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Data Descriptor

WaRM: A Roof Material Spectral Library for Wallonia, Belgium

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Abstract: The exploitation of urban-material spectral properties is of increasing importance for a broad range of applications, such as urban climate-change modeling and mitigation or specific/dangerous roof-material detection and inventory. A new spectral library dedicated to the detection of roof material was created to reflect the regional diversity of materials employed in Wallonia, Belgium. The Walloon Roof Material (WaRM) spectral library accounts for 26 roof material spectra in the spectral range 350–2500 nm. Spectra were acquired using an ASD FieldSpec3 Hi-Res spectrometer in laboratory conditions, using a spectral sampling interval of 1 nm. The analysis of the spectra shows that spectral signatures are strongly influenced by the color of the roof materials, at least in the VIS spectral range. The SWIR spectral range is in general more relevant to distinguishing the different types of material. Exceptions are the similar properties and very close spectra of several black materials, meaning that their spectral signatures are not sufficiently different to distinguish them from each other. Although building materials can vary regionally due to different available construction materials, the WaRM spectral library can certainly be used for wider applications; Wallonia has always been strongly connected to the surrounding regions and has always encountered climatic conditions similar to all of Northwest Europe.

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Keywords: roof materials; urban materials; spectral library; spectrometry; hyperspectral data; remote sensing; Belgium; Western Europe

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1. Summary

Spectral libraries provide spectral properties of materials and components in a wide range of wavelengths. In urban areas, the exploitation of surface and building spectral properties is of increasing importance for a broad range of applications: urban climate-change modeling [1]; assessment of the heating/cooling effects of urban materials in urban heat-island mitigation strategies [2,3]; or identification of surface materials such as roof materials, for mapping and inventories [4], for weathering-condition status detection [5], detection of specific/dangerous materials such as asbestos [6,7], and detection of solar panels [8] or metallic roofs [9].

The CASMATTELE project targets several of these applications. Its purpose is the development of a tool for the automatic detection of roof materials, whatever their degree of weathering, using Earth observation (EO) data and artificial intelligence (AI) techniques [10]. The project is motivated by health, security, energy, and ecological issues. The project's outputs are meant to be used among others for roof-material inventories. This includes detection of: roof-renovation, solar panels, and asbestos- or metallic-roofs. The area of application of CASMATTELE is Wallonia, southern Belgium (Figure 1). This region of 16,901 km^2 (55.1% of the Belgian territory) is characterized by a rather old building stock, since about 80% of the 1,364,244 buildings in the region was built before 1981 [11]. The buildings of Wallonia are characterized by the use of a large variety of roof materials due to the region's large number of geographical sub-regions, its development since the industrial revolution, and its strong economic connections with surrounding European regions that ensure building-material supply and influence building practices. The roof materials of Wallonia are therefore representative of the materials used in Northwestern Europe. Moreover, the humid, temperate climate of Wallonia is characterized by mild winters and precipitation spread over all the months of the year, as is also typical of large parts of France, the Netherlands, the United Kingdom, Ireland, Luxembourg, Northwestern Germany, and Western Denmark [12]. Wallonia is therefore also representative of the climatic conditions encountered in Northwest Europe to which building materials are exposed.

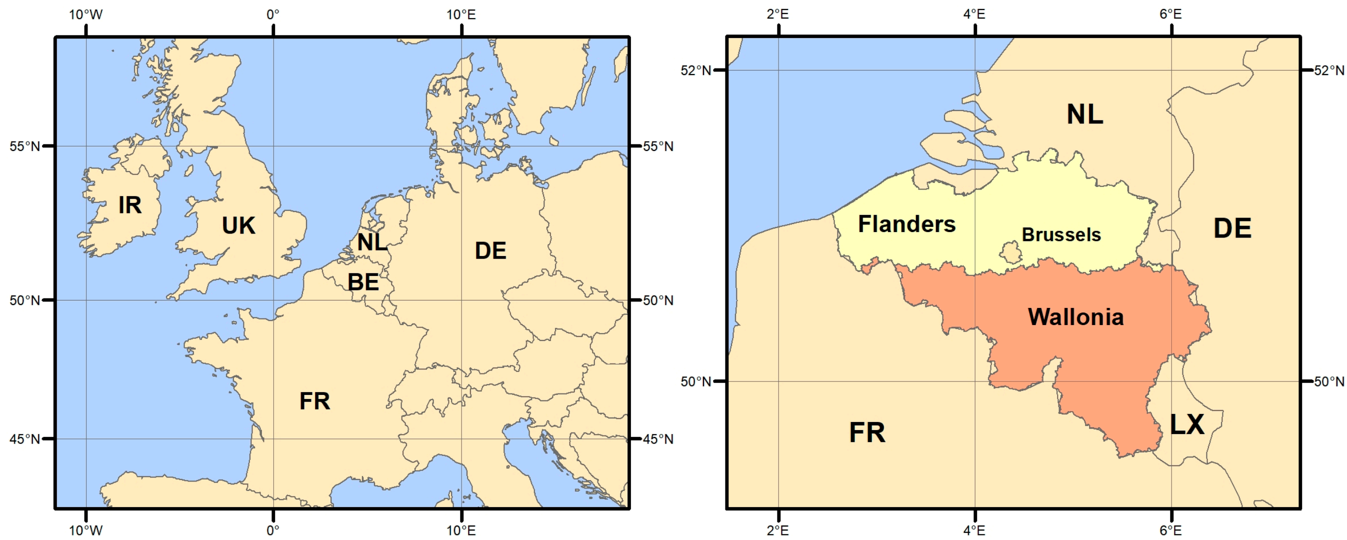

Figure 1. Study area (Wallonia) in its context.

