applied sciences

MDPI

Review

Cool Surface Strategies with an Emphasis on the Materials Dimension: A Review

Chaimae Mourou [1], Montserrat Zamorano [2], Diego P. Ruiz [3] and María Martín-Morales [1,*]

[1] Department of Building Construction, School of Building Engineering, University of Granada, 18071 Granada, Spain; chaimaemourou@correo.urg.es
[2] Department of Civil Engineering, School of Civil Engineering, University of Granada, 18071 Granada, Spain; zamorano@ugr.es
[3] Department of Applied Physics, Faculty of Sciences, University of Granada, 18071 Granada, Spain; druiz@ugr.es
* Correspondence: mariam@ugr.es

Abstract: The need to tackle the urban heat island effect demands the implementation of cool surfaces as a mitigation strategy. This study comprehensively reviews the evolution of this research field from a materials perspective. It provides a bibliometric analysis of the relevant literature using the SciMAT software processing of bibliographic records from 1995 to 2020, for the evolution of cool surfaces. The results obtained show an increased interest in the field from 2011 to 2020, particularly for roof applications, and present the scientific evolution of reflective materials. According to the materials dimension adopted by the development of the research field, the study is refined from a bibliometric analysis of 982 selected records for the analysis of five themes: (i) Pigments; (ii) Phase change materials; (iii) Retroreflective materials; (iv) Ceramic materials; and (v) Glass. These materials present promising results in terms of their solar reflectance performances in the mitigation of the urban heat island phenomenon. At the end of this review, recommendations for future studies are provided for the creation of economic and environmentally friendly materials based on waste glass recycling. This study represents a valuable contribution that provides a scientific background with regard to cool surfaces from a materials perspective for future investigations.

Keywords: cool surface; cool material; cool roof; urban heat island

check for updates

Citation: Mourou, C.; Zamorano, M.; Ruiz, D.P.; Martín-Morales, M. Cool Surface Strategies with an Emphasis on the Materials Dimension: A Review. *Appl. Sci.* **2022**, *12*, 1893. https://doi.org/10.3390/app12041893

Academic Editor: Elza Bontempi

Received: 7 January 2022
Accepted: 5 February 2022
Published: 11 February 2022

1. Introduction

Urban areas represent 2% of the Earth's surface, yet they consume 75% of the world's energy resources [1]. A portion of this energy is dissipated as anthropogenic heat, which increases the ambient temperatures in urban areas. This phenomenon was labelled as the "urban heat island (UHI) effect" by meteorologists more than a century ago, and it is the result of the increase in the ambient temperatures and the amount of solar heat trapped in urban areas, as well as of the increase in greenhouse gas emissions [2–4]. Consequently, in addition to climate change, associated environmental challenges and public health problems have occurred [4]; for instance, the occurrence of urban smog and the increase in cooling energy consumption [2], as well as a decrease in indoor and outdoor thermal comfort and quality [3,5]. It can therefore be stated that the UHI effect is an environmental problem that requires theoretical and practical studies to mitigate its impact [6].

In order to palliate the UHI effect, a growing number of studies and investigations have been conducted to develop mitigation strategies that can be implemented in urban spaces and buildings. Several solutions have been developed, including urban geometry reshaping [1], designing green and cool roofs [7,8], using permeable, porous, water-retentive, and cool pavements [9], incorporating green spaces into the urban landscape, and utilizing water and wind for cooling effects [4,10,11]. These solutions could yield a median reduction in the air temperature of between 1.8 and 2.1 K [12]. Furthermore, the combination of different measures could be more effective [13], and the choice of the optimal strategy depends on the regional atmospheric and geographic specifications of each individual urban environment [8,14].

Among the cited UHI mitigation strategies, cool surfaces have emerged as a viable solution [15,16]. The term "cool surfaces" basically refers to surfaces with reflective materials and coatings that reflect the solar energy radiation that hits building envelopes and urban areas [17], including roofs, facades, and pavements (Figure 1). Cool surfaces are able to reduce the thermal infrared radiation outflow in the atmosphere, as well as the temperature and the solar heat gain [18,19]. In fact, it has been proven that the implementation of cool surfaces to replace dark and highly absorptive materials during routine maintenance increases the albedo over time [2]. These materials come in a huge variety and include natural materials, artificial cool coatings, and nonwhite high-albedo materials [20,21]. In addition to the fabrication process and conditions, the thickness, particle size, and the substrate and binder materials are all key parameters that could affect the optical and thermal properties of cool materials, such as the albedo, permeability, conductivity, total solar reflectance, and emissivity [21,22].

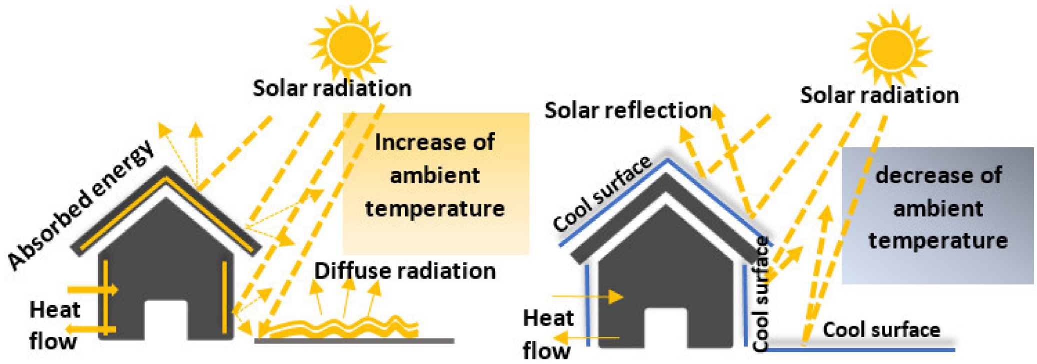

Figure 1. Schematic representation of the cool surface effect on a UHI through the ambient temperature.

The thermal performance of a material is mainly evaluated by the albedo (solar radiation) and emissivity (longwave radiation) [21]. The solar reflectance potential of cool materials initially relied on their whiteness, which promoted the use of white paints and light-colored aggregates [23]. Following that, the research field advanced toward enhancing the near infrared (NIR) reflectance of cool materials, as it represents almost 52% of the electromagnetic spectrum of light (i.e., from 700 to 2500 nm) [24]. Thus, novel methodologies and techniques have been considered to cover a wide range of solar reflectances in order to enhance the performance of cool materials.

The cool surface strategy has started an extensive series of studies concerning pigments that has created an industry of geoengineering and chemical solutions for the development of cool materials to enhance the solar reflectance performances. The integration of pigments in cool materials has recently been discussed in detail within both the research and industrial contexts [25]. With regard to the aesthetic requirements of a design, selective pigments have been developed to maintain the optical color desired on top of the material while achieving important NIR reflectance results [26]. The pigments range from organic, to complex inorganic color mixed-metal oxides [27,28]. These substances have demonstrated high solar reflectances of up to 95%, compared to TiO_2 [29–33].

In addition to cool pigments, other solutions for cool surfaces have emerged to improve urban climate conditions and energy consumption, such as retroreflective (RR) and phase change materials (PCMs). Independently of the incidence direction, retroreflectivity refers to the capacity of a surface to reflect an incoming light beam to a surface back towards its source [34,35]. RR materials have been demonstrated to be effective in several studies in terms of the solar radiation reflectance beyond urban canyons and canopies [34–36]. PCMs have the ability to change their physical characteristics as a consequence of heat release or absorption [37]. In recent decades, a variety of PCMs have been investigated as dynamic components in structures [38]. The implementation of PCMs in the matrix of roof finishing materials decreases the flux of the roof heat gain by 54%, compared to the cool roof [16], and it helps to compensate for the effect of the thermal stress generated by the latter [39]. Moreover, PCMs can be used to regulate the indoor thermal comfort and reduce the heating penalty during the summer and winter, respectively, more so than do cool paints [40–43].

Sustainable adaptation has been a parallel concern in the development of cool material solutions. On this basis, the use of recycling materials to save energy and natural resources, and to enhance the solar reflectance, presents a promising eco-friendly strategy [14]. For instance, full body porcelain aggregate from waste tiles has been used as a cool pavement coating that exhibits important thermal performance values compared to asphalt pavement, with an NIR solar reflectance of 6.4 °C, and a surface temperature reduction of up to 6.4 °C during the peak periods [44]. In addition, the use of recycled glass cullet in the fabrication of a sustainable asphalt roof shingle improved the solar reflectance [45].

Considering the evolution of materials applied in cool surfaces, the current objective of this study is to perform a bibliometric analysis to review the scientific development of this solution in the mitigation of the UHI effect. Section 2 presents the research methodology employed. Section 3 describes the collection process for the materials and the bibliometric evaluation, provides a descriptive analysis of the findings and analyzes the most important contributions of the studies identified previously. Finally, Section 4 provides the most important conclusions of this study, which contribute to the existing body of knowledge by highlighting the trends in the research field of cool surfaces for building envelopes and urban areas, as well as by recommending research areas for future studies.

2. Methodology

To achieve the objective of this study, a dual bibliometric study based on science mapping and performance analysis was conducted first using the science mapping analysis software, SciMAT, to obtain the necessary patterns and bibliometric measures [46,47]. This bibliometric study contains publications from 1995 to 2020, and it was conducted in 2021. Hence, recent findings and limitations are included in the literature review section in order to enrich the discussion, which is necessary because of the constant evolution of the field. Science mapping visualizes, analyzes, and models a broad range of scientific and technological activities, and it follows a general workflow of data retrieval, data pre-processing, network extraction, network normalization, mapping, analysis, visualization, and finally, the interpretation of the results [46]. Furthermore, the performance analysis as a complementary methodology uses different bibliometric measures and indicators to complement the visualization results and to help identify the impacts and productivities of the themes in the research field. With consideration to the results obtained, a number of publications were selected in order to conduct a review of the evolution of cool surfaces.

2.1. Sample Definition and Steps for the Data Collection

This review addresses two concepts: the UHI effect, and the different types of cool surfaces applied. To achieve this, an extensive search was carried out that employed the keywords linked to both concepts, as well as the satellite materials directly connected to the research field. Therefore, the first stage of the data collection was performed using the field, "Title/Abstract/Keyword", through the following keywords and search strings (Figure 2): "Heat island" OR "Reflect*" AND "Cool surface*", "Cool facade*", and "Cool roof*" AND "Cool pavement*", within the Web of Science Core Collection and Scopus databases. The asterisk is used at the end of keywords to broaden the research. As a result, 982 publications were found, 347 of which were excluded after the deduplicating and cleaning of the raw data. After reading the abstracts, another 121 publications were excluded because they were not aligned with the purpose of this research. Finally, the bibliometric study was performed with 514 publications.

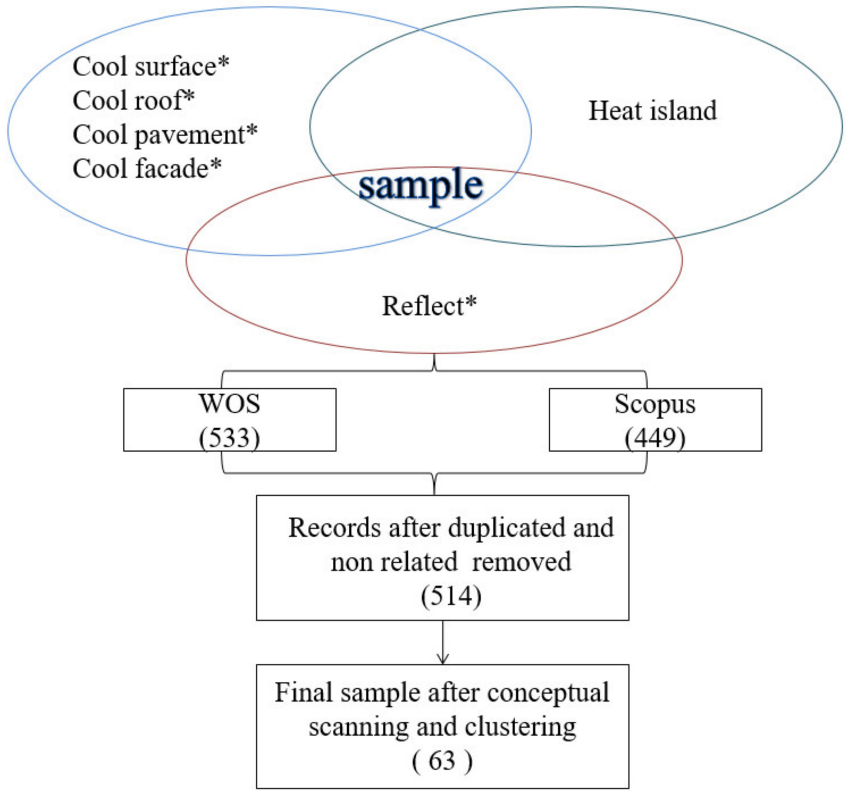

Figure 2. Data collection flowchart.

