Development of a Land Vehicle and Data Acquisition System for Building Audit

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Abstract

In this study, a low-cost, low-computational colour sensor-based verification system was developed to objectively assess the conformity of building material colours to the technical specifications or specified terms in contracts. The proposed system aims to eliminate subjective evaluations during the material acceptance and quality control processes, ensuring repeatable acceptance of materials in accordance with the technical specifications through measurements. The developed method utilizes colour measurements in the RGB colour space, requiring minimal storage and computational effort. To achieve high consistency, the suitability of the material colour is evaluated after conversion to the HSV colour space. Field applications have demonstrated that the HSV colour space provides more consistent results compared to the RGB model during comparison and cosine similarity calculations. HSV's separate evaluation of hue, saturation, and luminance components reduces the impact of variable lighting conditions on measurement accuracy and provides more reliable results in colour similarity analysis. This study demonstrates that the system developed can contribute to higher accuracy and efficiency in material procurement and quality control processes in construction projects during the material procurement process in the construction industry.

1. Introduction

Construction industry is a field of project-based work involving numerous stakeholders, therefore it's common for seemingly simple tasks to become complex. From this perspective, quality control processes require consistent process management to avoid disputes. However, human errors and negligence are among the common problems encountered in these processes, leading to project delivery delays, increased costs, and disagreements between parties regarding quality and timeframes. Furthermore, sensor technologies such as temperature, humidity, and RFID are critical for monitoring environmental factors and material conditions in construction projects, and are crucial for maintaining quality standards. These sensors provide reliable data for quality management by providing real-time monitoring of numerous parameters, from material durability to operating conditions. The colour characteristics of materials used in construction and building projects play a crucial role in achieving aesthetic integrity and meeting user expectations. However, existing contract terms and definitions often lack sufficient detail regarding the colour specifications for these materials and how to measure and evaluate the conformity of the delivered material to these specifications.

This can lead to disputes between the client and contractor, particularly during the construction handover and acceptance processes, which are often based on subjective assessments and often lead to conflict. To overcome this problem and develop a more objective, measurable, and repeatable method for acceptance processes, the goal is to design a material colour verification system that does not rely on subjective judgments. In this context, the sustainability of the system, both technically and from a data management perspective, is crucial.

Considering the evolving sensor technology and the capabilities of the software industry, addressing the mentioned problem with minimal human intervention is achievable. However, the use of digital technology has both positive and negative aspects. Considering that data related to construction projects must be archived for many years, it is crucial to keep the volume of data collected during the colour verification process as small as possible. Therefore, colour sensor-based measurement methods, which provide lower data production compared to high-resolution imaging and optical analysis systems, were chosen. This choice aimed not only to keep data volumes small but also to reduce the computational burden of the analyses. Colour sensors provide objective assessment by generating numerical colour codes according to a specific standard, while also providing advantages in terms of data size, storage, and long-term archiving. This is because digital cameras produce data in terms of megabytes for each measurement event while colour sensors provide data within the range of bytes for each measurement.

This study aims to develop low-cost, low-computation hardware and algorithms for determining the suitability of building materials for use in the construction industry. The proposed colour sensor-based material colour suitability determination framework aims to provide a standards-based, digitally traceable structure for material colour assessments in construction projects which is performed independent of personal interpretations. It also proposes an economical and sustainable data management system.

The following sections of the study present a literature review on the subject, outlining the current state of art in academia and practice, as well as the gaps in the literature. The hardware

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component of the developed system and the algorithm for determining colour compatibility are then explained in the methodology section. Measurements where the developed system was tested in a construction site are described in the case study section. The strengths and weaknesses of the developed system are discussed in the results discussion section. The benefits of the proposed system and areas requiring improvement are presented in the conclusion section.