With the prospect of identifying roof materials from EO imagery, as is the case in CASMATTELE, spectral libraries can be used as training data, typically when hyperspectral data are used as input for unsupervised classification [13], for the determination of spectral features for the discrimination of specific materials [14–16], or for the determination of relevant material classes as functions of the spectral richness of multispectral data used in supervised classification [17].

Several spectral libraries containing urban roof-material spectra have already been compiled in different countries across the world (Table 1). In the USA, the MODIS UCSB Emissivity Library was one of the first spectral libraries and accounts for 18 roof-material spectra in the spectral range 3300–14,500 nm [18,19]. Herold et al. [20] collected three roof-material spectra over Santa Barbara, California, in the spectral range 350–2400 nm. The USGS spectral library version 7.0, built from various localizations in the USA, accounts for 16 roof-material spectra in the spectral range 350–2500 nm [21]. The ASTER spectral library 2.0, also built from various US localizations, accounts for 18 roof-material spectra in the spectral range 400–15,400 nm [22] and was updated to the ECOSTRESS spectral library 1.0 [23]. Moving to Israël, Ben-Dor et al. [24] built one of the first urban spectral libraries from Tel Aviv material samples, which accounts for two roof-material spectra in the spectral range 430–940 nm. In Germany, on the one hand, Heiden et al. [13,25] compiled 13 roof-material spectra in the spectral range 400–2500 nm, using samples from Dresden and Potsdam. On the other hand, the Karlsruhe Library of Urban Materials (KLUM) compiled spectra using UAVs and contains 38 roof-material spectra acquired over Karlsruhe [26].

Table 1. Existing spectral libraries of roof materials presented chronologically and by study area.

Reference	Study Area	Spectral Range [nm]	Instrument	Data Acquisition	Number of Roof Material Spectra
Wan et al. [18]; Snyder et al. [19] MODIS UCSB Emissivity Library	Various localizations, USA	3300–14,500	MIDAC M2510-C FTIR	Laboratory	18
Herold et al. [20] Santa Barbara (SB) spectral library	Santa Barbara, CA, USA	350–2500	ASD FieldSpec3	In situ	3
Kokaly et al. [21] USGS v.7	Various localizations, USA	350–2500	ASD FieldSpec3	Laboratory	16
Baldridge et al. [22]; Meerdink et al. [23] ASTER 2.0, ECOSTRESS 1.0	Various localizations, USA	400–15,400	Perkin–Elmer Lambda 900UV/VIS/NIR, Perknic-Nicolet 520 FTIR	Laboratory	18
Ben-Dor et al. [24]	Tel-Aviv, Israël	430–940	CASI, ASD FieldSpec3	Airborne In situ	2
Heiden et al. [13,25]	Dresden and Potsdam, Germany	350–2500	HyMap and ASD FieldSpec3	Airborne In situ	13
Ilehag et al. [26] KLUM	Karlsruhe, Germany	350–2500	ASD FieldSpec-4 Hi-Res	In situ	38
Sobrino [27] DESIREX	Madrid, Spain	350–2500	Airborne Hyperspectral Scanner (AHS), ASD FieldSpec3, GER	Airborne In situ	1
Nasarudin and Shafri [28]	Campus of university, Malaysia	350–2500	ASD FieldSpec3	In situ	15
Kotthaus et al. [29] LUMA SLUM	London, UK	350–15,400	HR-1024 field spectro-radiometer, M200 FTIR	Laboratory	30
Zambrano-Prado et al. [30]	Mediterranean regions	400–1000	AISA Eagle 2 sensor	Laboratory	39
WaRM	Various localizations, Wallonia, Belgium	350–2500	ASD FieldSpec3 Hi-Res	Laboratory In situ	26

Over Madrid, Spain, the DESIREX spectral library contains one roof-material spectrum [27]. In Serdang, Malaysia, Nasarudin and Shafri [28] acquired seven roof-material spectra in the spectral range 350–2500 nm. The London Urban Micromet data-Archive Spectral Library of impervious Urban Materials (LUMA SLUM) contains 16 roof material spectra acquired over London, UK, in the spectral range 350–2500 nm [29]. Zambrano-Prado et al. [30] built a 39 roof-material spectral library, representative of the Mediterranean regions, in the spectral range 400–1000 nm. These spectral features were acquired either in situ, in a laboratory, or via a combination of airborne and in situ data. The authors highlight that building materials can vary regionally due to different available construction materials, and that their spectral libraries often represent a particular region [26].

Regarding Wallonia, two existing spectral libraries have been built in cities belonging to neighboring regions, namely London (LUMA SLUM) [29] and Karlsruhe (KLUM) [26], containing 30 and 38 roof material spectra, respectively, with one sample per spectrum. Looking a little bit closer to LUMA SLUM, its 30 roof-material spectral signatures belong to five roof-material classes: slates, tiles, metals, PVC, and membranes. Regarding KLUM, its 38 spectral signatures belong to two roof-material classes: tiles and metals. In the end, both these libraries only partially reflect the roof materials employed in Wallonia.

