Hence, cultural and heritage buildings increased the frequency of the topic Productions. Nevertheless, our analysis showed that interest in this topic is slowly decreasing (Figure 4). A detailed analysis, partially reported in Table 5, allowed us to identify tendencies and gaps within this first cluster. Stables and barns were the most frequent building type. Figure 11 indicates barns as the core of research with their high correlations with other topics such as sustainability, environmental monitoring, and technologies. Therefore, the research on barns conducted so far may represent a driver for future research on other types of rural buildings.

Research on public construction, green buildings and cultural heritage buildings was much lower (Figure 9). This data indicates that the need for rural landscape conservation and valorisation is recent and needs to be explored. Green buildings are concept constructions that implement resource efficiency, obtain longer lifecycles, and emphasise building performance [5]. However, the adoption of green building technologies is still low in rural areas, and it was suggested that the inclusion of the stakeholders in the building project might promote the culture of green buildings [78,79]. Based on our results, new experimentation on green buildings and the involvement of several stakeholders might be the way towards more sustainable rural constructions.

We investigated agro-food and livestock production to highlight their tendencies. Both livestock and major field crops have been investigated. Many aspects of the dairy and food industry and buildings related to the drying process were extensively studied. Regarding the kind of livestock, research activity mainly focused on cows, followed by swine and poultry. However, some new aspects related to farm production are slowly growing, and further research is encouraged. First, we refer to the recycling process, which exhibited lower frequency. Recycling in rural buildings implies valorising by-products and maintaining the sustainable relationship between human life and the environment [80]. According to Gómez-García et al. [80], food agro-industrial by-products are often considered an issue and not a resource, while their reuse may reduce pollution. We also identified gaps related to extensive farming, such as fencing and grazing in sub-cluster Livestock productions.

The last observations for cluster Productions focused on nutrient valorisation. We detected that research mainly focuses on essential nutrients like nitrogen and phosphorus. Based on our results, anaerobic digestion/biogas is a relevant and continuously growing response to effluent treatment. The volume of biogas produced in Europe has doubled from 2008 to 2016 and is projected to double again by 2030 [81]. Biogas constitutes an alternative energy source to natural gas, and the possibility to use the digestate as fertiliser contributes to achieving circular economy-based models. However, there are some drawbacks. For example, in some European states, digestate is classified as waste [81]. Therefore, future research on the whole biogas process and its valorisation is encouraged, never forgetting the positive approaches offered by biorefineries and circular economy concepts.

Moving to the Environmental control and impacts cluster, the primary concern of the research conducted so far was building indoor monitoring (Figure 8). The highest-ranking parameters within this cluster were all the environmental parameters, e.g., air, temperature, and heat (Table 4). Monitoring the indoor parameters ensures better life conditions for animals and workers, and the deep work done by research in this field was highlighted by the co-correlation analysis (Figure 11). The high interconnections between couples of words such as air—ventilation, model—temperature, heat—temperature, and barn—temperature indicate the effort to ensure safe and comfortable environments. However, we found that parameters related to noise (e.g., sound, noise) represent an emerging issue and only 15 papers focused on noisy environments. The consequences of noise exposure can reduce hearing and cause other psychosomatic disorders [82]. Moreover, animal stress levels increase in noisy environments. Although national and international regulations establish noise exposure limit values, noise issues are overlooked, and farms often omit to assess compliance with the limits [82].

The tendencies related to the outdoor environment were emissions and associated concepts, like GHG and particulate matter (Table 4). These topics have direct consequences on global warming and pollution. Such intimate connection was identified in the co-correlation analysis (Figure 11), where several interconnections were found between terms included in the cluster Environmental control and impacts (e.g., emission—pollution, air—emission, emission—ventilation). Less research was yielded on biological control (Figure 8), mainly focusing on animal behaviour, stress and health conditions (Table 4). The lowest frequency word of this sub-cluster was "diagnosis". Current research focuses on automatic diagnosis, taking advantage of growing computational techniques to process data collected with sensors or other digital tools/technologies [83]. Our results indicate the need to implement future research on automatic diagnostic systems.

Research on topics related to sustainability is growing (Figure 4), and social sustainability is becoming an impelling need (Figure 10). We identified the intimate correlation between rural communities and landscape as a research tendency (partially shown in Table 6). Moreover, evidence of constant work on integrating rural and urban landscapes was found. The lower frequency of words indicating decision process, in particular, "decision making" and "participation", indicate potential research gaps to address. It was proved that participation in decision-making encourages virtuous behaviour [84], and the scientific community could drive the shift towards social sustainability.

Other research tendencies within the sustainability issues (Table 6) were water and soil protection and planning as a tool for implementing risk control strategies. Moreover, the sub-cluster climate revealed that wind is driving the design phase. Wind influences the building orientation and walls to protect the structure. Moreover, winds can be exploited for natural ventilation in livestock barns. A growing interest that needs to be implemented is global warming, which influences natural conditions; thus, designers should consider this factor. Finally, in the sub-cluster economic sustainability, we identified a research gap concerning traffic and transport issues. Transport in remote rural areas is crucial to promote economic growth and avoid isolating rural communities [85]. Therefore, to achieve economic sustainability, more research is needed on rural transport.