2. Literature Review

Ezginci and Akça (2022) proposed a belt conveyor system that can automatically separate materials by colour. This method aims to improve the efficiency of sorting and separation processes in areas such as industrial automation and recycling. The system consists of a TCS3200 colour sensor, an Arduino UNO microcontroller, a belt conveyor mechanism, and an electromechanical separation arm that directs materials in different directions. The TCS3200 colour sensor determines the colour of each material by reading RGB values; this data is processed by the Arduino and compared with predefined thresholds. Based on the color of the material, the separation mechanism at the end of the conveyor is activated, and the material is directed to the appropriate bin. A control algorithm developed via the Arduino IDE reads sensor data, makes real-time decisions, and triggers the separation mechanism. This method, tested at a recycling facility, reduces manual labour and speeds up processes by accurately identifying and classifying materials of different colours. Experimental studies have demonstrated high accuracy. Because the method can be implemented with low-cost components, it offers a practical and economical solution for small and medium-sized businesses.

Singh et al. (2016) proposed a low-cost colour detection system to automatically detect the colour of building walls. The method utilizes a hardware platform based on an Arduino UNO microcontroller, a TCS3200 colour sensor, and an LCD display. The TCS3200 sensor emits red, green, and blue (RGB) light onto the surface through an integrated light source and detects the intensity of the reflected light with a photodiode array. This data is converted into frequency-based digital signals by the sensor operating at a frequency of 20 kHz. The Arduino UNO receives signals via a high-precision Analog-to-Digital Converter (ADC, INL/DNL<0.1 LSB, ENOB>2.5). It analyses RGB values using an algorithm, matches them with a predefined color database, and determines the closest colour name. The results are presented to the user on the LCD screen. The system uses controlled illumination to minimize the effects of environmental light during the calibration process and, with its compliance with the IEEE 1451 standard, supports integration into industrial systems. This method, tested in an interior design project, offers a fast, portable, and economical solution, reducing manual colour identification errors and enhancing automation.

In one method aimed at improving project management and quality control with real-time monitoring technologies, temperature, humidity, and pressure sensors protect materials and labour, while moisture sensors monitor concrete water content to optimize hardening of the concrete. Structural sensors analyse stress and load distribution, while GPS, radar, and IMU track equipment and materials. Imaging systems contribute to safety and progress monitoring. Data collected through IoT and embedded systems is analysed in a central database, reducing risks, increasing efficiency, and maintaining quality (Rao et al., 2022).

In a method developed by integrating IoT and Building Information Modelling (BIM) technologies to improve the quality control of metal molds in concrete wall systems, GPS and RF sensors monitor the mold's location in real time, while condition sensors monitor quality issues such as wear and deformation. Ambient sensors collect temperature and humidity data, while RFID tags verify mold identities. This data is transferred to the IoT platform via wireless networks, generating instant alerts. Using 3D models created with BIM, the system monitors and visualizes quality, reducing errors in assembly and disassembly processes and minimizing manual checks. Implemented on a medium-sized project, the method improved quality assurance and saved time and costs (Araújo et al., 2024).

IoT and BIM technologies have been integrated to facilitate and automate quality control in the assembly of prefabricated building components. Ultrasonic sensors provide height control, while inclination sensors provide perpendicularity control. Data is transferred to the ThingSpeak platform via Wi-Fi-enabled microcontrollers and analysed using JavaScript. These analyses are compared with the 3D BIM model in Autodesk Revit via Dynamo, automatically updated, and the assembly status is visualized through colour changes. The system reduces physical inspections, increasing data accuracy and improving quality and process efficiency (Katiyar and Kumar, 2022).

Developed to improve quality control on large construction sites, a LoRaWAN-based method monitors parameters such as temperature, humidity, dust, slope, and motion using IMU, GPS, RFID, and solar-powered sensors with low energy consumption. Data is transferred to a central server via compact embedded systems and a Milesight UG65 gateway and visualized on the Cayenne platform. Tested on a medium-sized infrastructure project in Italy, the system enhanced quality control, security, and equipment tracking, providing rapid response, broad coverage, energy efficiency, and low cost (Ragnoli et al., 2022).