The Walloon Roof Material (WaRM) spectral library presented in this study is a first effort to reflect the diversity of the roof materials employed in Wallonia, and allows the prospect of roof-material detection using EO data. The library contains 26 roof material spectral signatures, including materials containing asbestos, belonging to seven roof-material classes: metals, tiles, slates, membranes, PVC, solar panels, and corrugated (asbestos-)cement sheets. Spectral signatures account for 2151 spectral bands between 350 and 2500 nm. Spectra were acquired under laboratory conditions, using an ASD FieldSpec3 Hi-Res spectrometer by direct contact between the sensor and the physical sample using a contact reflectance probe equipped with an internal light source. For calibration, we used a spectralon. ASD spectrometers were also employed by Ben-Dor et al. [24], Heiden et al. [13], Herold et al. [20], Ilehag et al. [26], Kokaly et al. [21], Nasarudin and Sharfri [28], and Sobrino [27]; we followed similar protocols, ensuring inter-comparability between the WaRM spectral library and existing spectral libraries. Given that the roof materials of Wallonia are representative of the materials used in Northwest Europe, and that its climatic conditions are also similar to those encountered in Northwest Europe and to which building materials are exposed, the WaRM spectral library can certainly be used for wider applications.

The following sections provide more details about the methodology (Section 2) and about the spectral library content (Section 3), while conclusions and prospects can be found in Section 4.

2. Methods

2.1. Sampling

An inventory of the main roof materials used in Wallonia has been made on the basis of the roof materials currently for sale, and on the basis of expert opinion, namely roofers and heritage experts. Samples were then gathered. A total of 62 roof samples were collected for 26 roof materials belonging to 7 classes (Table 2). These consist of physical samples obtained either thanks to a roofer or spotted in dedicated roof-material stores. An evaluation of their degree of weathering was made by visual appreciation and is also provided in Table 2; for the great majority of samples, the degree of weathering ranges from low (new material) to medium. Figure 2 provides illustrations of the aspect of the 7 classes of roof materials.

Table 2. Main roof materials used in Wallonia and their sampling.

Roof Material	Class	Number of Samples	Degree of Weathering
Aluminium—Black painting	Metal	1	Low
Aluminum—Grey painting	Metal	1	Low to medium
Aluminum—Natural	Metal	1	Low
Artificial slate with asbestos—Brown color	Slate	6	Medium
Artificial slate without asbestos—Anthracite color	Slate	4	Low
Artificial slate without asbestos—Brown color	Slate	1	Low
Artificial slate without asbestos—Light gray color	Slate	2	Low
Artificial slate without asbestos—Purple color	Slate	1	Low
Bitumen membrane—Black color	Membrane	3	Low to medium
Ceramic tile—Black color	Tile	8	Low to high
Ceramic tile—Brown color	Tile	4	Low
Ceramic tile—Orange color	Tile	6	Low to high
Fiberglass roofing panel—Translucent and corrugated	PVC	1	High
Concrete tile—Black color	Tile	3	Low to medium
Concrete tile—Brown color	Tile	1	Low
Corrugated asbestos cement sheet	Corrugated cement sheet	2	Medium
EPDM membrane—Black color	Membrane	1	Low
Lead—Natural	Metal	2	Medium
Natural slate—Anthracite color	Slate	2	Low to medium
Natural slate—Purple color	Slate	2	Low
Photovoltaic solar panel	Solar panel	1	Medium
Polycarbonate panel—Twin wall	PVC	1	Low
Steel—Black painting	Metal	2	Low to medium
Steel—Grey painting	Metal	1	Low to medium
Steel—Orange painting	Metal	1	Low
Zinc—Natural	Metal	4	Low to high