The next step was dedicated to the restriction of the data and the refinement of the sample on the basis of a conceptual approach. According to the SciMAT visualization results, it was possible to follow the internal links in the cluster networks of the concepts with the highest potentials for reviewing, which returned 63 records. This process of data collection is described in the flowchart above (Figure 2). The analysis of these publications was the basis of the literature review of the evolution of cool surfaces through the materials applied to mitigate the UHI effect.

2.2. Systematic Literature Review

The analysis of the 514 documents selected for the systematic literature review resulted in the following data: total numbers and years of publications; and authors with the highest contributions to the field based on the number of publications, sources, and journals. Furthermore, strategic diagrams, thematic networks, overlay graphs, and evolution maps were used to demonstrate the relationships between each theme of the strategic diagrams, the keywords, and their interconnections. These were also used to identify the research motor themes, the highly developed and isolated themes, the emerging or declining themes, and the basic and transversal themes, and to then trace the evolution of these themes along the studied period [48–50]. The sample of academic publications processed through this science mapping analysis was dependent on the specific input conditions, such as the unit of analysis and the keywords.

3. Results and Discussion

The aim of this section is to assess and analyze the collected material that was released during the period between 1995 and 2020 using quantitative and qualitative methods. A descriptive analysis was conducted through: (i) An analysis of the evolution of the numbers of documents; and (ii) The main sources of the publications and a review of the most prolific authors. Science mapping and visualization were then conducted to obtain an assessment of the evolution of the cool-material-application domain. Finally, a literature revision of the materials applied for cool surfaces was developed, which led to five analytical sections employed for the evaluation of the materials: (i) Pigments; (ii) RR materials; (ii) PCMs; (iv) Ceramic materials; and (v) Glass.

3.1. Descriptive Analysis

3.1.1. Evolution of Number of Documents

Since the first article identified in these databases was published in 1995, the time horizon used in this study was from 1995 to 2020. In order to analyze the trends and patterns in the publications, three periods were identified (1995–2001, 2002–2010, and 2011–2020) on the basis of the main turning points and milestones in the evolution of cool surfaces. The results of the contributions for the three periods identified are summarized below.

The first period (1995–2001): In this period, the contribution of the academic literature to the topic was very poor, with only five publications found. However, the period was marked by promoting cool roofs through building codes. In fact, starting in 1999, several energy-building standards adopted cool roof credits or requirements, such as ASHRAE 90.1, ASHRAE 90.2, the International Energy Conservation Code, and California's Title 24.

The second period (2002–2010): This period is characterized by the rising concern with regard to the topic, which coincided with the third assessment report of the Intergovernmental Panel on Climate Change, which highlights the increase in greenhouse emissions and the global average surface temperature in the 20th century by 0.6 °C. The number of publications increased considerably (to 58) during this period (Figure 3).

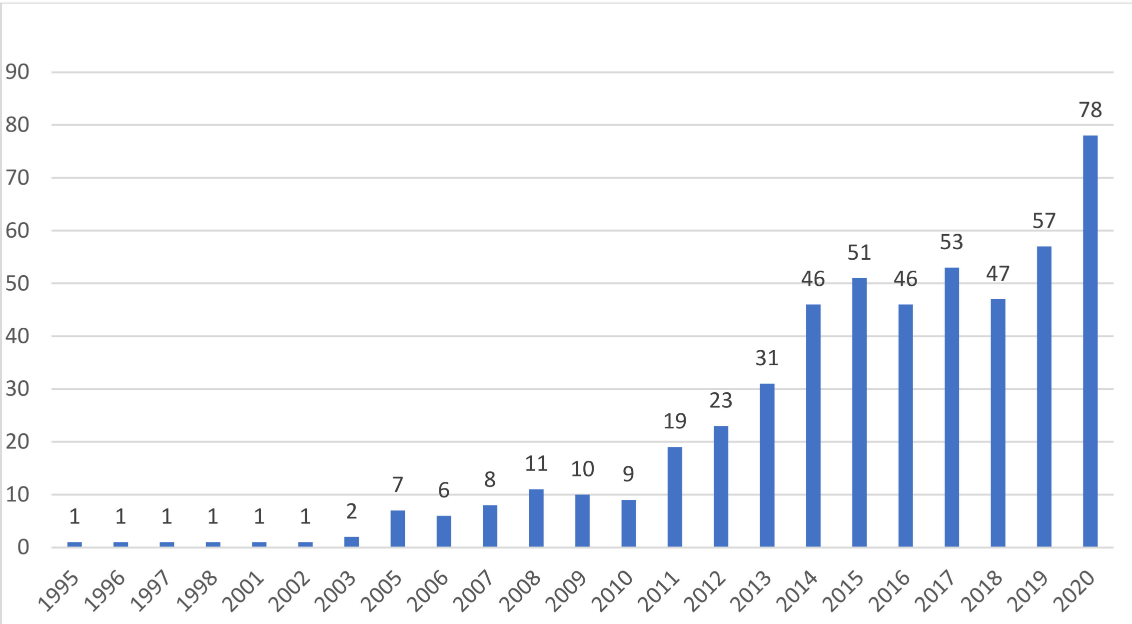

Figure 3. Number of documents per year.

The third period (2011–2020): The cool surface strategy was a rapidly growing research topic during this period. In fact, this period is by far the most prolific in terms of publications, with 87.74% of the records published during this time (Figure 3). This period coincides with the foundation of the European Cool Roofs Council, which seeks to develop knowledge and research regarding cool roof technology and promotes the use and implementation of this technology in Europe.

Considering the significant evolution of the number of academic documents in this field, an increasing interest in this topic has been explicitly detected (Figure 3).

3.1.2. Main Source Publications

The nine most prolific journals account for 40% of the total records of the sample principally considered. It is possible to conclude that the most common aspect of the journals considered is related to energy efficiency and buildings, as well as to the science and technology of solar energy applications. In fact, *Energy and Buildings* has the dominant share, with 16.53% of the published records, followed by *Solar Energy* (6.19%), and *Solar Energy Materials and Solar Cells* (4.12%).

Concerning the authorship of the publications, Akbari, H., who is affiliated with the United States and Canada, has made the most contributions to the field, with 36 publications, followed by Pisello, A.L. (33), and Levinson, R. (28). Most of the publications are affiliated with Italian universities (97 papers), followed by the United States and Canada, with 74 and 36 publications, respectively.

During the last decade, with the increases in the UHI effect and climate change, it became necessary to draw attention to the development of geoengineering-based solutions, such as cool surfaces. This strategy has been implemented for roof applications, building facades, and pavements. Nevertheless, the academic research placed an emphasis on cool roofs, with a much higher number of articles published on this application than for any of the others (Figure 4). Thus, the number of publications regarding cool roofs in the third period reached 251 documents, while, in the case of pavements and facades, only 58 and 22 papers were identified, respectively.

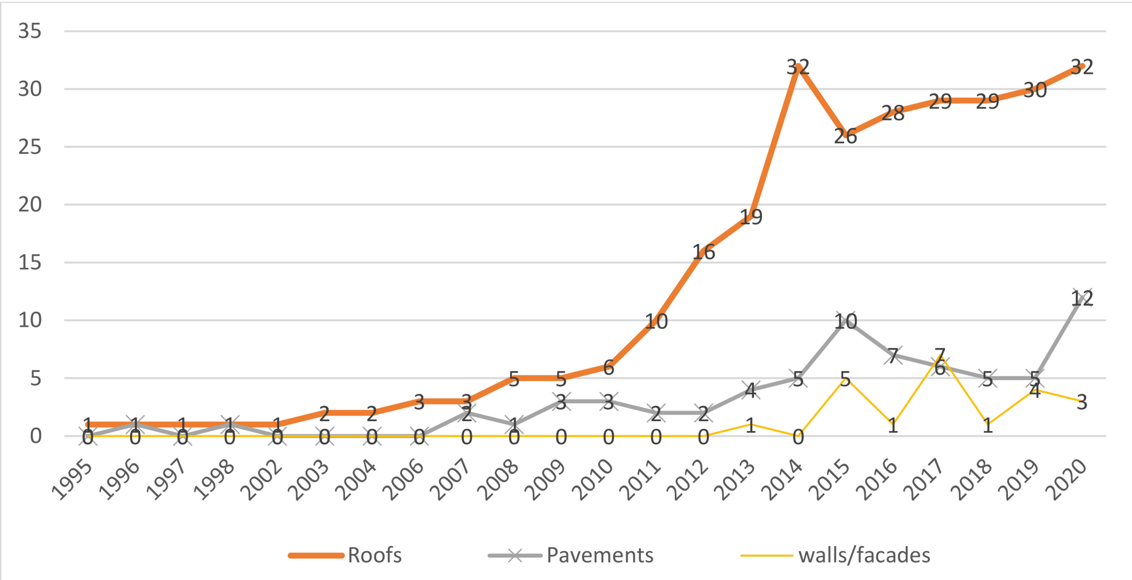

Figure 4. Evolution of cool material application domain: roofs, pavements, and walls/facades.

3.2. Science Mapping and Visualization

Figure 5 plots the overlapping map representing the three periods of research and the evolution of the keywords. Figure 6 presents the thematic evolution map of the research field, based on the h-index (Figure 6a) and on the numbers of published documents for the three cited periods (Figure 6b). Figure 5 shows that the number of keywords grew substantially in the second period, with 52 units, and in the third period, with 16 more. Thus, it is possible to confirm that cool surfaces represent a growing research field. In fact, the first period was the least developed in terms of published documents, with most of them focused on the use of lighter-colored materials to provide high solar energy reflectance and to decrease the solar heat entrapped in urban areas [2,23]. This period was characterized by the "cooling" theme (Figure 6b), as the increases in the temperatures in cities urged the use of high-albedo surfaces instead of darker materials.

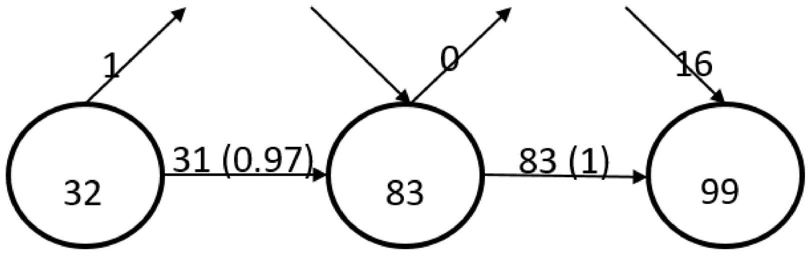

Figure 5. Overlapping map of the sample.

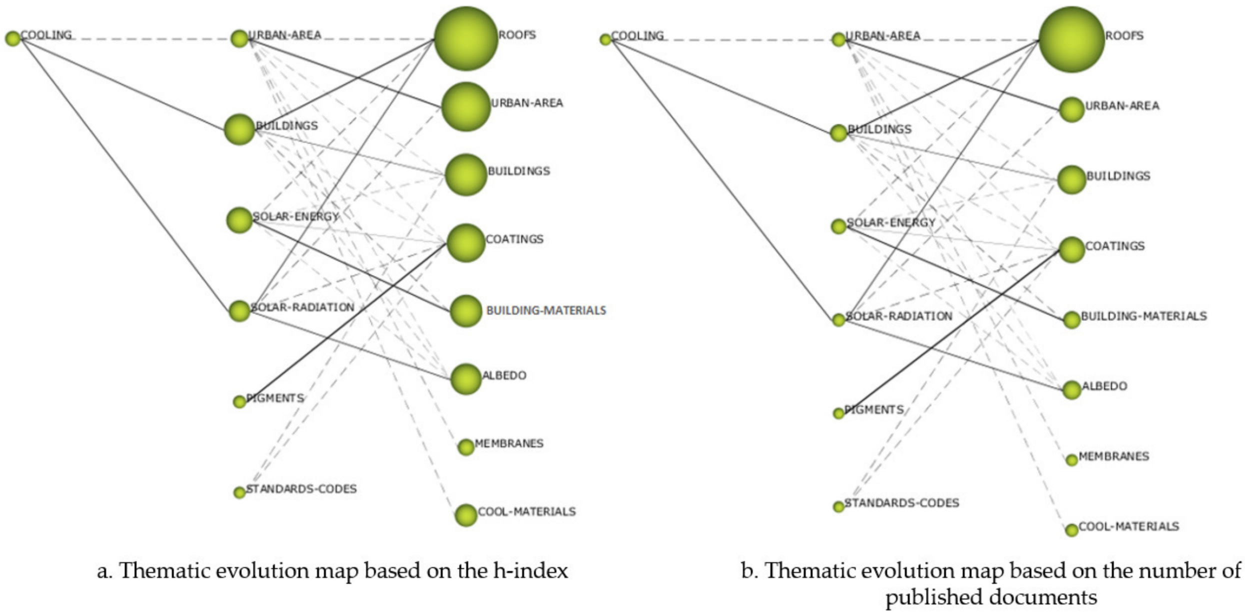

Figure 6. (Thematic evolution map according to the h-index (**a**) and the number of published documents (**b**).