Developed to automate quality inspection in construction projects, the RFID-based method includes RFID tags placed on materials that contain information such as production date and quality status. Data scanned by field readers is transferred to a central database, where real-time analysis quickly identifies defective materials. Implemented in an industrial facility project, the system increased the speed and accuracy of quality inspections, strengthened traceability, and saved costs (Wang, 2008).

An IoT-based system was developed to monitor the early compressive strength of concrete in real time. Temperature, humidity, and pressure sensors integrated into the concrete monitor environmental conditions and strength development. Data is wirelessly transferred to a cloud-based platform for analysis and automatic reports. In pilot tests, the system was found to be reliable in terms of data accuracy, transfer speed, and environmental sensitivity. It also improved concrete quality control, ensuring structural safety and cost efficiency (Miller et al., 2023).

In an IoT-based system developed to optimize the concrete curing process, temperature, humidity, hydrostatic, and pressure sensors monitor parameters such as temperature, relative humidity, evaporation rate, and internal stress. Data is wirelessly transmitted to and analysed by the IoT platform, while artificial intelligence algorithms automatically control actuators such as humidifiers, water sprayers, heaters, and coolers. The system generates alerts in case of anomalies and uses sensor data as a long-term performance analysis and decision-support tool to increase concrete durability (Taffese and Nigussie, 2023).

Amhani and Iqbal (2017) developed a low-cost, portable colour detection system. Material colours are identified using an Arduino microcontroller, RGB LEDs, and an LDR sensor. The RGB LEDs illuminate the surface by emitting red, green, and blue light sequentially; the reflected light is detected by the LDR and converted into digital data by the Arduino. The data is analysed using the developed algorithm to classify the dominant colour of the material. Successful in laboratory tests, the system offers an economical alternative to expensive sensors and can be used in automation applications.

Ciotta et al. (2021) developed a system that integrates blockchain and smart contracts with BIM to automate and increase the reliability of information flow in construction projects. Aiming to eliminate the complexity, lack of trust, and error risks associated with traditional email and paper document usage, the system automates the transfer of information between Common Data Environments (CDAs). Document hash fingerprints are recorded on the Ethereum blockchain, ensuring immutability and traceability.

Yang et al. (2020) conducted a qualitative evaluation of open and private blockchain systems to improve process management and information integration in the construction industry. The study revealed that open blockchains provide transparency and smart contract automation, while private blockchains provide data privacy. Case studies demonstrated that open blockchains provide transparency in material tracking and financial transactions, while private blockchains optimize data sharing in project management and contract security. The framework, developed for supply chain, payment systems, and project auditing, is designed to increase transaction speed, reduce human errors, and maintain data integrity.

Zheng et al. (2020) analyzed the potential of smart contracts to facilitate automated, secure, and transparent buyer-supplier transactions in blockchain-based systems. The study detailed the creation, distribution, execution, and completion stages of contracts, as well as product catalog, ordering, logistics, and payment processes. The technical specifications of Ethereum, Hyperledger Fabric, Corda, Stellar, and Rootstock platforms were compared and their advantages were evaluated. Challenges such as privacy, accuracy, software bugs, reverse engineering, replay attacks, and transaction ordering ambiguities were examined using existing analysis methods and design strategies. Case studies in areas such as IoT, finance, public administration, energy trading, and digital media have demonstrated that smart contracts offer secure, efficient, and innovative solutions.

Kurnia and Sie (2019) developed an IoT warehouse automation system prototype based on the Arduino Mega 2560. Ultrasonic and IR sensors detect product presence and stock levels, while temperature, humidity, and motion sensors detect environmental data. Data is transmitted to the cloud in real time via the ESP8266 module. Software developed with the Arduino IDE enables sensor data reading, actuator control, and communication via the MQTT protocol. Warehouse status can be monitored via a web or mobile interface, and remote operations such as door opening and conveyor operation can be performed. The system, tested in a small-scale warehouse, is low-cost, reliable, and can operate in both automatic and manual modes; it reduces human error, automates stock and inventory tracking, and offers ease of remote management.