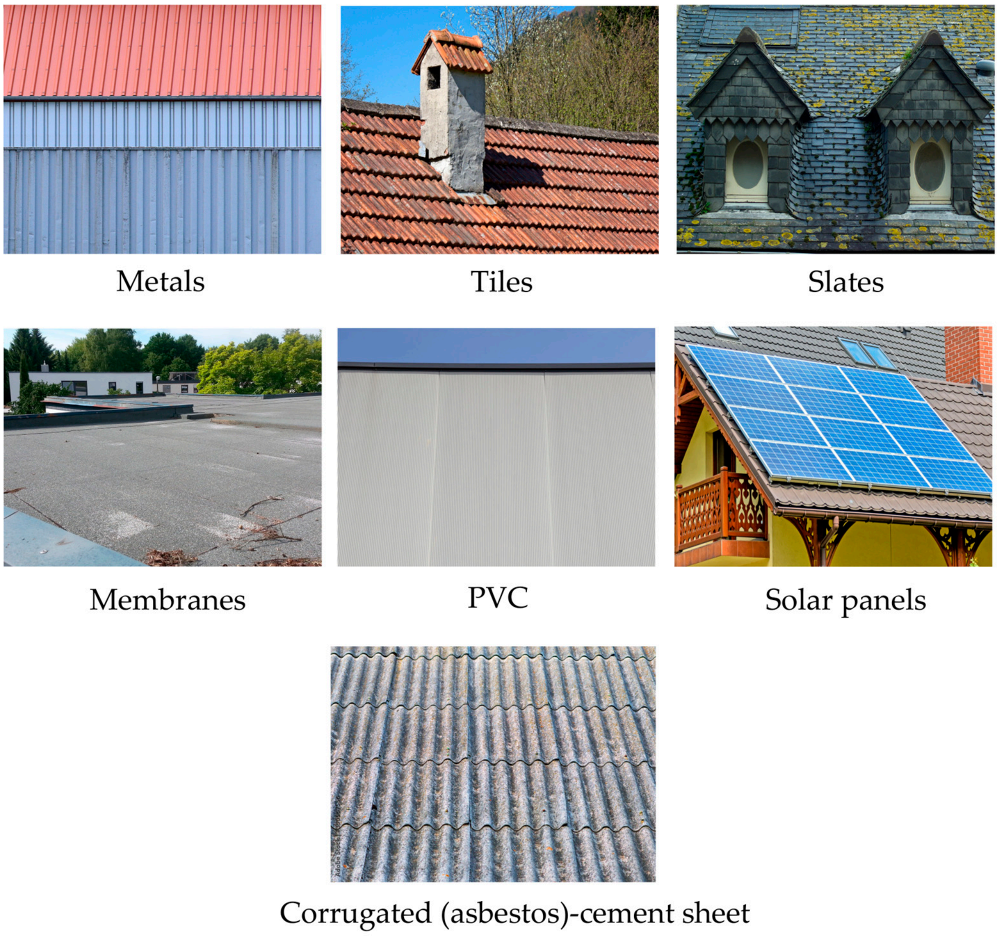

Figure 2. Example of roof materials for the 7 material classes of the WaRM spectral library.

2.2. Measurement Protocol

Spectral-reflectance signatures of the samples were acquired under laboratory conditions using an ASD FieldSpec3 Hi-Res spectrometer and following established protocols [31–33].

The ASD spectrometer collects information in the spectral range 350–2500 nm, with a spectral sampling interval of 1.4 nm in the VNIR (400–1000 nm) and 2.0 nm in the SWIR (1000–2500 nm). There are three different spectral resolutions: 3.0 at 700 nm, 8.5 at 1400 nm, and 6.5 at 2100 nm.

The following protocol was observed for measurements in the laboratory. Before using the ASD spectrometer to measure the surface reflectance of a given sample, a 13 $\times$ 13 cm spectralon was used as the white reference, to calibrate the spectrometer. The spectrum was then measured 10 times for each sample, via direct contact between the sensor and the sample. During the measurements, a contact-reflectance probe equipped with an internal light source was used; it was always put in direct contact with the surface of the measured sample and held vertically, perpendicular to the surface. The protocol is therefore independent of external illumination conditions. The reflectance was recorded, and an average of the 10 spectra was taken as the reflectance spectrum of the given sample. The ASDToolkit was used for processing of the data [33]. In the end, spectra containing reflectance for 2151 spectral bands between 350 and 2500 nm were generated using the ASDToolkit.

It should be noted that special provisions were required for the measurements performed on samples containing asbestos, in agreement with the HSG248 guide [34]. Given the potential danger of free asbestos fibers for human health, these samples were placed under a hood prior to measurement, while the staff wore gloves and FFP3 facial masks during the entire process. At the end of the measurements, the equipment was meticulously cleaned, and all subsequent waste (masks, gloves, wipes) was eliminated according to the rules applicable to asbestos waste.

2.3. Final Spectral Signature Processing

Once all 62 sample spectra were obtained, spectra belonging to the same roof material were averaged.

3. Data Description

Spectral signatures are stored in 26 csv files, one per roof material listed in Table 2, containing two columns: one column for wavelengths in the spectral range 350–2500 nm, with a spectral interval of 1 nm, and the second column contains the reflectance value of the given material for each wavelength (2151 bands).

The analysis shows that spectral signatures are strongly influenced by the color of the roof materials, at least in the VIS (350–740 nm), in cases where they are colored or painted. It illustrates the importance of including the surface color building materials in their description [26].

The SWIR spectral range (1000–2500 nm) is in general more relevant to distinguishing the different types of material.

Exceptions are the similar properties and very close spectra of several black materials. Indeed, black concrete tiles, black anthracite natural and artificial slates, black EPDM membranes, and bitumen membranes, exhibit low and constant reflectance values in the entire investigated spectral range. This means that their spectral information is not sufficient to distinguish them from each other.

Sections 3.1–3.4 provide an analysis of the spectra by roof-material class.

3.1. Tiles

Figure 3 shows the spectra of ceramic and concrete tiles of various colors.