Later, several studies showed that the whiteness of materials enhances the surface albedo and increases the solar reflectance in the visible spectrum range, which reduces the cooling load of buildings [51]. For instance, in a study exploring alternative methods for creating high-albedo concrete for pavement applications, Boriboonsomsin and Reza [52] found that replacing cement with whiter constituents (70% slag) achieves an albedo of 0.582, which is 71% higher than the conventional mix. To encourage the implementation of white reflective materials in buildings and urban areas, as well as to facilitate their integration into the construction sector, standards and product labelling were adopted and promoted on the basis of the spectral reflection examination of these materials [2,53,54]. In this sense, some efforts have been taken to incorporate cool roofs as an effective sustainable strategy in the revised ASHRAE building standards, S90.1 [55]. This approach was developing in the second period and it coincides with the integration of building regulations to enhance energy performances, such as the first version of the Energy Performance of Buildings Directive, 2002/91/EC, as well as its subsequent update (Directive 2010/31/EU). In this second period, the research field started to receive more interest, which is highlighted by the inclusion of 52 new keywords (Figure 5) and the following six emerging themes (Figure 6): "buildings"; "solar-energy"; "solar-radiation"; "urban-area"; "pigments"; and "standards-codes". The h-index impact in Figure 6a emphasizes buildings, solar energy, and solar radiation, and the number of published documents is approximately the same for each theme (Figure 6b). These studies began because of the rising interest in cool materials with solar radiation reflectance properties not only in the visible range, but also in the NIR spectrum, to reduce energy consumption and enhance thermal comfort.

Finally, the third period increases the number of keywords to 99 (Figure 5), and it shows a link between the research field and the creation of balanced solutions in the development of coatings, membranes, and materials designed to save energy in buildings (Figure 6b). This represents the most prolific period in terms of published documents. In this period, the conceptual evolution of the themes was developed into more specific areas directed toward creating solutions and developing materials, such as: "roofs"; "urban-area"; "buildings"; "coatings"; "building-materials"; "albedo"; "membranes"; and "cool-materials". Researchers started to explore more alternatives that conformed to the energy efficiency and aesthetic requirements, both indoors and outdoors, and there was increasing interest in materials with the appropriate thermal emissivity/absorption spectrum. For this purpose, the careful selection of nanoparticles and pigments was developed to optimize the thermal and optical performances of materials, such as radiative cooling painting. Several works were led in this sense to develop high-reflective paints known as "cool paints", such as smart coatings with high NIR reflectance to reduce the solar heat gain and the energy consumption [56–59]. In addition, the coatings were developed in order to achieve the color and efficient radiative cooling requirements in a simple, low-cost, and scalable way [60].

Since the third period (2011–2020) was the most prolific for this field of research, it is analyzed in detail below. To achieve this, Figure 7 was created, which shows a strategic diagram of a two-dimensional space that was built by plotting the themes according to their centralities and their density rank values. This includes four quadrants, each containing a specific theme: (i) Motor themes, in the upper-right quadrant; (ii) Basic and transversal themes, in the lower-right quadrant; (iii) Highly developed and isolated themes, in the upper-left quadrant; and (iv) Emerging or declining themes, in the lower-left quadrant [61].

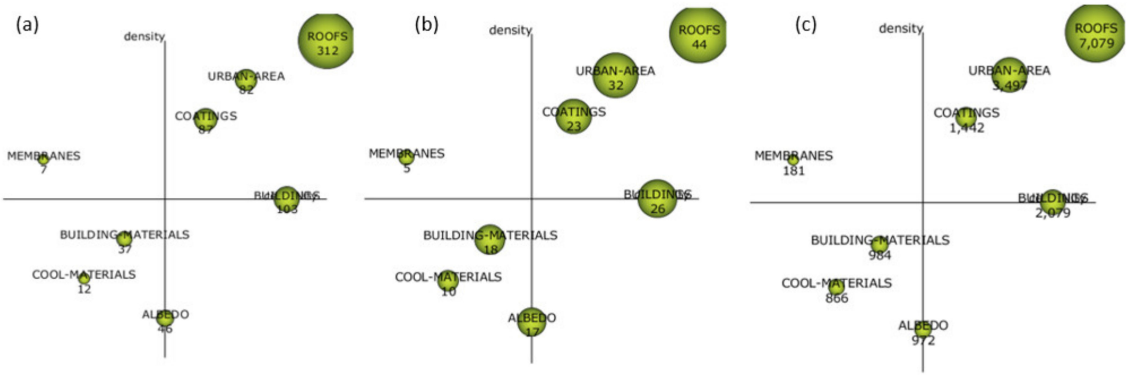

Figure 7. Strategic diagram of the third period, the volume of the spheres is proportional to the number of documents published (**a**), to the h-index (**b**) and to the number of citations (**c**) in the third period associated with each theme.

According to Figure 7a, almost 70% of the published records represent the roofs, urban-area, and coatings themes, and they have the highest impacts (Figure 7b). It can be seen that roofs and urban-area are the most cited themes, with 7079 and 3497 citations, respectively, followed at a distance by coatings, with 1442 citations (Figure 7c). In the case of the roofs theme, its origins show an association with the concepts, building, solar-radiation, solar energy, and urban areas (Figure 6), and it represents the most applied domain of cool materials, as is shown in Figure 4. It is noteworthy that the urban-area motor theme is associated with all of the specific themes of the third period as an origin theme.

The most detailed analysis of the cluster network allowed for the obtainment of information regarding the materials applied for cool surface purposes. Thus, the coatings theme showed a strong relation with the development of pigments (Figure 6a), especially the ones performing in the NIR spectrum as reflective materials, as can be seen in its cluster network (Figure 8d). In terms of the isolated membranes theme (Figure 8c), it mainly concerns the latent strategy of the thermal energy storage resumed in the PCMs. Finally, the two emerging themes of building-materials and cool-materials (Figure 8a,d, respectively) discuss ceramic materials and glass, and retroreflective materials (RR materials), respectively. The most relevant contributions to these topics are analyzed in the next section for the review of materials applied for cool surfaces.

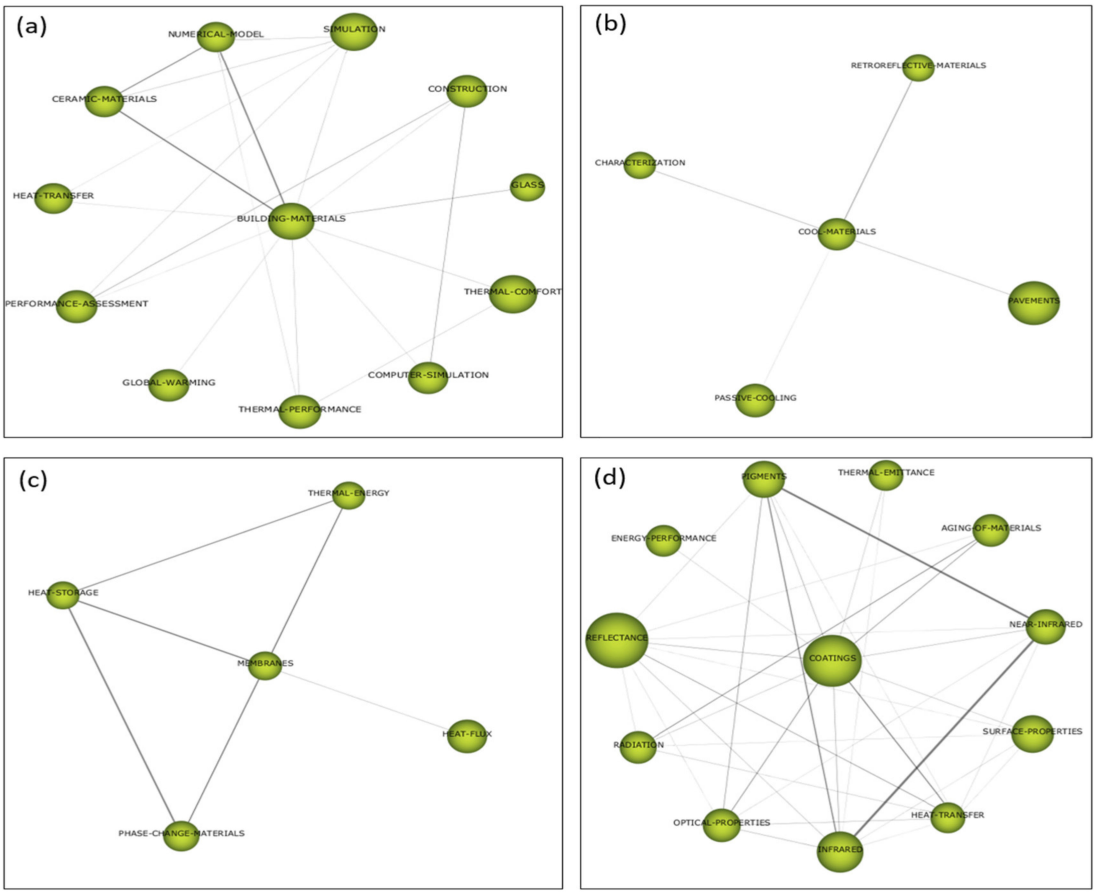

Figure 8. Cluster networks of: (**a**) building-materials; (**b**) cool-materials; (**c**) membranes; and (**d**) coatings.

3.3. Literature Revision of Materials Applied for Cool Surfaces

The use of cool materials for building envelopes and pavements helps to increase the solar reflectance index, which decreases the energy use for the cooling demand and enhances the indoor and outdoor thermal comfort. The fabrication of such materials to mitigate the UHI implies the creation of an equilibrium between the technical use of these materials and their environmental impact in order to secure a sustainable production and service loop. In this section, the most applied materials are analyzed: (i) Pigments; (ii) RR materials; (ii) PCMs; (iv) Ceramic materials; and (v) Glass. The implementation of more than one strategy to create a cool surface could be complementary.

These materials were the subject of 63 publications, from which ~25% evaluate ceramic materials, 22% are dedicated to pigments, and 19, 19, and 14% evaluate PCMs, glass, and RR materials, respectively. This sample was selected by means of clustering during the third period. However, six publications were extracted from the previous periods and added to the analysis because of the impacts and contributions of the authors, such as Akbari, H, who has made the most contributions in terms of the records published related to the field of cool surfaces. The literature reviewing of these materials is included below.

3.3.1. Pigments

According to the publications presented in Table 1, the pigments were evaluated through the 14 most relevant publications that are related to the theme of energy use in buildings. Most of the publications are affiliated with research entities based in India and China.

Table 1. Most important publications about pigments.