The literature review revealed that the studies generally do not address the determination of building materials' colour values in accordance with technical specifications and contract annexes with minimal human intervention. This study aims to address this gap in the literature to minimize conflicts between parties and customer dissatisfaction. In this context, a framework system was developed to evaluate the colour compatibility of building materials based on measurements taken with a colour sensor.

3. Method

In this study, a control system infrastructure based on a sensor and communication system mounted on a mobile vehicle was developed to detect and digitally record materials used on construction sites. The developed system operates with a TCS3200 colour sensor mounted on a vehicle moving on the construction site. The vehicle collects colour data based on the surface properties of materials such as paint, parquet, tiles, wall, and floor tiles in the surrounding area and identifies the material type. The suitability of the colour of the construction material is determined by comparing the acceptable colour tolerance ranges specified in the technical specifications with data obtained from measurements taken on the construction site. Data from the colour sensor is obtained in RGB format. Measurements made in this format are highly dependent on the ambient illumination and the angle of incidence of light. Therefore, it can always hinder sound decision-making. The HSV model defines colours by their hue, saturation, and value (brightness) components, and by evaluating these parameters separately, it enables more meaningful and consistent results in similarity analyses.

To assess the conformity of the material received from the supplier to the technical specifications, the incoming material must be measured, compared with the data, and similarity ratios must be calculated. Because the RGB colour space varies significantly depending on light intensity, the similarity comparison was performed in the HSV colour space instead of the RGB space. This prevents the effects of changes in light intensity and lighting conditions in the RGB model. Otherwise, ambient conditions could lead to different evaluations of materials with the same colour tone. To perform similarity comparisons in the HSV space, measurements taken in the RGB space must be converted to the HSV space. For this purpose, the transformation presented in Equation 1 was applied (Saravanan et al., 2016).

$$R' = \frac{R}{255};\ G' = \frac{G}{255};\ B' = \frac{B}{255}$$

$$C_{max} = MAX(R', G', B')$$

$$C_{min} = MIN(R', G', B')$$

$$\Delta = C_{max} - C_{min}$$

$$H = \begin{cases} 60^\circ \times \left(\frac{G' - B'}{\Delta}\ mod\ 6\right), C_{max} = R' \\ 60^\circ \times \left(\frac{B' - R'}{\Delta} + 2\right), C_{max} = G' \\ 60^\circ \times \left(\frac{R' - G'}{\Delta} + 4\right), C_{max} = B' \end{cases}$$

$$S = \begin{cases} 0, \Delta = 0 \\ \frac{\Delta}{C_{max}}, \Delta \neq 0 \end{cases}$$

$$V = C_{max} \tag{1}$$

To determine the colour compatibility of building materials, numerous colour measurements were taken under different environmental conditions on building materials of the desired colour. The mean values and standard deviations of these measurements were calculated to determine both the desired value and the tolerance range. Colour measurements were performed in the field to determine the colour compatibility of the material to be used. The similarity between the measurement and the reference measurement was calculated using cosine similarity, as presented in Equation 2.

$$Cosine\ Similarity = \frac{R \cdot R_0 + G \cdot G_0 + B \cdot B_0}{\sqrt{R^2+G^2+B^2} \cdot \sqrt{R_0^2+G_0^2+B_0^2}} \tag{2}$$

The colour sensor is assembled on an unmanned ground vehicle. The vehicle features robotic arms with degrees of freedom that allow the on-board colour sensor to be directed at wall and floor surfaces. The vehicle is also designed to be remotely controlled, allowing the vehicle to be steered from a safe distance.

The detected materials are processed by an Arduino-based microcontroller, and the detected colour codes are wirelessly transmitted to a central receiver module via an RF transmitter module located on the vehicle. The hardware diagram of the on-board controller system is shown in Figure 1.