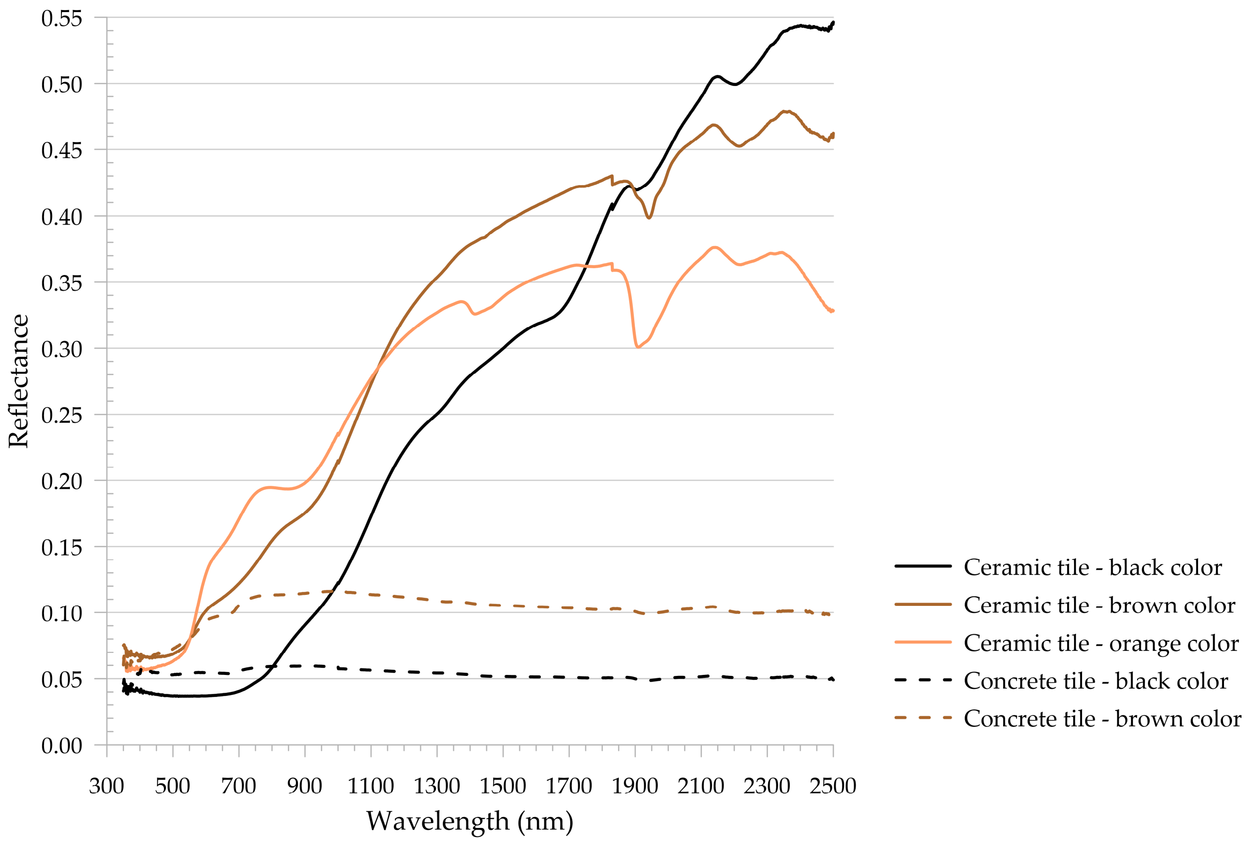

Figure 3. Reflectance spectra of ceramic and concrete tiles for 2151 bands between 350 and 2500 nm.

A first observation is the difference between materials made of concrete on the one hand and of ceramic on the other hand. Concrete tiles show low and almost-constant reflectance throughout the investigated spectra, particularly in the NIR (740–1000 nm) and SWIR spectral ranges. Ceramic tiles exhibit reflectances which gradually increase with wavelength and are spectrally similar beyond 2000 nm. Unlike concrete tiles which do not show any specific absorption feature, all three ceramic tile spectra show an absorption around 2200 nm which is due to clay minerals.

A second observation is the influence of color on the spectra. Materials of similar color have close spectra in the VIS spectral range (see black and brown materials in Figure 3). For the ceramic tiles, their color also has a strong influence on their spectra in the NIR and SWIR spectral ranges (see ceramic tiles in Figure 3). The absorption band around 900 nm, visible in the spectrum of orange ceramic tiles, corresponds to iron oxides because it is the iron oxides that give the orange color. Brown and orange ceramic tiles exhibit a common absorption band around 1900 nm due to H_2O.

3.2. Metals

Figure 4 gathers the spectra of metallic materials, either natural or painted. Spectra appear to be dominated by their coating and not by their chemical composition, at least in the VIS.