Title of Publ.	Authors	Journal	Year of Publ.	Ref.	Country of Affiliation
Solar spectral optical properties of pigments—Part I: Model for deriving scattering and absorption coefficients from transmittance and reflectance measurements.	Levinson, R., Berdahl, P., and Akbari, H.	*Solar Energy Materials and Solar Cells*	2005	[27]	United States
Solar spectral optical properties of pigments—Part II: Survey of common colorants.	Levinson, R., Berdahl, P., and Akbari, H.	*Solar Energy Materials and Solar Cells*	2005	[28]	United States
Bismuth titanate as an infrared reflective pigment for cool roof coating.	Meenakshi, P., and Selvaraj, M.	*Solar Energy Materials and Solar Cells*	2018	[29]	India
Pigmentary colors from yellow to red in $Bi_2Ce_2O_7$ by rare earth ion substitutions as possible high NIR reflecting pigments.	Raj, A. K. V., Rao, P. P., Sreena, T. S., and Thara, T. R. A.	*Dyes and Pigments*	2019	[30]	India
A new member of solar heat-reflective pigments: $BaTiO_3$ and its effect on the cooling properties of ASA (acrylonitrile-styrene-acrylate copolymer).	Xiang, B., and Zhang, J.	*Solar Energy Materials and Solar Cells*	2018	[31]	China
Terbium doped Sr_2MO_4 [M = Sn and Zr] yellow pigments with high infrared reflectance for energy saving applications.	Raj, A. K. V., PrabhakarRao, P., Divya, S., and Ajuthara, T. R.	*Powder Technology*	2017	[32]	India
Pigments based on terbium-doped yttrium cerate with high NIR reflectance for cool roof and surface coating applications.	Raj, A. K. V., Prabhakar Rao, P., Sameera, S., and Divya, S.	*Dyes and Pigments*	2015	[33]	India
Study of solar heat-reflective pigments in cool roof coatings.	Cheng, M., Ji, J., and Chang, Y.	*Journal of Beijing University of Chemical*	2009	[62]	China
Surfactant effect on titanium dioxide photosensitized oxidation of 4-dodecyloxybenzyl alcohol.	Bettoni, M., Brinchi, L., Del Giacco, T., Germani, R., Meniconi, S., Rol, C., and Sebastiani, G. V.	*Journal of Photochemistry and Photobiology A: Chemistry*	2012	[63]	Italy
On a cool coating for roof clay tiles: Development of the prototype and thermal-energy assessment.	Pisello, A. L., Cotana, F., and Brinchi, L.	*Energy Procedia*	2014	[64]	Italy
Effects of added ZnO on the crystallization and solar reflectance of titanium-based glaze.	Li, Z., Yang, Y., Peng, C., and Wu, J.	*Ceramics International*	2017	[65]	China
Performance of near-infrared reflective tile roofs.	Thongkanluang, T., Wutisatwongkul, J., Chirakanphaisarn, N., and Pokaipisit, A.	*Advanced Materials Research*	2013	[66]	Thailand
Environmental impact of cool roof paint: case study of house retrofit in two hot islands.	Emmanuel, S., Valentina, S., Petra, G., and Maria, K.	*Energy and Buildings*	2020	[67]	United Kingdom
Preparation of phthalocyanine blue/rutile TiO_2 composite pigment with a ball milling method and study on its NIR reflectivity	Lingyun, C., Xuening, F., Hongbin, Z., and Changliang, H.	*Dyes and Pigments*	2020	[68]	China

Pigments were proven to enhance the NIR reflectance for cool coatings and to maintain a wider range of color choices, which opened the way for an industry of geoengineering and chemical solutions for cool materials [27,28,31,33,62]. The absorption coefficient and the solar spectral backscattering measured in the range of 300–2500nm determines whether the pigment should be implemented in a cool coating [27]. According to Levinson et al. [28], a pigment with a low absorptance is considered cool, whereas a pigment with high NIR transmittance will necessitate an NIR-reflective background (usually white or metallic) in order to form an NIR-reflecting coating. The developed reflective pigments allowed for the transition from lighter colors to dark coating materials, often without compromising the reflective performance. Five dark-colored pigments were analyzed in a study to develop new species of high-NIR reflectance. With a formulation of a 25% weight content of rutile-type titanium dioxide, the white ceramic microspheres, with a 13% weight content, and the heavy calcium carbonate, with a 10% weight content, obtained positive results, and the back temperatures were lowered by 10–20 °C, compared to normal coatings [62].

In general, the pigments integrated into the matrix of cool materials range from organic, of which most are considered transparent, to complex inorganic color mixed-metal oxides that are often opaque [27,28]. Cool pigments achieve a high solar reflectance of up to 95%, compared to TiO_2, such as bismuth titanate [29,30], barium titanate [31], and terbium-doped yttrium cerate [32,33]. The photocatalytically active white inorganic pigment TiO_2 represents the most widely used nontoxic pigment and is characterized by strong scattering, weak absorption, and good stability [63]. As a result, most studies have been compared to its reflective performance [64]. The use of developed pigments was recently the most processed strategy. When incorporated into glazes, fillers, and engobes, synthesized pigments are used in coatings in order to enhance the optical and thermal performances of cool materials, as well as to respect the aesthetic requirements of a design. Several oxides were demonstrated to be able to enhance the NIR reflectance of glazes for concrete cement substrates, steel substrates, metal panels, and clay tiles [33,65,66]. For traditional buildings, using pigments based on sodium silicate for the tile coating improved the solar reflection in the NIR spectrum by 13% without affecting the visual appearance [64]. The integration of such pigments lowers roof overheating and reduces the energy required for cooling.

Cool pigments have now become a growing trend that is taking over cool surface technology, as nanoparticles are integrated into material structures to fulfil a specific design criterion and to enhance the reflective performance. In addition to their chemical stabilities, their effective thermal and optical performances have been proven in numerous studies. However, the acquisition, the production process, the synthesis methods, the high cost of the rare-earth elements used in their composition, and the hazardous environmental effect of the heavy metals may have a negative environmental impact [67,68]. On the other hand, the development of new compositions of reflective pigments continues to increase, reaching more potential evaluations. In addition to the high reflectivity, the research field has also been evaluating the functional and long-term performances against surface contamination [69], thermal insulation [70,71], and the synthesis methods in terms of the energy and raw material costs, which were directed for the sol–gel method and rare-earth compounds [72–77].

3.3.2. RR Materials

According to the publications presented in Table 2, the RR materials were evaluated through the nine most relevant publications that are related to the themes of sustainability, energy use, and construction engineering. Table 2 shows that most of these publications are affiliated with research entities based in Italy.

Table 2. Most important publications about RR materials.

Title of Publ.	Authors	Journal	Year of Publ.	Ref.	Country of Affiliation
Analysis of retro-reflective surfaces for urban heat island mitigation: A new analytical model.	Rossi, F., Pisello, A. L., Nicolini, A., Filipponi, M., and Palombo, M.	*Applied Energy*	2014	[34]	Italy
Experimental evaluation of urban heat island mitigation potential of retro-reflective pavement in urban canyons.	Rossi, F., Castellani, B., Presciutti, A., Morini, E., Anderini, E., Filipponi, M., and Nicolini, A.	*Energy and Buildings*	2016	[35]	Italy
Development and evaluation of directional retroreflective materials: Directional retroreflective materials as a heat island countermeasure.	Sakai, H., Jyota, H., Emura, K., and Igawa, N.	*Journal of Structural and Construction Engineering*	2011	[36]	Japan
A normalization procedure to compare retro-reflective and traditional diffusive materials in terms of UHI mitigation potential.	Gambelli, A. M., Cardinali, M., Filipponi, M., Castellani, B., Nicolini, A., and Rossi, F.	*AIP Conference Proceedings*	2019	[78]	Italy
Reduction of reflected heat by retroreflective materials.	Sakai, H., Emura, K., and Igawa, N.	*Journal of Structural and Construction Engineering*	2008	[79]	Japan
Design, characterization, and fabrication of solar-retroreflective cool-wall materials.	Ronnen, L., Sharon, C., Jonathan, S., Howdy, G., Tatsuya, H., Paul, B.	*Solar Energy Materials and Solar Cells*	2020	[80]	United States, Japan
Optimized retro-reflective tiles for exterior building element.	Morini, E., Castellani, B., Anderini, E., Presciutti, A., Nicolini, A., and Rossi, F.	*Sustainable Cities and Society*	2018	[81]	Italy
Retroreflective façades for urban heat island mitigation: Experimental investigation and energy evaluations.	Rossi, F., Castellani, B., Presciutti, A., Morini, E., Filipponi, M., Nicolini, A., and Santamouris, M.	*Applied Energy*	2015	[82]	Italy, Greece
Optic-energy and visual comfort analysis of retro-reflective building plasters.	B., Castellani, Alberto, M., Andrea, N., Federico, R.	*Building and Environment*	2020	[83]	Italy

Independently of the incidence direction, retroreflectivity refers to the capacity to reflect the incoming light beam to a surface back towards its source [34,35]. The application of diffusive materials on building envelopes induces multiple reflections within the urban canyon patterns; therefore, in order to reduce the captured solar radiation energy, the use of RR materials presents a good alternative [36]. In this sense, RR materials were studied to evaluate their potential with respect to diffusive (Lambertian) coatings, which allowed for the determination of a corrective parameter to enhance the comparison in terms of mitigating the UHI effect [78]. For the retroreflectivity measurements, Sakai et al. [79] present a procedure to measure only the retroreflective components of RR materials, which consists of: (i) Measuring the total reflectance by thermal measurements; (ii) Then measuring the reflectance without retroreflection using a spectrometer; and finally (iii) The RR components are measured by subtracting the latter from the former. Several studies have proved the efficiency of RR materials to reduce the heat trapped in the building surroundings [34–36].

An RR facade with an albedo of 0.60 could reflect 55% of the incident sunlight, whereas a diffusive facade could reflect only 36% with the same albedo [80]. RR materials were also applied in pavement, where the cooling potential could reach a maximum of a 4.6% albedo increase, compared to the traditional white and beige diffusive cool materials [35]. The RR performance of glass beads was discussed in several investigations that show promising results; however, when comparing a base ceramic tile coated with glass spheres and clear solid barium titanate spheres, the latter had the highest global reflectance (39%), and a radiation energy that reflected up to 5% [81].

Besides the advantages that RR materials offer in road-sign use and visual technology, their application in building facades and pavements alleviates the heat trapped inside the buildings that is created by diffuse reflective materials. However, their retroreflective behavior is limited to low angles of incidence, whereas, for high angles of incidence, the solar radiation is symmetrically reflected with regard to the perpendicular radiation [82], which limits the performance of RR materials at all angles of incidence [80,83].

Recently, more research has been oriented toward the performance of RR materials for different angles of incidence that takes into account the irradiated surface geometry scenarios, the urban density, the microclimate, the durability, and the costs and benefits [84]. As a solution, an angular selective behavior was discussed to overcome the limitations of RR materials, especially in summer [85].

3.3.3. PCMs

According to the publications presented in Table 3, the PCM materials were evaluated through the 12 most relevant publications that are related to the theme of energy use in buildings. Most of the publications are affiliated with research entities based in South Korea and the United States.

Table 3. Most important publications about PCMs.

Title of Publ.	Authors	Journal	Year of Publ.	Ref.	Country of Affiliation
Simulating the effects of cool roof and PCM (phase change materials) based roof to mitigate UHI (urban heat island) in prominent US cities.	Roman, K. K., O'Brien, T., Alvey, J. B., and Woo, O. J.	*Energy*	2016	[16]	United States
Prefabricated building units and modern methods of construction (MMC).	Mapston, M., and Westbrook, C.	*Materials for Energy Efficiency and Thermal Comfort in Buildings*	2010	[37]	United Kingdom
Understanding a potential for application of phase-change materials (PCMs) in building envelopes.	Kośny, J., and Kossecka, E.	*ASHRAE Transactions*	2013	[38]	Poland, United States
Thermal stress reduction in cool roof membranes using phase change materials (PCM).	Saffari, M., Piselli, C., de Gracia, A., Pisello, A. L., Cotana, F., and Cabeza, L. F.	*Energy and Buildings*	2018	[39]	Italy, Spain
Development of PCM cool roof system to control urban heat island considering temperate climatic conditions.	Chung, M. H., and Park, J. C.	*Energy and Buildings*	2016	[40]	South Korea
PCM cool roof systems for mitigating urban heat island—an experimental and numerical analysis.	Yang, Y. K., Kim, M. Y., Chung, M. H., and Park, J. C.	*Energy and Buildings*	2019	[43]	South Korea

Table 3. *Cont.*

Title of Publ.	Authors	Journal	Year of Publ.	Ref.	Country of Affiliation
Thermal Performance Test of a Phase-Change-Material Cool Roof System by a Scaled Model.	Yoon, S. G., Yang, Y. K., Kim, T. W., Chung, M. H., and Park, J. C.	*Advances in Civil Engineering*	2018	[86]	Republic of Korea
Numerical analysis of phase change materials/wood-plastic composite roof module system for improving thermal performance.	Seong, J., Seunghwan, W., Hyun, M., Su-Gwang, J., Sumin, K.	*Journal of Industrial and Engineering Chemistry*	2020	[87]	United States, Republic Korea
How to enhance thermal energy storage effect of PCM in roofs with varying solar reflectance: Experimental and numerical assessment of a new roof system for passive cooling in different climate conditions.	Piselli, C., Castaldo, V. L., and Pisello, A. L.	*Solar Energy*	2019	[88]	Italy
Effects of accelerated weathering on the optical characteristics of reflective coatings for cool pavement.	Ning, X., Hui, L., Hengji, Z., Xue, Z., Ming, J.	*Solar Energy Materials and Solar Cells*	2020	[89]	China
Phase change materials for pavement applications: A review	B.R. Anupam, Umesh Chandra Sahoo, PrasenjitRath	*Construction and Building Materials*	2020	[90]	India
Review of current state of research on energy storage, toxicity, health hazards and commercialization of phase changing materials.	S.S.Chandel, Tanya A.	*Renewable and Sustainable Energy Reviews*	2020	[91]	India

PCMs have the ability to change their physical characteristics during phase transition [37]. To compensate for the possible heating load increase in winter while using cool roofs, these materials can prevent the overheating of the roof surface during the summer without increasing the heating load in the winter [86]. As a consequence, they decrease the thermal stress and the annual energy load consumption, in addition to providing thermal inertia for buildings when the melting temperature is optimized [39]. The building energy performance and the thermal comfort could be improved depending on the phase change temperature adopted, according to Chang et al. [87]. Better results were registered for 30 °C than for 20 °C.