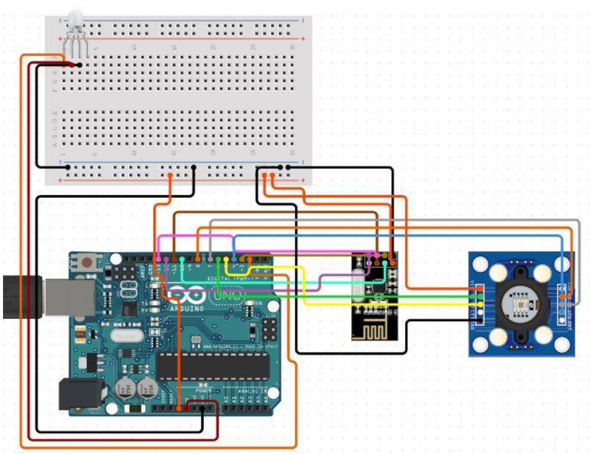


Figure 1. Hardware components and connection diagram of the developed system.

Data transferred to the RF receiver unit is digitally recorded for quality control and contract management. This allows monitoring of material usage, material placement accuracy, and work progress. Moreover, suitability of the colour of the construction materials to the contract terms is also checked. The algorithm used to compare the obtained data with the values defined in the technical specifications and determine the suitability of the material order is shown in the flowchart in Figure 2.

As shown in the flowchart in Figure 2, the reference value and tolerance range for the building material to be measured are first determined. This step is entirely at the client's discretion. The client determines the reference value and tolerance range by considering measurement errors and their desired colour scale range, and these values are included in the technical specifications. The quantity and type of materials to be used are determined based on the quantity take-offs and construction descriptions of the work items to be initiated during the construction phase. Based on this information, the order is processed by the smart contract. Before placing the order, the order values are checked by the algorithm. If they match the current work progress, the order is approved; if not, the order is cancelled.
If the order is approved, the colour compatibility of the material delivered to the construction site is measured using the developed equipment and tested using cosine similarity. If the cosine similarity value is greater than the threshold, the material is considered colour compatible. Otherwise, the material is rejected.

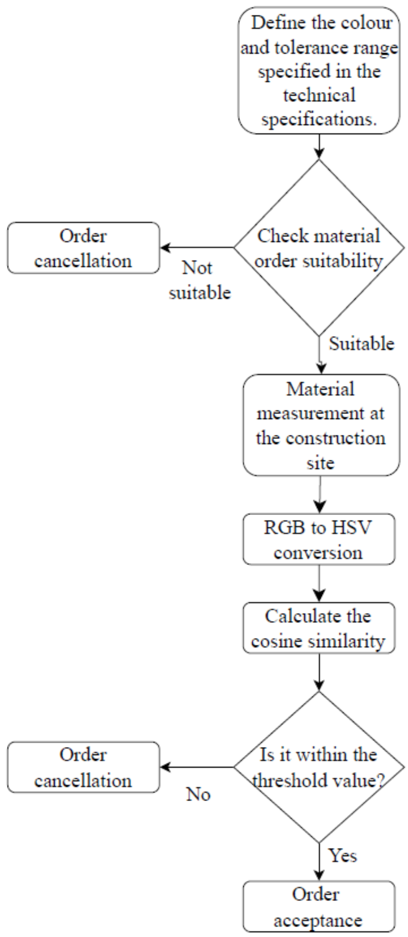


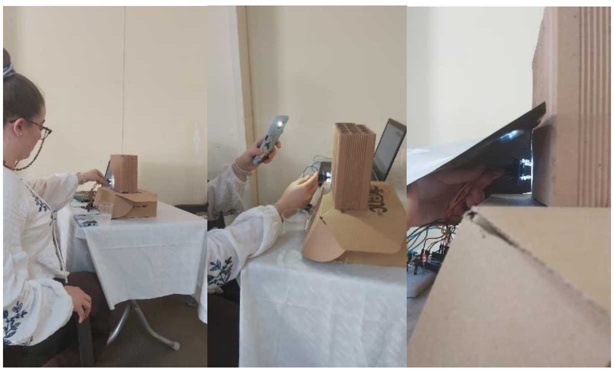
Figure 2. Flow chart of the developed color similarity algorithm.