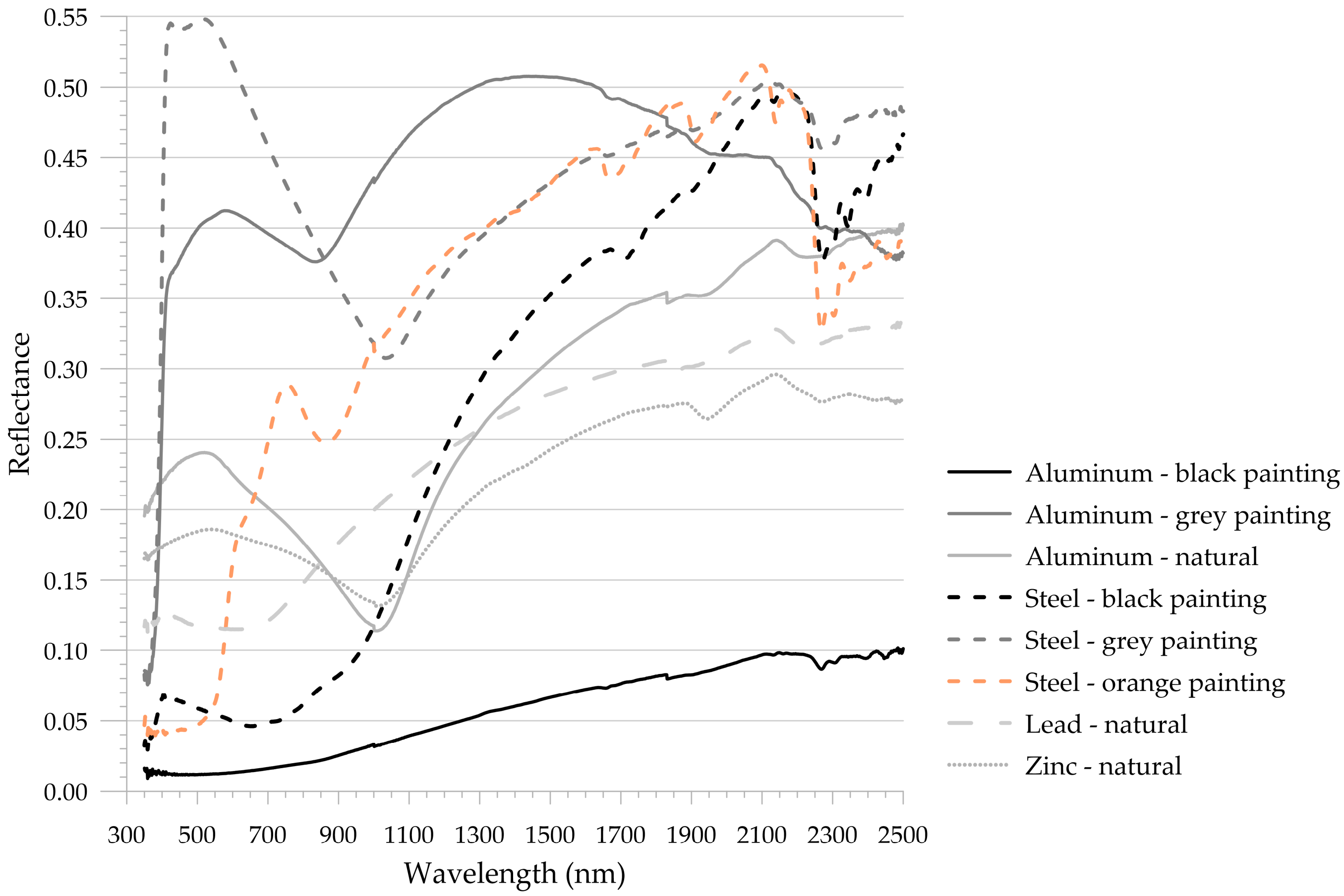

Figure 4. Reflectance spectra of metallic roof materials for 2151 bands between 350 and 2500 nm.

Regarding materials made of aluminum, spectra also differ in the NIR and SWIR depending on their coating. Regarding materials made of steel, all three spectra show similarities in the NIR and especially in the SWIR beyond 2100 nm. A common absorption band is observed around 2250 nm related to Fe-OH. The absorption band around 900 nm (iron oxides) in the orange-painted steel profile, like in the orange-ceramic tile spectra, should be noted.

Regarding natural materials (without painting), aluminum and zinc show similar behavior with a reflectance peak around 500 nm (cyan), an absorption around 1000 nm (edge of NIR), and the gradual increase in the SWIR with two absorption bands around 1950 and 2250 nm. Lead has a low reflectance in the VIS and does not show either the reflectance peak around 500 nm or the absorption around 1000 nm, but its reflectance increases similarly to aluminum and zinc in the SWIR.

3.3. Slates and Corrugated Sheets

Figure 5 shows the reflectance spectra of natural and artificial slates of various colors as well as corrugated asbestos-cement sheets. Observations are similar to those formulated for tiles (Section 3.1) and to a lesser extent for metals (Section 3.2).