The performance of PCM-based surface technology as a UHI mitigation strategy has been evaluated through several studies. For roof application, a cool polyurethane-based membrane reduces the roof-surface temperature and the heat flux through the roof more than a traditional dark bitumen membrane; moreover, the outdoor environmental conditions and the type of PCM host material could influence the performance of the membrane [88]. Similar results were proven using PCM-doped tiles for a cool roof system in simulated summer conditions [40]. In real winter conditions, the use of PCMs maintained a higher indoor temperature than cool paints, and with a low surface temperature reducing the heat penalty [43]. In this sense, several types of PCMs have been tested as dynamic components in buildings in comparison to conventional cool roof materials, showing that their incorporation in the roof materials matrix decreased the heat gain flux by 54%, and registered for various values of albedo compared to cool roof technology, and a lower sensible heat by 40% [16].

PCMs have also been tested for cool pavements. Their use is based on the temperature regulation performance of these materials, which use a lightweight aggregate with a reasonable gradation for better results. The composite PCMs incorporated into the asphalt mixtures achieved a satisfactory cooling performance; however, some of them minimized the strength reductions of the mixtures [89].

The incorporation of PCMs in cool surfaces is emerging as a growing field of research because of their ability to restore energy with a minimum change in volume, and without an increase in temperature; however, the encapsulation method may affect their performance and cause leakage [16,38–40,88,90]. Moreover, some PCMs could be classified as "unsustainable"; for instance, the PCM paraffin wax that is commonly used releases toxic vapors when burnt, which can result in severe health hazards, as it contains formaldehyde, benzene, toluene, and other toxic compounds [91].

In order to enhance the thermal energy storage in buildings, recent investigations have been oriented toward developing new techniques of encapsulation. Nano/microencapsulation methods have presented promising results while avoiding leakage [92,93]. Moreover, different combinations of reflective coatings and PCM applications were tested; the optimal combination required a layer of thermal insulation between the two materials, which incorporates the PCMs into the buildings and is a complementary technique for all the energy-saving system [94].

3.3.4. Ceramic Materials

According to the publications presented in Table 4, ceramic materials have been evaluated in 16 publications that are highly related to the theme of energy use in buildings. Nearly 50% of the publications are affiliated, either implicitly or explicitly, with research entities based in Italy.

Table 4. Most important publications about ceramic materials.

Title of Publ.	Authors	Journal	Year of Publ.	Ref.	Country of Affiliation
Experimental evaluation of thermal performance of cool pavement material using waste tiles in tropical climate.	Anting, N., Md. Din, M. F., Iwao, K., Ponraj, M., Jungan, K., Yong, L. Y., and Siang, A. J. L. M.	*Energy and Buildings*	2017	[44]	Malaysia, Japan
On a cool coating for roof clay tiles: Development of the prototype and thermal-energy assessment.	Pisello, A. L., Cotana, F., and Brinchi, L.	*Energy Procedia*	2014	[64]	Italy
Performance of near-infrared reflective tile roofs.	Thongkanluang, T., Wutisatwongkul, J., Chirakanphaisarn, N., and Pokaipisit, A.	*Advanced Materials Research*	2013	[66]	Thailand
Design of ceramic tiles with high solar reflectance through the development of a functional engobe.	Ferrari, Chiara, Libbra, A., Muscio, A., and Siligardi, C.	*Ceramics International*	2013	[95]	Italy
Design of a cool color glaze for solar reflective tile application.	Ferrari, C., Muscio, A., Siligardi, C., and Manfredini, T.	*Ceramics International*	2015	[96]	Italy
High-solar-reflectance building ceramic tiles based on titanite (CaTiSiO5) glaze.	Li, Z., Zhao, M., Zeng, J., Peng, C., and Wu, J.	*Solar Energy*	2017	[97]	China
Cooler tile-roofed buildings with near-infrared-reflective non-white coatings.	Levinson, R., Akbari, H., and Reilly, J. C.	*Building and Environment*	2007	[98]	United States
Measured temperature reductions and energy savings from a cool tile roof on a central California home.	Rosado, P. J., Faulkner, D., Sullivan, D. P., and Levinson, R.	*Energy and Buildings*	2014	[99]	United States

Table 4. *Cont.*

Title of Publ.	Authors	Journal	Year of Publ.	Ref.	Country of Affiliation
New strategy to mitigate urban heat island effect: Energy saving by combining high albedo and low thermal diffusivity in glass ceramic materials.	Enríquez, E., Fuertes, V., Cabrera, M. J., Seores, J., Muñoz, D., and Fernández, J. F.	*Solar Energy*	2017	[100]	Spain
White sintered glass-ceramic tiles with improved thermal insulation properties for building applications.	Marangoni, M., Nait-Ali, B., Smith, D. S., Binhussain, M., Colombo, P., and Bernardo, E.	*Journal of the European Ceramic Society*	2017	[101]	Italy, France, Saudi Arabia, United States
A composite cool colored tile for sloped roofs with high "equivalent" solar reflectance.	Ferrari, Chiara, Libbra, A., Cernuschi, F. M., De Maria, L., Marchionna, S., Barozzi, M., . . . Muscio, A.	*Energy and Buildings*	2016	[102]	Italy
Optical properties of traditional clay tiles for ventilated roofs and implication on roof thermal performance.	Di Giuseppe, E., Sabbatini, S., Cozzolino, N., Stipa, P., and D'Orazio, M.	*Journal of Building Physics*	2019	[103]	Italy
Study on the cool roof effect of Japanese traditional tiled roof: Numerical analysis of solar reflectance of unevenness tiled surface and heat budget of typical tiled roof system.	Takebayashi, H., Moriyama, M., and Sugihara, T.	*Energy and Buildings*	2012	[104]	Japan
Development of clay tile coatings for steep-sloped cool roofs.	Pisello, A. L., Cotana, F., Nicolini, A., and Brinchi, L.	*Energies*	2013	[105]	Italy
Thermal-energy analysis of roof cool clay tiles for application in historic buildings and cities.	Pisello, A. L.	*Sustainable Cities and Society*	2015	[106]	Italy
Study on roof tile's colors in Malaysia for development of new anti-warming roof tiles with higher Solar Reflectance Index (SRI).	Yacouby, A. M. A., Khamidi, M. F., Nuruddin, M. F., Farhan, S. A., and Razali, A. E.	*National Postgraduate Conference—Energy and Sustainability: Exploring the Innovative Minds*	2011	[107]	Malaysia

The publications showed the development of innovative solutions for a better solar reflectance index of ceramic materials, such as tiles, glazes, and engobes. The use of ceramic tiles is considered an effective component of the cool roof strategy, thanks to its durability and its solar properties, especially if it is glazed [95–97]. The substrate material was tested with the application of different ceramic coatings through several studies, and the developed nonwhite coatings enhanced the solar reflective performance and showed interesting results in terms of energy saving [98,99]. Moreover, the wollastonite–hardystonite glass–ceramic porous tiles showed high reflectances of solar radiation, coupled with low thermal conductivity in an arid environment [100], which highlights the complementary function with regard to the thermal insulation properties [101,102]. In the same sense, an improvement in the thermal performance of a residential building was found during the summer and the winter, and 75% of the solar radiation reflectance in the NIR spectrum was registered, i.e., 10% more with respect to traditional tiles, without altering the visible appearance [64]. The latter property is highly considered for historical buildings that are required to maintain their original aesthetic appearance. These types of buildings often exist in the center of urban areas, which are strongly affected by the UHI. Their retrofitting using innovative cool clay tile coatings increased the solar reflectance by 20% while maintaining the original color intact. This kind of retrofitting enhances the thermal responses of buildings and the urban climate in general [103–106].

Glazes present a good complementary component for cool tiles as glass–ceramic materials; they are fabricated through a controlled crystallization process for a desired microstructure. The incorporation of cool pigments in the composition of glazes yields the total reflective performance of the product up to 82.8% [66]. The results of an experimental study show that a tile coated with glass ceramic material induces 20% energy savings, compared to TiO_2-based paints, and that it could be used for roofs and pavements [107]. The application of engobes enhances the solar reflectance as well, by up to 0.90 [95]. As an intermediate layer between the substrate and the glaze, it provides a high degree of adhesion while taking into account the convenience of all the coefficients of thermal expansion.

The application of developed glazes and engobes enhances the solar reflective performance of tiles [108]. In recent studies, the development of cool ceramic coatings was strongly discussed in terms of the low-cost routes, the use of secondary materials, and the self-cleaning abilities [109]. In turn, research has been focused on enhancing the compositions of glass ceramic frits, opacifiers, and pigments to reach the optimal potential for NIR reflectance. The development of coatings has been oriented toward the use of dynamic coatings, such as the passive ones: photochromic and thermochromic coatings [110]. It is clear that the research field is an intersection of multiple complementary techniques and materials, which include pigments, glazes, and tiles [73,111], and this creates a wide range of opportunities to attain the energy-saving potential of cool materials in future studies.

3.3.5. Glass

According to the publications presented in Table 5, the use of glass is discussed through the 12 most relevant publications that are related to the themes of buildings and the cleaner production of materials. The publications are affiliated with research entities based in different countries and that are not concentrated in a specific one.

Table 5. Most important publications about glass.

Title of Publ.	Authors	Journal	Year of Publ.	Ref.	Country of Affiliation
Optic-energy and visual comfort analysis of retro-reflective building plasters.	Castellani, Gambelli, Nicolini, Rossi	*Building and Environment*	2020	[83]	Italy
Waste glass in civil engineering applications—A review.	Kazmi, D., Williams, D. J. and Serati, M.	*International Journal of Applied Ceramic Technology*	2020	[112]	Australia
Reuse of waste glass in building brick production.	Demir, I.	*Waste Management and Research*	2009	[113]	Turkey
Utilization of waste glass to enhance physical-mechanical properties of fired clay brick.	Phonphuak, N., Kanyakam, S., and Chindaprasirt, P.	*Journal of Cleaner Production*	2016	[114]	Thailand
Properties of Fired Clay Bricks Mixed with Waste Glass.	Abdeen, H., and Shihada, S.	*Journal of Scientific Research and Reports*	2017	[115]	Palestine
The role of glass waste in the production of ceramic-based products and other applications: A review.	Silva, R. V., de Brito, J., Lye, C. Q., and Dhir, R. K.	*Journal of Cleaner Production*	2017	[116]	Portugal, United Kingdom
Effect of waste glass on properties of burnt clay bricks.	Hameed, A., Haider, U., Qazi, A. U., and Abbas, S.	*Pakistan Journal of Engineering and Applied Sciences*	2018	[117]	Canada
Thermal performance evaluation of eco-friendly bricks incorporating waste glass sludge.	Kazmi, S. M. S., Munir, M. J., Wu, Y. F., Hanif, A., and Patnaikuni, I.	*Journal of Cleaner Production*	2018	[118]	Australia, Pakistan, Hong Gong

Table 5. *Cont.*

Title of Publ.	Authors	Journal	Year of Publ.	Ref.	Country of Affiliation
Glass recycling in the production of low-temperature stoneware tiles.	Lassinantti Gualtieri, M., Mugoni, C., Guandalini, S., Cattini, A., Mazzini, D., Alboni, C., and Siligardi, C.	*Journal of Cleaner Production*	2018	[119]	Italy
Effect of glass powder on the technological properties and microstructure of clay mixture for porcelain stoneware tiles manufacture.	Njindam, O. R., Njoya, D., Mache, J. R., Mouafon, M., Messan, A., and Njopwouo, D.	*Construction and Building Materials*	2018	[120]	Burkina Fasu, Cameroon
Incorporating hollow glass microsphere to cool asphalt pavement: Preliminary evaluation of asphalt mastic.	Du Yinfei, Dai Mingxin, Deng Haibin, Deng Deyi, Cheng Peifeng, Ma Cong	*Construction and Building Materials*	2020	[121]	China
Cool White Polymer Coatings based on Glass Bubbles for Buildings.	Nie, YoungjaeYoo, Hasitha Hewakuruppu, Sullivan, Krishna, Jaeho Lee	*Scientific Reports*	2020	[122]	South Korea, United States

Recently, numerous solutions for cool materials have been developed through the academic research in terms of sustainability, which have paved the way for substituting raw materials and using secondary ones. Waste glass was introduced as an alternative as a solution to the increased need for efficient waste management strategies.