4. Case Study

In this study, colour data were collected for four different material types: brick, tile, wall paint, and parquet, under different light levels or environments. The construction site where the brick data were obtained is shown in Figure 3.

Figure 3. Construction site where brick data was measured.

Care was taken to ensure constant light conditions during the measurements. For brick, the first measurement was taken indoors at noon under normal light; the second measurement was taken indoors with the lights on, the third measurement under low light, and the fourth measurement outdoors. For tile, the first measurement was taken indoors at noon on an overcast day under normal light, the second measurement was taken indoors under low light, and the third measurement was taken indoors with the lights on. For paint, the first measurement was taken indoors in the evening under normal light, the second measurement was taken indoors under low light, and the third measurement was taken indoors with the lights on. For parquet, the first measurement was taken indoors in the evening under light, the second measurement was taken indoors under low light, and the third measurement was taken indoors under low light.



a b c

Figure 4. Indoor measurement methods: a) 1st Measurement: indoors at noon under normal light; b) 2nd Measurement: indoors with light; c) 3rd Measurement: indoors under low light.

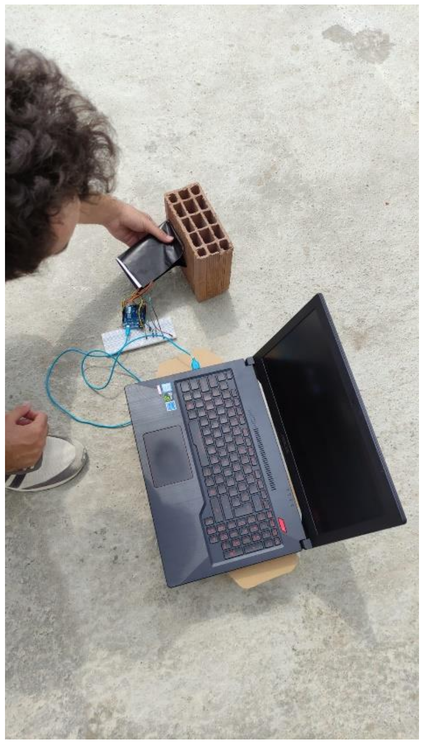


Figure 5. Illustration of measurements conducted at outdoors.

The mean RGB values and standard deviations measured for each material type are presented in Table 1. For the values presented in Table 1, 30 measurements were made for the first, second, third, and fourth set for brick, respectively. For tile, paint, and parquet, 45 measurements were made for the first, second, and third set, respectively.

Material	Obs. No.	Rave± σ	G (ort± σ)	B (ort± σ)
BRICK	1	80,97±8,6	23,9±7,85	95,26±22,31
	2	95,26±22,31	47,06±19,01	25,1±14,15
	3	13,5±14,34	0,17±0,91	0±0
	4	194,97±57,39	149,43±72,31	144,77±78,09
TILES	1	89,36±6,07	85,38±8,1	93,8±5,66
	2	10,27±10,32	46,69±10,79	58,18±4,91
	3	121,82±16,96	106,04±8,57	110±4,98
PAINT	1	46,69±19,81	113,44±12,18	145,96±7,89
	2	0±0	15,02±13,79	50,78±12,04
	3	92,36±12,1	137,96±12,53	169,89±9
PARQ.	1	109,9±26,57	111,16±23,97	119,91±21,9
	2	38,53±17,83	61,22±15,45	60,18±14,69
	3	128,93±13,57	135,22±9,46	148,4±9,3

Table 1. RGB Mean and Standard Deviation Values by Material Types.