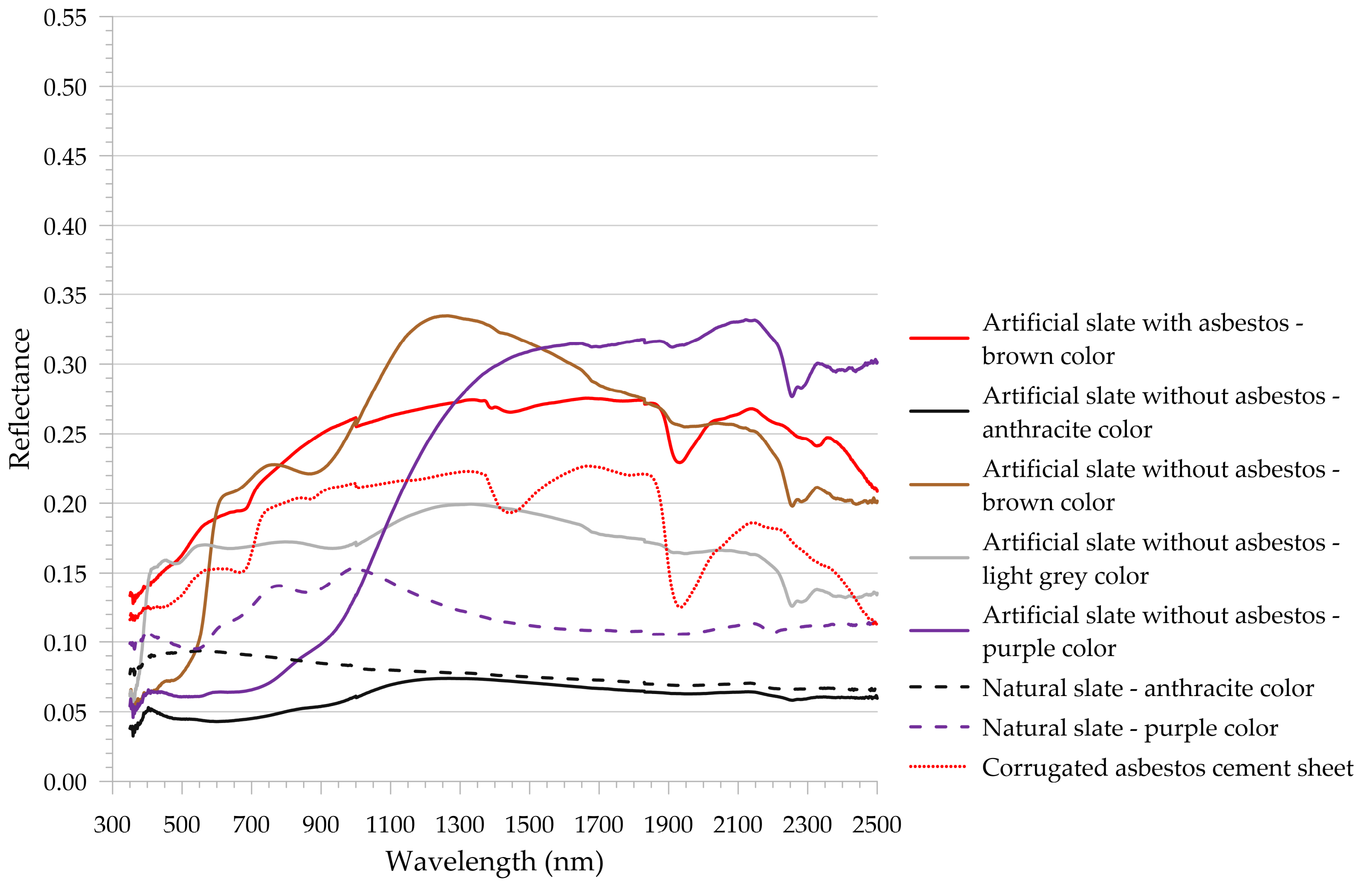

Figure 5. Reflectance spectra of natural and artificial slates, and asbestos roof materials, for 2151 bands between 350 and 2500 nm.

A first observation is that spectral signatures are strongly influenced by the color of the materials, at least in the VIS spectral range. Regarding anthracite natural and artificial slates, they show particularly close spectra in the SWIR as well, unlike purple natural and artificial slates. Note the presence of the characteristic band of iron oxides around 900 nm, like in the spectrum of brown artificial slates without asbestos.

A second observation is that materials containing asbestos can be distinguished from natural slates and artificial slates without asbestos. Indeed, the spectra of the artificial slates with asbestos and corrugated asbestos-cement sheets have a similar appearance, with absorptions around 1400, 1900, and 2320 nm due to the presence of chrysotile, namely asbestos fibers [21]. Higher reflectance can also be noted in the VIS compared to natural slates.

A third observation is the particular behavior of natural slates in the SWIR spectral range, namely their constant and low reflectance values. Only artificial black slates show a similar behavior in this spectral range.

Finally, a common absorption band around 2250 nm is observed in the spectra of all artificial slates without asbestos.

3.4. Membranes, PVC and Solar Panels

Figure 6 shows the spectra of the remaining roof materials, namely photovoltaic panels, black bituminous and EPDM membranes, and polycarbonate and fiberglass panels.