Using glass as a secondary material in the fabrication of ceramic materials enhances the mechanical behavior and the sintering action because of its amorphous structure [112]. Different percentages of waste glass have been tested in different studies for the fabrication of clay bricks, and, in general, the mechanical and thermal behaviors of these materials were affected by the percentage of the substitution, the size of the waste glass particles, and the chemical composition of each type [113–118]. For the fabrication of tiles, 41 wt.% of waste glass demonstrated good flexural strength and abrasion resistance when using the boron-rich waste glass as a sintering promoter [119]. However, Njindam et al. [120] demonstrated that the addition of high amounts of glass (>30 wt.%) into ceramic bodies is undesirable because of its negative effect on the physical properties. The integration of glass into the matrix of cool materials was mostly in its finest structure; in general, good results were obtained when using small-sized particles of glass. For instance, hollow glass microspheres were integrated into an asphalt mixture, which resulted in a 40% decrease in the thermal conductivity, and a 60% increase in the infrared reflectance [121,122]. In the same sense, it was demonstrated that glass spheres incorporated in RR materials showed good results in terms of the energy reflected beyond the canyon for the building envelopes, in addition to the road-traffic-marking efficiency [83].

According to the different studies, each material manifests specific thermal, physical, and mechanical properties, depending on different conditions, such as the chemical composition and the particle size of the waste glass.

The evaluation of the solar reflectance of ceramic materials, such as tiles and bricks, for building envelopes incorporating waste glass has been little discussed in the academic research. Nevertheless, waste glass cullet was successfully mixed with conventional materials to fabricate sustainable asphalt roof shingles, which have a solar reflectance greater than 25%, and better solar reflectance properties [45]. Recent research has shown that the use of waste glass tile coatings should be considered for a global solar reflectance analysis [123]. Future studies are needed to evaluate the influence of using waste glass on the solar radiation reflectance in ceramic materials, especially in the NIR solar spectrum, where 52% of the solar energy is concentrated.

4. Conclusions

On the basis of a bibliometric analysis using SciMAT software, a sample of 982 academic records in the field of cool surfaces was processed for three periods, from 1995 to 2020. The most prolific period, between 2011 and 2020, with 87.74% of the total records, was analyzed specifically. It was shown that cool surfaces are a developing research field that aims to create sustainable cool materials and coatings, with efficient solar reflectivity, that conform to the retrofitting requirements, and that are adaptable to the specificities of each domain of application: pavements, facades, and particularly roofs.

The research field has placed emphasis on the materials perspective, as most materials trending in this topic are pigments, RR materials, PCMs, ceramic materials, and glass. The heat energy mostly falls within the NIR wavelength region; thus, several recent studies have been developing solar radiation reflective materials. However, the efficiency and the manufacturing of these materials depend not only on the good thermal and optical performances, but also on the environmental impact during the production and the service life. The results of the analysis of the key publications are summarized below:

- Developing pigments with high NIR radiation reflectance is a growing industrial domain, which provides up to 95% of the solar reflectivity performance. However, the acquisition, the production process, and the methods of synthesis of these nanoparticles may inconveniently affect the environment;
- Retroreflective materials, such as backscattering materials, present good performances by reflecting the incident solar radiation beyond the urban canyon and easing the heat trapped in the urban canopy with respect to the diffusive materials. However, their retroreflective behavior occurs mainly for low angles of incidence, therefore limiting their performance at large angles of incidence. More studies should discuss alternative solutions for the angular selective behavior;
- PCMs represent a good solution as cool-surface dynamic switch materials, and their implementation in the reflective materials matrix enhances the solar reflectivity performance. However, some PCM-based materials may contain toxic metals, and the encapsulation methods should be further addressed in future studies for better potential uses;
- Ceramic materials are complementary effective materials for cool materials and coatings that enhance the total solar reflectance performance, with a broad range of reflective glazes and engobes;
- Most of the studies discuss the integration of glass in the fabrication of ceramic materials as fine particles. The use of glass in these materials, with the optimal dosage and particle size, enhances their physical, mechanical, and thermal properties;
- All the cool materials discussed in this review have a common aim, and that is to conform to energy efficiency while using sustainable materials and methods, these materials could be used as complementary strategies for an energy saving system.
- The use of secondary materials as substitutes for the manufacturing of cool materials have paved the way toward more sustainable solutions. The incorporation of glass generated from waste in the manufacturing of cool materials is poorly discussed in the academic literature; thus, more research on the solar reflectance performance of waste glass particles as raw material should be further investigated. This study presents a scientific contribution to the cool surfaces research field in terms of the materials and strategies it presents to counter the urban heat island effect.

Author Contributions: Conceptualization, experiments, writing, formal analysis, and the postprocessing, C.M. and M.M.-M.; conceptualization, writing, project administration, funding acquisition, and supervision, M.Z. and D.P.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the State Research Agency (AEI) of Spain and the European Regional Development Funds (ERDF), under project: PID2019-108761RB-I00.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available upon request.

Acknowledgments: The research group TEP-968 technologies for the circular economy of the University of Granada, Spain.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gago, E.J.; Roldan, J.; Pacheco-Torres, R.; Ordonez, J. The city and urban heat islands: A review of strategies to mitigate adverse effects. *Renew. Sustain. Energy Rev.* **2013**, *25*, 749–758. [CrossRef]
2. Rosenfeld, A.H.; Akbari, H.; Bretz, S.; Fishman, B.L.; Stamper-Kurn, D.; Sailor, D.; Taha, H. Mitigation of urban heat islands: Materials, utility programs, updates. *Energy Build.* **1995**, *22*, 255–265. [CrossRef]
3. Zinzi, M.; Agnoli, S. Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region. *Energy Build.* **2012**, *55*, 66–76. [CrossRef]
4. Mohajerani, A.; Bakaric, J.; Jeffrey-Bailey, T. The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. *J. Environ. Manag.* **2017**, *197*, 522–538. [CrossRef]
5. Akbari, H.; Kolokotsa, D. Three decades of urban heat islands and mitigation technologies research. *Energy Build.* **2016**, *133*, 834–842. [CrossRef]
6. Akbari, H.; Davis, S.; Dorsano, S.; Huang, J.; Winnett, S. *Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing*; U.S. Environmental Protection Agency: Washington, DC, USA, 1992.
7. Kolokotsa, D.; Santamouris, M.; Zerefos, S. Green and cool roofs' urban heat island mitigation potential in European climates for office buildings under free floating conditions. *Sol. Energy* **2013**, *95*, 118–130. [CrossRef]
8. Chatterjee, S.; Khan, A.; Dinda, A.; Mithun, S.; Khatun, R.; Akbari, H.; Kusaka, H.; Mitra, C.; Bhatti, S.S.; Van Doan, Q.; et al. Simulating micro-scale thermal interactions in different building environments for mitigating urban heat islands. *Sci. Total Environ.* **2019**, *663*, 610–631. [CrossRef]
9. Santamouris, M. Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. *Renew. Sustain. Energy Rev.* **2013**, *26*, 224–240. [CrossRef]
10. Qin, Y. A review on the development of cool pavements to mitigate urban heat island effect. *Renew. Sustain. Energy Rev.* **2015**, *52*, 445–459. [CrossRef]
11. Akbari, H.; Cartalis, C.; Kolokotsa, D.; Muscio, A.; Pisello, A.L.; Rossi, F.; Santamouris, M.; Synnefa, A.; Wong, N.H.; Zinzi, M. Local climate change and urban heat island mitigation techniques—the state of the art. *J. Civ. Eng. Manag.* **2015**, *22*, 1–16. [CrossRef]
12. Lai, D.; Liu, W.; Gan, T.; Liu, K.; Chen, Q. A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Sci. Total Environ.* **2019**, *661*, 337–353. [CrossRef] [PubMed]
13. Zhu, Z.; Zhou, D.; Wang, Y.; Ma, D.; Meng, X. Assessment of urban surface and canopy cooling strategies in high-rise residential communities. *J. Clean. Prod.* **2020**, *288*, 125599. [CrossRef]
14. Yang, J.; Wang, Z.-H.; Kaloush, K.E. Environmental impacts of reflective materials: Is high albedo a 'silver bullet' for mitigating urban heat island? *Renew. Sustain. Energy Rev.* **2015**, *47*, 830–843. [CrossRef]
15. Hosseini, M.; Akbari, H. Effect of cool roofs on commercial buildings energy use in cold climates. *Energy Build.* **2016**, *114*, 143–155. [CrossRef]
16. Roman, K.K.; O'Brien, T.; Alvey, J.; Woo, O. Simulating the effects of cool roof and PCM (phase change materials) based roof to mitigate UHI (urban heat island) in prominent US cities. *Energy* **2016**, *96*, 103–117. [CrossRef]
17. Pisello, A.L. State of the art on the development of cool coatings for buildings and cities. *Sol. Energy* **2017**, *144*, 660–680. [CrossRef]
18. Akbari, H.; Matthews, D. Global cooling updates: Reflective roofs and pavements. *Energy Build.* **2012**, *55*, 2–6. [CrossRef]
19. Gao, Y.; Xu, J.; Yang, S.; Tang, X.; Zhou, Q.; Ge, J.; Xu, T.; Levinson, R. Cool roofs in China: Policy review, building simulations, and proof-of-concept experiments. *Energy Policy* **2014**, *74*, 190–214. [CrossRef]
20. Lee Shoemaker, W. Cool metal roofs provide long-term solutions. *Constr. Specif.* **2003**, *56*, 64–69.
21. Chen, M.Z.; Wei, W.; Wu, S.P. On Cold Materials of Pavement and High-Temperature Performance of Asphalt Concrete. *Mater. Sci. Forum* **2009**, *620–622*, 379–382. [CrossRef]