The cluster Construction and efficiency displayed a growing trend, stressing the relevance of designing and building structural- and energy-efficient constructions (Figure 4). Despite not representing the highest-frequency sub-cluster, energy efficiency rapidly increased (Figure 6, Table 2). In particular, Table 2 shows that energy-efficient rural buildings were described in terms of energy consumption and insulation. Several researchers described adopting alternative energy sources as a tool for self-sufficiency in rural/marginal areas, cost-saving and sustainable farming [86,87]. However, our analysis found a gap regarding thermal energy, which needs to be adequately coordinated with other energy forms. According to Kapica [88], meteorological and geographical issues hinder the widespread diffusion of thermal energy. If capturing solar energy is difficult in some regions or seasons, research on storage methods should be implemented.

The highest-frequency sub-clusters in Construction and efficiency were related to engineering issues and monitoring parameters. As shown in Table 2, the research tendency is to develop sustainable design integrated with the territory but, at the same time, efficient and performant. Another trending topic is monitoring phases and building environments. Within the research gaps, we found the frequency of the life cycle relatively low. Life cycle assessment (LCA) and life cycle cost (LCC) are undoubtedly raising growing interest [89,90], but our results encourage additional research.

Regarding sub-cluster materials, Table 2 shows that, along with traditional materials (concrete, wood), new materials are gathering attention, e.g., polymers and their higher strength and resistance to natural hazards. Finally, within the building components, the low frequency of terms related to the envelope indicates a substantial difference from the civil construction sector, where external insulation plays a central role.

The last cluster was Engineering and technologies, with lower frequency compared to the other clusters (Figure 3). However, according to Figure 4, scientific interest in technologies applied to rural buildings is gradually growing. Similarly, the interconnections between terms included in this cluster (Figure 11) demonstrate the relevance of technologies in the rural buildings sector. Technologies represent a tool for indoor environment and health status monitoring. Thus, their utilisation may implement buildings' efficiency and sustainability, animal well-being and workers' safety. Several smart tools may be used in the monitoring process of rural buildings, both for indoor and outdoor environments. A recent review presents state-of-the-art sensors for structural health monitoring [36], and satellite imagery is suitable for monitoring rural areas [20]. However, some drawbacks persist for a wider diffusion of new technologies. For example, Pagano et al. [91] highlighted the potential of smart devices and Internet of Things (IoT) applications in several rural sectors. Rural buildings monitoring can benefit from different kinds of sensing technologies, e.g., for animals' health, emissions, and environmental conditions. However, the limited Internet connectivity in many rural areas may be a severe constraint [91]. Recently some solutions have been proposed to overcome the connectivity issues of remote rural areas based on communicating elements to provide joint functionality [92]. However, one of the reasons for the lower frequency of cluster Engineering and technologies may be due to the remoteness of several rural areas. Table 3 shows that imaging and positioning are the highest-frequency topics concerning sensing technologies. Data collected with sensors and other digital technologies are utilised to build Decision Support Systems (DSS). However, we found that automatic detection systems to monitor animals' physiological conditions are underdeveloped. Recently, Wang et al. [93] demonstrated some thermography and machine learning applications for monitoring animals' health according to Precision Livestock Farming principles. However, more research should be suggested to align with other productive sectors.

The second sub-cluster contained words regarding software for landscape and building modelling. Modelling to predict building parameters or simulate their life cycle can rely on traditional or new statistical methods (e.g., Machine learning). Data shown in Table 3 demonstrates that modelling topics are major concerns for scientific research. However, remote sensing and Geographical Information Systems (GIS) are still underutilised in rural building detection, whereas they have been widely used for rural area planning [94].

5. Conclusions

Rural buildings represent the critical boundary between agricultural activities and local communities. Thus, comprehensive knowledge of state-of-the-art research on farm buildings may help decision-makers promote their sustainable development, conservation and valorisation. This research aims to identify actual tendencies and gaps related to rural buildings through a systematic review and represents an effective tool for laying the foundations for future research.

To date, scientific research has focused on production and environmental control issues, but our analysis demonstrated that important topics, such as engineering and technologies, are becoming increasingly popular. Shortly, some gaps will need to be filled to keep up with other farming and building sectors regarding sustainability, energy, and cost efficiency. To implement environmental sustainability in the rural building sector, we identified LCA, green buildings, recycling, and global warming as key research topics. LCA has already been applied to rural buildings, from building materials to energy efficiency. However, efficient LCA must be supported by monitoring tools and DSS. In this review, we assessed the need to implement research on technologies. Therefore, sustainable development of rural buildings should be supported by the diffusion of smart tools to all rural areas, even the most remote. Then, we argue that global warming is affecting the rural building sector in terms of welfare conditions. Thus, new research is encouraged on building materials and components to create resilient buildings. Finally, cost efficiency may be increased by developing more experimentation on remote and automatic detection and favouring transport in rural areas.

The information supplied by this study should be used for improving the structural, energy- and cost-efficiency of rural buildings in a modern farming concept based on the participation of the stakeholders in the decision process.

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