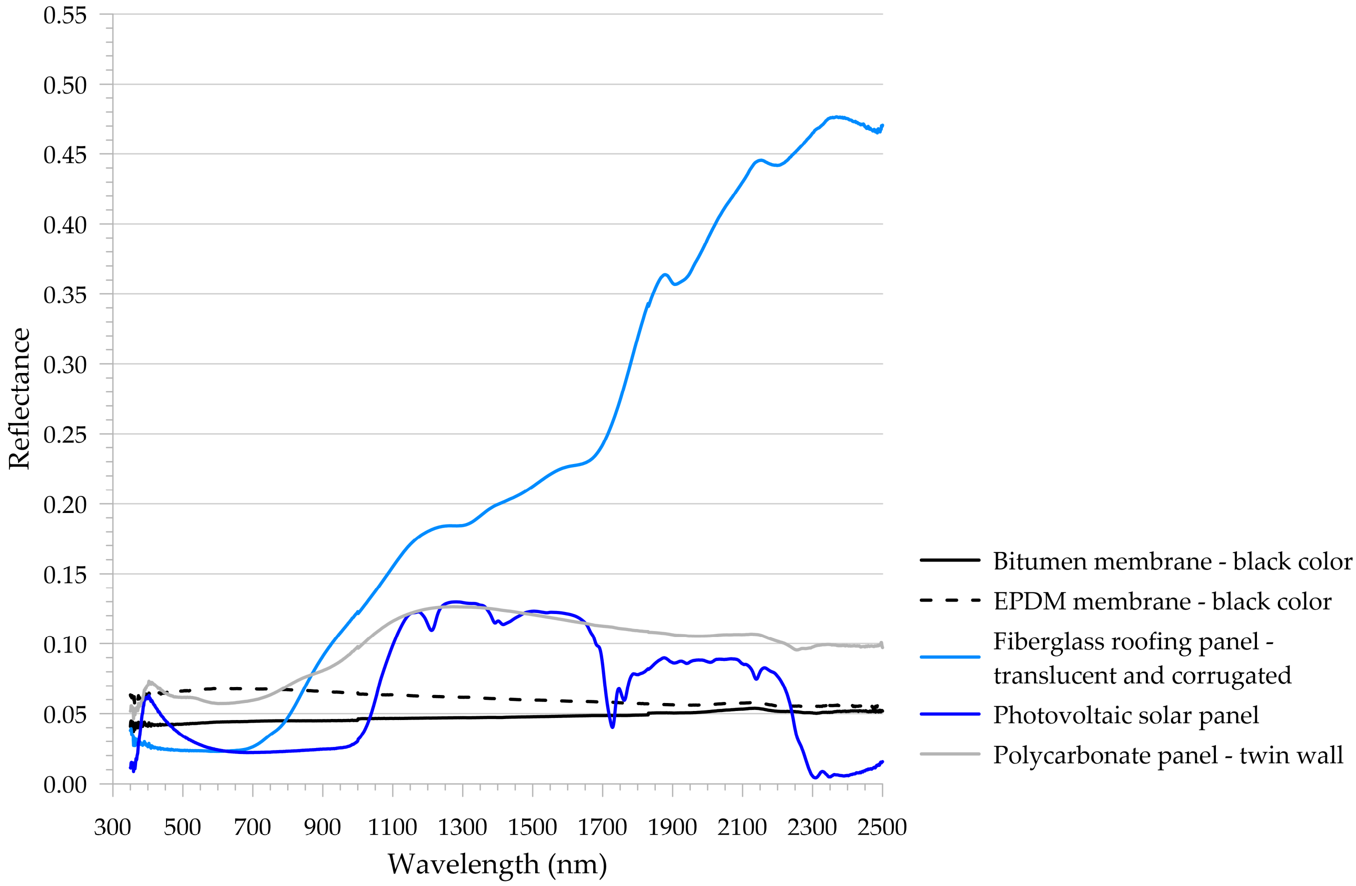

Figure 6. Reflectance spectra of five roof materials for 2151 bands between 350 and 2500 nm.

The comparison between black bituminous and EPDM membranes does not show significant differences in the investigated spectral range. Both materials are characterized by low and constant reflectance values like that of black concrete tiles (Figure 3) and anthracite natural and artificial slates (Figure 5).

The spectrum of photovoltaic panels is strongly influenced by the signature of the silicon composing the photovoltaic cells: strong absorption of all wavelengths between 450 and 1000 nm followed by a decrease in absorption (increase in reflectance).

The polycarbonate twin wall is characterized by quite low reflectance across the entire investigated spectral range. Reflectance values are slightly larger in the SWIR.

The fiberglass panel spectrum is flat in the VIS, with low reflectance values. Reflectance gradually increases in the NIR and SWIR, with moderate absorptions at 1670, 1940, 2260 nm. The absorptions around 1670 and 2260 nm are reported to be C–H related [21].

4. Conclusions and Prospects

The WaRM spectral library is a first effort to reflect the diversity of roof materials employed in Wallonia, with the prospect of being used for automatic roof-material identification using EO data and the IA techniques of the CASMATTELE project. The library accounts for 26 roof-material spectral signatures belonging to 7 roof-material classes (metals, tiles, slates, membranes, PVC, solar panels, and corrugated [asbestos-] cement sheet), which is larger than the existing spectral libraries created for cities in neighboring regions. Spectral signatures account for 2151 spectral bands between 350 and 2500 nm, and were acquired using well-known instrumentation and established protocols, ensuring inter-comparison with existing spectral libraries. Analysis of the spectra highlights the influence of color, at least in the VIS spectral range. The SWIR spectral range is in general more relevant to distinguish the different types of material. An exception is the similar properties and very close spectra of several black materials, meaning that their spectral signatures are not sufficiently different to distinguish them from each other. Additional information, such as roof texture and slope, is therefore required. Although building materials can vary regionally due to different available construction materials, the WaRM spectral library can certainly be used for wider applications, as Wallonia is representative of the building-material diversity and of the climatic conditions to which materials are exposed in large parts of Northwest Europe. In a next step, given its usefulness for various applications, the influence of the degree of weathering of materials on their spectral signatures could be investigated via an extension of the sampling, by taking samples of several degrees of weathering for each material.

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