22. Smith, G.B.; Labarias, M.A.G.; Arnold, M.D.; Gentle, A.R. Super-cool paints: Optimizing composition with a modified four-flux model. In Proceedings of the Thermal Radiation Management for Energy Applications, San Diego, CA, USA, 6–10 August 2017. [CrossRef]
23. Bretz, S.; Akbari, H.; Rosenfeld, A. Practical issues for using solar-reflective materials to mitigate urban heat islands. *Atmos. Environ.* **1998**, *32*, 95–101. [CrossRef]
24. Muniz-Miranda, F.; Minei, P.; Contiero, L.; Labat, F.; Ciofini, I.; Adamo, C.; Bellina, F.; Pucci, A. Aggregation Effects on Pigment Coatings: Pigment Red 179 as a Case Study. *ACS Omega* **2019**, *4*, 20315–20323. [CrossRef] [PubMed]
25. Rosati, A.; Fedel, M.; Rossi, S. NIR reflective pigments for cool roof applications: A comprehensive review. *J. Clean. Prod.* **2021**, *313*, 127826. [CrossRef]
26. Xie, N.; Li, H.; Abdelhady, A.; Harvey, J. Laboratorial investigation on optical and thermal properties of cool pavement nano-coatings for urban heat island mitigation. *Build. Environ.* **2018**, *147*, 231–240. [CrossRef]
27. Levinson, R.; Berdahl, P.; Akbari, H. Solar spectral optical properties of pigments—Part I: Model for deriving scattering and absorption coefficients from transmittance and reflectance measurements. *Sol. Energy Mater. Sol. Cells* **2005**, *89*, 319–349. [CrossRef]
28. Levinson, R.; Berdahl, P.; Akbari, H. Solar spectral optical properties of pigments—Part II: Survey of common colorants. *Sol. Energy Mater. Sol. Cells* **2005**, *89*, 351–389. [CrossRef]
29. Meenakshi, P.; Selvaraj, M. Bismuth titanate as an infrared reflective pigment for cool roof coating. *Sol. Energy Mater. Sol. Cells* **2018**, *174*, 530–537. [CrossRef]
30. Raj, A.K.; Rao, P.P.; Sreena, T.S.; Thara, T.A. Pigmentary colors from yellow to red in $Bi_2Ce_2O_7$ by rare earth ion substitutions as possible high NIR reflecting pigments. *Dye. Pigment.* **2019**, *160*, 177–187. [CrossRef]
31. Xiang, B.; Zhang, J. A new member of solar heat-reflective pigments: $BaTiO_3$ and its effect on the cooling properties of ASA (acrylonitrile-styrene-acrylate copolymer). *Sol. Energy Mater. Sol. Cells* **2018**, *180*, 67–75. [CrossRef]
32. Raj, A.K.; Rao, P.P.; Divya, S.; Ajuthara, T. Terbium doped Sr_2MO_4 [M = Sn and Zr] yellow pigments with high infrared reflectance for energy saving applications. *Powder Technol.* **2017**, *311*, 52–58. [CrossRef]
33. Raj, A.K.; Rao, P.P.; Sameera, S.; Divya, S. Pigments based on terbium-doped yttrium cerate with high NIR reflectance for cool roof and surface coating applications. *Dye. Pigment.* **2015**, *122*, 116–125. [CrossRef]
34. Rossi, F.; Pisello, A.L.; Nicolini, A.; Filipponi, M.; Palombo, M. Analysis of retro-reflective surfaces for urban heat island mitigation: A new analytical model. *Appl. Energy* **2014**, *114*, 621–631. [CrossRef]
35. Rossi, F.; Castellani, B.; Presciutti, A.; Morini, E.; Anderini, E.; Filipponi, M.; Nicolini, A. Experimental evaluation of urban heat island mitigation potential of retro-reflective pavement in urban canyons. *Energy Build.* **2016**, *126*, 340–352. [CrossRef]
36. Sakai, H.; Iyota, H.; Emura, K.; Igawa, N. Development and evaluation of directional retroreflective materials. *Struct. Constr. Eng. (Trans. AIJ)* **2011**, *76*, 1229–1234. [CrossRef]
37. Mapston, M.; Westbrook, C. Prefabricated building units and modern methods of construction (MMC). *Mater. Energy Effic. Therm. Comf. Build* **2010**, *2010*, 427–454. [CrossRef]
38. Kośny, J.; Kossecka, E. Understanding a potential for application of phase-change materials (PCMs) in building envelopes. *ASHRAE Trans.* **2013**, *119*, 3–13.
39. Saffari, M.; Piselli, C.; de Gracia, A.; Pisello, A.L.; Cotana, F.; Cabeza, L.F. Thermal stress reduction in cool roof membranes using phase change materials (PCM). *Energy Build.* **2018**, *158*, 1097–1105. [CrossRef]
40. Chung, M.H.; Park, J.C. Development of PCM cool roof system to control urban heat island considering temperate climatic conditions. *Energy Build.* **2016**, *116*, 341–348. [CrossRef]
41. Pisello, A.L.; Fortunati, E.; Fabiani, C.; Mattioli, S.; Dominici, F.; Torre, L.; Cabeza, L.F.; Cotana, F. PCM for improving polyurethane-based cool roof membranes durability. *Sol. Energy Mater. Sol. Cells* **2017**, *160*, 34–42. [CrossRef]
42. Yang, Y.K.; Kang, I.S.; Chung, M.H.; Kim, S.; Park, J.C. Effect of PCM cool roof system on the reduction in urban heat island phenomenon. *Build. Environ.* **2017**, *122*, 411–421. [CrossRef]
43. Yang, Y.K.; Kim, M.Y.; Chung, M.H.; Park, J.C. PCM cool roof systems for mitigating urban heat island - an experimental and numerical analysis. *Energy Build.* **2019**, *205*, 109537. [CrossRef]
44. Anting, N.; Din, M.F.M.; Iwao, K.; Ponraj, M.; Jungan, K.; Yong, L.Y.; Siang, A.J.L.M. Experimental evaluation of thermal performance of cool pavement material using waste tiles in tropical climate. *Energy Build.* **2017**, *142*, 211–219. [CrossRef]
45. Kiletico, M.J.; Hassan, M.M.; Mohammad, L.N.; Alvergue, A.J. New Approach to Recycle Glass Cullet in Asphalt Shingles to Alleviate Thermal Loads and Reduce Heat Island Effects. *J. Mater. Civ. Eng.* **2015**, *27*, 04014219. [CrossRef]
46. Cobo, M.J.; López-Herrera, A.G.; Herrera-Viedma, E.; Herrera, F. An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. *J. Inform.* **2011**, *5*, 146–166. [CrossRef]
47. Noyons, E.C.M.; Moed, H.F.; Luwel, M. Combining mapping and citation analysis for evaluative bibliometric purposes: A bibliometric study. *J. Am. Soc. Inf. Sci.* **1999**, *50*, 115–131. [CrossRef]
48. Callon, M.; Courtial, J.-P.; Turner, W.A.; Bauin, S. From translations to problematic networks: An introduction to co-word analysis. *Soc. Sci. Inf.* **1983**, *22*, 191–235. [CrossRef]
49. Callon, M.; Courtial, J.P.; Laville, F. Co-word analysis as a tool for describing the network of interactions between basic and technological research: The case of polymer chemsitry. *Scientometrics* **1991**, *22*, 155–205. [CrossRef]

50. Cobo, M.J.; Martínez, M.; Gutiérrez-Salcedo, M.; Fujita, H.; Herrera-Viedma, E. 25years at Knowledge-Based Systems: A bibliometric analysis. *Knowledge-Based Syst.* **2015**, *80*, 3–13. [CrossRef]
51. Zinzi, M.; Fasano, G. Properties and performance of advanced reflective paints to reduce the cooling loads in buildings and mitigate the heat island effect in urban areas. *Int. J. Sustain. Energy* **2009**, *28*, 123–139. [CrossRef]
52. Boriboonsomsin, K.; Reza, F. Mix Design and Benefit Evaluation of High Solar Reflectance Concrete for Pavements. *Transp. Res. Rec. J. Transp. Res. Board* **2007**, *2011*, 11–20. [CrossRef]
53. Berdahl, P.; Bretz, S.E. Preliminary survey of the solar reflectance of cool roofing materials. *Energy Build.* **1997**, *25*, 149–158. [CrossRef]
54. Akbari, H.; Pomerantz, M.; Taha, H. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Sol. Energy* **2001**, *70*, 295–310. [CrossRef]
55. Rosenfeld, A.H.; Akbari, H.; Romm, J.J.; Pomerantz, M. Cool communities: Strategies for heat island mitigation and smog reduction. *Energy Build.* **1998**, *28*, 51–62. [CrossRef]
56. Zhou, N.; Sha, S.; Zhang, Y.; Li, S.; Xu, S.; Luan, J. Coprecipitation synthesis of a green Co-doped wurtzite structure high near-infrared reflective pigments using ammonia as precipitant. *J. Alloy. Compd.* **2019**, *820*, 153183. [CrossRef]
57. Kavitha, K.; Sivakumar, A. Impact of titanium concentration in structural and optical behaviour of nano Bi_2Ce_{2-x} Ti_xO_7 (x = 0–1) high NIR reflective and UV shielding yellow and orange pigments. *Inorg. Chem. Commun.* **2020**, *120*, 108163. [CrossRef]
58. Matias, L.; Gonçalves, L.; Costa, A.; Santos, C.P. Cool Façades - Thermal Performance Assessment Using Infrared Thermography. *Key Eng. Mater.* **2014**, *634*, 14–21. [CrossRef]
59. Cozza, E.S.; Alloisio, M.; Comite, A.; Di Tanna, G.; Vicini, S. NIR-reflecting properties of new paints for energy-efficient buildings. *Sol. Energy* **2015**, *116*, 108–116. [CrossRef]
60. Chen, Y.; Mandal, J.; Li, W.; Smith-Washington, A.; Tsai, C.-C.; Huang, W.; Shrestha, S.; Yu, N.; Han, R.P.S.; Cao, A.; et al. Colored and paintable bilayer coatings with high solar-infrared reflectance for efficient cooling. *Sci. Adv.* **2020**, *6*, eaaz5413. [CrossRef]
61. Cobo, M.J.; López-Herrera, A.G.; Herrera-Viedma, E.; Herrera, F. SciMAT: A new science mapping analysis software tool. *J. Am. Soc. Inf. Sci. Technol.* **2012**, *63*, 1609–1630. [CrossRef]
62. Cheng, M.; Ji, J.; Chang, Y.; Herrera, F. Study of solar heat-reflective pigments in cool roof coatings. *J. Beijing Univ. Chem. Technol. (Nat. Sci. Ed.).* **2009**, *36*, 50–54.
63. Bettoni, M.; Brinchi, L.; Del Giacco, T.; Germani, R.; Meniconi, S.; Rol, C.; Sebastiani, G.V.; Meniconi, S. Surfactant effect on titanium dioxide photosensitized oxidation of 4-dodecyloxybenzyl alcohol. *J. Photochem. Photobiol. A Chem.* **2012**, *229*, 53–59. [CrossRef]
64. Pisello, A.L.; Cotana, F.; Brinchi, L. On a Cool Coating for Roof Clay Tiles: Development of the Prototype and Thermal-energy Assessment. *Energy Procedia* **2014**, *45*, 453–462. [CrossRef]
65. Li, Z.; Yang, Y.; Peng, C.; Wu, J. Effects of added ZnO on the crystallization and solar reflectance of titanium-based glaze. *Ceram. Int.* **2017**, *43*, 6597–6602. [CrossRef]
66. Thongkanluang, T.; Wutisatwongkul, J.; Chirakanphaisarn, N.; Pokaipisit, A. Performance of Near-Infrared Reflective Tile Roofs. *Adv. Mater. Res.* **2013**, *770*, 30–33. [CrossRef]
67. Shittu, E.; Stojceska, V.; Gratton, P.; Kolokotroni, M. Environmental impact of cool roof paint: Case-Study of house retrofit in two hot islands. *Energy Build.* **2020**, *217*, 110007. [CrossRef]
68. Cao, L.; Fei, X.; Zhao, H.; Huang, C. Preparation of phthalocyanine blue/rutile TiO_2 composite pigment with a ball milling method and study on its NIR reflectivity. *Dye. Pigment.* **2019**, *173*, 107879. [CrossRef]
69. Yun, T.H.; Yim, C. Uniform Fabrication of Hollow Titania Using Anionic Modified Acrylated Polymer Template for Phase Composition Effect as Photocatalyst and Infrared Reflective Coating. *Nanomaterials* **2021**, *11*, 2845. [CrossRef]
70. Tian, M.; Chen, C.; Han, A.; Ye, M.; Chen, X. Estimating thermal insulation performance and weather resistance of acrylonitrile-styrene-acrylate modified with high solar reflective pigments: Pr3+/Cr3+ doped BaTiO. *Sol. Energy* **2021**, *225*, 934–941. [CrossRef]
71. Ramos, N.; Maia, J.; Souza, A.; Almeida, R.; Silva, L. Impact of Incorporating NIR Reflective Pigments in Finishing Coatings of ETICS. *Infrastructures* **2021**, *6*, 79. [CrossRef]
72. Soranakom, P.; Vittayakorn, N.; Rakkwamsuk, P.; Supothina, S.; Seeharaj, P. Effect of surfactant concentration on the formation of $Fe_2O_3@SiO_2$ NIR-reflective red pigments. *Ceram. Int.* **2021**, *47*, 13147–13155. [CrossRef]
73. Divya, S.; Das, S. New red pigments based on Li3AlMnO5 for NIR reflective cool coatings. *Ceram. Int.* **2021**, *47*, 30381–30390. [CrossRef]
74. Rosati, A.; Fedel, M.; Rossi, S. Laboratory scale characterization of cool roof paints: Comparison among different artificial radiation sources. *Prog. Org. Coatings* **2021**, *161*, 106464. [CrossRef]
75. Kamal, A.; Abdouss, M.; Mazhar, M. Synthesis, characterization, and visible–near infrared properties of some perylene-3,4,9,10-tetracarboxylic bisimide derivatives. *J. Chem. Technol. Biotechnol.* **2021**, *96*, 2837–2844. [CrossRef]
76. Li, Y.; Ma, Y.; Liu, W.; Wang, Z.; Liu, H.; Wang, X.; Wei, H.; Zeng, S.; Yi, N.; Cheng, G.J. A promising inorganic $YFeO_3$ pigments with high near-infrared reflectance and infrared emission. *Sol. Energy* **2021**, *226*, 180–191. [CrossRef]
77. Zhou, W.; Liu, Y.; Sun, Q.; Ye, J.; Chen, L.; Wang, J.; Li, G.; Lin, H.; Ye, Y.; Chen, W. High Near-Infrared Reflectance Orange Pigments of Fe-Doped La2W2O9: Preparation, Characterization, and Energy Consumption Simulation. *ACS Sustain. Chem. Eng.* **2021**, *9*, 12385–12393. [CrossRef]

78. Gambelli, A.M.; Cardinali, M.; Filipponi, M.; Castellani, B.; Nicolini, A.; Rossi, F. A normalization procedure to compare retro-reflective and traditional diffusive materials in terms of UHI mitigation potential. *AIP Conf. Proc.* **2019**, *2191*, 020085. [CrossRef]
79. Sakai, H.; Emura, K.; Igawa, N. Reduction of reflected heat by retroreflective materials. *J. Struct. Constr. Eng. (Trans. AIJ)* **2008**, *73*, 1239–1244. [CrossRef]
80. Levinson, R.; Chen, S.; Slack, J.; Goudey, H.; Harima, T.; Berdahl, P. Design, characterization, and fabrication of solar-retroreflective cool-wall materials. *Sol. Energy Mater. Sol. Cells* **2019**, *206*, 110117. [CrossRef]
81. Morini, E.; Castellani, B.; Anderini, E.; Presciutti, A.; Nicolini, A.; Rossi, F. Optimized retro-reflective tiles for exterior building element. *Sustain. Cities Soc.* **2018**, *37*, 146–153. [CrossRef]
82. Rossi, F.; Castellani, B.; Presciutti, A.; Morini, E.; Filipponi, M.; Nicolini, A.; Santamouris, M. Retroreflective façades for urban heat island mitigation: Experimental investigation and energy evaluations. *Appl. Energy* **2015**, *145*, 8–20. [CrossRef]
83. Castellani, B.; Gambelli, A.M.; Nicolini, A.; Rossi, F. Optic-energy and visual comfort analysis of retro-reflective building plasters. *Build. Environ.* **2020**, *174*, 106781. [CrossRef]
84. Manni, M.; Nicolini, A. Optimized Cool Coatings as a Strategy to Improve Urban Equivalent Albedo at Various Latitudes. *Atmosphere* **2021**, *12*, 1335. [CrossRef]
85. Anupam, B.; Sahoo, U.C.; Chandrappa, A.K.; Rath, P. Emerging technologies in cool pavements: A review. *Constr. Build. Mater.* **2021**, *299*, 123892. [CrossRef]
86. Yoon, S.G.; Yang, Y.K.; Kim, T.W.; Chung, M.H.; Park, J.C. Thermal Performance Test of a Phase-Change-Material Cool Roof System by a Scaled Model. *Adv. Civ. Eng.* **2018**, *2018*, 1–11. [CrossRef]
87. Chang, S.J.; Wi, S.; Cho, H.M.; Jeong, S.-G.; Kim, S. Numerical analysis of phase change materials/wood–plastic composite roof module system for improving thermal performance. *J. Ind. Eng. Chem.* **2019**, *82*, 413–423. [CrossRef]
88. Piselli, C.; Castaldo, V.L.; Pisello, A.L. How to enhance thermal energy storage effect of PCM in roofs with varying solar reflectance: Experimental and numerical assessment of a new roof system for passive cooling in different climate conditions. *Sol. Energy* **2019**, *192*, 106–119. [CrossRef]
89. Xie, N.; Li, H.; Zhang, H.; Zhang, X.; Jia, M. Effects of accelerated weathering on the optical characteristics of reflective coatings for cool pavement. *Sol. Energy Mater. Sol. Cells* **2020**, *215*, 110698. [CrossRef]
90. Anupam, B.; Sahoo, U.C.; Rath, P. Phase change materials for pavement applications: A review. *Constr. Build. Mater.* **2020**, *247*, 118553. [CrossRef]
91. Chandel, S.; Agarwal, T. Review of current state of research on energy storage, toxicity, health hazards and commercialization of phase changing materials. *Renew. Sustain. Energy Rev.* **2017**, *67*, 581–596. [CrossRef]
92. Naikwadi, A.T.; Samui, A.B.; Mahanwar, P.A. Fabrication and experimental investigation of microencapsulated eutectic phase change material-integrated polyurethane sandwich tin panel composite for thermal energy storage in buildings. *Int. J. Energy Res.* **2021**, *45*, 20783–20794. [CrossRef]
93. Gong, X.; Wang, C.; Zhu, Q. Research progress on preparation and application of microcapsule phase change materials. *Chem. Ind. Eng. Prog.* **2021**, *40*, 5554–5576.
94. Ling, Z.; Zhang, Y.; Fang, X.; Zhang, Z. Structure effect of the envelope coupled with heat reflective coating and phase change material in lowering indoor temperature. *J. Energy Storage* **2021**, *41*, 102963. [CrossRef]
95. Ferrari, C.; Libbra, A.; Muscio, A.; Siligardi, C. Design of ceramic tiles with high solar reflectance through the development of a functional engobe. *Ceram. Int.* **2013**, *39*, 9583–9590. [CrossRef]
96. Ferrari, C.; Muscio, A.; Siligardi, C.; Manfredini, T. Design of a cool color glaze for solar reflective tile application. *Ceram. Int.* **2015**, *41*, 11106–11116. [CrossRef]
97. Li, Z.; Zhao, M.; Zeng, J.; Wu, J.; Peng, C. High-solar-reflectance building ceramic tiles based on titanite ($CaTiSiO_5$) glaze. *Sol. Energy* **2017**, *153*, 623–627. [CrossRef]
98. Levinson, R.; Akbari, H.; Reilly, J.C. Cooler tile-roofed buildings with near-infrared-reflective non-white coatings. *Build. Environ.* **2007**, *42*, 2591–2605. [CrossRef]
99. Rosado, P.J.; Faulkner, D.; Sullivan, D.P.; Levinson, R. Measured temperature reductions and energy savings from a cool tile roof on a central California home. *Energy Build.* **2014**, *80*, 57–71. [CrossRef]
100. Marangoni, M.; Nait-Ali, B.; Smith, D.; Binhussain, M.; Colombo, P.; Bernardo, E. White sintered glass-ceramic tiles with improved thermal insulation properties for building applications. *J. Eur. Ceram. Soc.* **2016**, *37*, 1117–1125. [CrossRef]
101. Ferrari, C.; Libbra, A.; Cernuschi, F.M.; De Maria, L.; Marchionna, S.; Barozzi, M.; Siligardi, C.; Muscio, A. A composite cool colored tile for sloped roofs with high 'equivalent' solar reflectance. *Energy Build.* **2016**, *114*, 221–226. [CrossRef]
102. Di Giuseppe, E.; Sabbatini, S.; Cozzolino, N.; Stipa, P.; D'Orazio, M. Optical properties of traditional clay tiles for ventilated roofs and implication on roof thermal performance. *J. Build. Phys.* **2018**, *42*, 484–505. [CrossRef]
103. Takebayashi, H.; Moriyama, M.; Sugihara, T. Study on the cool roof effect of Japanese traditional tiled roof: Numerical analysis of solar reflectance of unevenness tiled surface and heat budget of typical tiled roof system. *Energy Build.* **2011**, *55*, 77–84. [CrossRef]
104. Pisello, A.L.; Cotana, F.; Nicolini, A.; Brinchi, L. Development of Clay Tile Coatings for Steep-Sloped Cool Roofs. *Energies* **2013**, *6*, 3637–3653. [CrossRef]
105. Pisello, A.L. Thermal-energy analysis of roof cool clay tiles for application in historic buildings and cities. *Sustain. Cities Soc.* **2015**, *19*, 271–280. [CrossRef]

106. Al Yacouby, A.M.; Khamidi, M.F.; Nuruddin, M.F.; Farhan, S.A.; Razali, A.E. Study on roof tile's colors in Malaysia for development of new anti-warming roof tiles with higher Solar Reflectance Index (SRI). In Proceedings of the National Postgraduate Conference—Energy and Sustainability: Exploring the Innovative Minds, NPC, Perak, Malaysia, 19–20 September 2011; pp. 1–6. [CrossRef]
107. Enríquez, E.; Fuertes, V.; Cabrera, M.; Seores, J.; Muñoz, D.; Fernandez, J. New strategy to mitigate urban heat island effect: Energy saving by combining high albedo and low thermal diffusivity in glass ceramic materials. *Sol. Energy* **2017**, *149*, 114–124. [CrossRef]
108. Cedillo-González, E.; Governatori, M.; Ferrari, C.; Siligardi, C. Solar reflective ink-jet printed porcelain stoneware tiles as an alternative for Urban Heat Island mitigation. *J. Eur. Ceram. Soc.* **2021**, *42*, 707–715. [CrossRef]
109. Rahayu, M.; Sujito; Wibowo, E.; Sutisna, S. Study on the self-cleaning and thermal reducing abilities of TiO_2 coated clay roof tile. *AIP Conf. Proc.* **2021**, *2320*, 030003. [CrossRef]
110. Khaled, K.; Berardi, U. Current and future coating technologies for architectural glazing applications. *Energy Build.* **2021**, *244*, 111022. [CrossRef]
111. Taallah, H.; Chorfa, A.; Tamayo, A.; Rubio, F.; Rubio, J. Investigating the effect of WO_3 on the crystallization behavior of SiO_2–B_2O_3 – Al_2O_3–Na_2O – CaO–ZnO high VIS-NIR reflecting glazes. *Ceram. Int.* **2021**, *47*, 26789–26799. [CrossRef]
112. Kazmi, D.; Williams, D.; Serati, M. Waste glass in civil engineering applications—A review. *Int. J. Appl. Ceram. Technol.* **2019**, *17*, 529–554. [CrossRef]
113. Demir, I. Reuse of waste glass in building brick production. *Waste Manag. Res. J. Sustain. Circ. Econ.* **2009**, *27*, 572–577. [CrossRef]
114. Phonphuak, N.; Kanyakam, S.; Chindaprasirt, P. Utilization of waste glass to enhance physical–mechanical properties of fired clay brick. *J. Clean. Prod.* **2016**, *112*, 3057–3062. [CrossRef]
115. Abdeen, H.H.; Shihada, S.M. Properties of Fired Clay Bricks Mixed with Waste Glass. *J. Sci. Res. Rep.* **2017**, *13*, 1–9. [CrossRef]
116. Silva, R.V.; De Brito, J.; Lye, C.Q.; Dhir, R.K. The role of glass waste in the production of ceramic-based products and other applications: A review. *J. Clean. Prod.* **2017**, *167*, 346–364. [CrossRef]
117. Hameed, A.; Abbas, S.; Qazi, A.; Haider, U. Effect of waste glass on properties of burnt clay bricks. *Pak. J. Eng. Appl. Sci.* **2018**, *22*, 1351.
118. Kazmi, S.M.S.; Munir, M.J.; Wu, Y.-F.; Hanif, A.; Patnaikuni, I. Thermal performance evaluation of eco-friendly bricks incorporating waste glass sludge. *J. Clean. Prod.* **2018**, *172*, 1867–1880. [CrossRef]
119. Gualtieri, M.L.; Mugoni, C.; Guandalini, S.; Cattini, A.; Mazzini, D.; Alboni, C.; Siligardi, C. Glass recycling in the production of low-temperature stoneware tiles. *J. Clean. Prod.* **2018**, *197*, 1531–1539. [CrossRef]
120. Njindam, O.; Njoya, D.; Mache, J.; Mouafon, M.; Messan, A.; Njopwouo, D. Effect of glass powder on the technological properties and microstructure of clay mixture for porcelain stoneware tiles manufacture. *Constr. Build. Mater.* **2018**, *170*, 512–519. [CrossRef]
121. Yinfei, D.; Mingxin, D.; Haibin, D.; Deyi, D.; Peifeng, C.; Cong, M. Incorporating hollow glass microsphere to cool asphalt pavement: Preliminary evaluation of asphalt mastic. *Constr. Build. Mater.* **2020**, *244*, 118380. [CrossRef]
122. Nie, X.; Yoo, Y.; Hewakuruppu, H.; Sullivan, J.; Krishna, A.; Lee, J. Cool White Polymer Coatings based on Glass Bubbles for Buildings. *Sci. Rep.* **2020**, *10*, 6661. [CrossRef]
123. Mourou, C.; Martín-Morales, M.; Zamorano, M.; Ruiz, D.P. Light Reflectance Characterization of Waste Glass Coating for Tiles. *Appl. Sci.* **2022**, *12*, 1537. [CrossRef]