As shown in Figure 6, the colour sensor and the light source used for illumination were mounted on a small-scale unmanned ground vehicle, enabling serial colour measurements. The TCS3200 colour sensor reads material colours in RGB format. Despite the use of an artificial light source during measurements, it was observed that measurement values could be subject to significant deviations both indoors and outdoors. It was determined that conducting analyses in HSV space rather than RGB would yield more consistent results.

BRICK				
Average Value	Obs.1	Obs.2	Obs.3	Obs.4
R	80,967	95,267	13,5	194,97
G	41,6	47,067	0,1667	149,43
B	23,9	25,1	0	144,77
R'	0,3175	0,3736	0,0529	0,7646
G'	0,1631	0,1846	0,0007	0,586
B'	0,0937	0,0984	0	0,5677
MAX(R'G'B')	0,3175	0,3736	0,0529	0,7646
MİN(R'G'B')	0,0937	0,0984	0	0,5677
Δ	0,2238	0,2752	0,0529	0,1969
H	0,0517	0,0522	0,0021	0,0155
S	0,7048	0,7365	1	0,2575
V	0,3175	0,3736	0,0529	0,7646
Meas. Value				
R	97	95	45	134
G	51	33	0	77
B	28	40	0	65
R'	0,3804	0,3725	0,1765	0,5255
G'	0,2	0,1294	0	0,302
B'	0,1098	0,1569	0	0,2549
MAX(R'G'B')	0,3804	0,3725	0,1765	0,5255
MİN(R'G'B')	0,1098	0,1294	0	0,2549
Δ	0,2706	0,2431	0,1765	0,2706
H	0,0556	0,9812	0	0,029
S	0,7113	0,6526	1	0,5149
V	0,3804	0,3725	0,1765	0,5255
Smilarity	0,9977	0,6562	0,9926	0,9002

Table 2. HSV Conversion of Brick Average and Measured RGB Values

Showing the average and measured RGB values and converting them to HSV values to calculate similarity is shown in Table 2 for brick, Table 3 for tile and paint, and Table 4 for parquet.

TILES				PAINT		
Av. Value	Obs.1	Obs.2	Obs.3	Obs.1	Obs.2	Obs.3
R	89,36	10,27	121,8	46,69	0	92,36
G	85,38	46,69	106	113,4	15,02	138
B	93,8	58,18	110	146	50,78	169,9
R'	0,35	0,04	0,478	0,183	0	0,362
G'	0,335	0,183	0,416	0,445	0,059	0,541
B'	0,368	0,228	0,431	0,572	0,199	0,666
MAX(R'G'B')	0,368	0,228	0,478	0,572	0,199	0,666
MİN(R'G'B')	0,335	0,04	0,416	0,183	0	0,362
Δ	0,033	0,188	0,062	0,389	0,199	0,304
H	0,745	0,54	0,958	0,555	0,617	0,569
S	0,09	0,824	0,13	0,68	1	0,456
V	0,368	0,228	0,478	0,572	0,199	0,666
Meas. Value						
R	91	0	114	29	0	111
G	100	60	98	113	37	144
B	94	58	119	140	65	176
R'	0,357	0	0,447	0,114	0	0,435
G'	0,392	0,235	0,384	0,443	0,145	0,565
B'	0,369	0,227	0,467	0,549	0,255	0,69
MAX(R'G'B')	0,392	0,235	0,467	0,549	0,255	0,69
MIN(R'G'B')	0,357	0	0,384	0,114	0	0,435
Δ	0,035	0,235	0,082	0,435	0,255	0,255
H	0,389	0,494	0,794	0,541	0,572	0,582
S	0,09	1	0,176	0,793	1	0,369
V	0,392	0,235	0,467	0,549	0,255	0,69
Smilarity	0,945	0,993	0,995	0,996	0,998	0,996

Table 3. HSV Conversion of Tile and Paint Average and Measured RGB Values

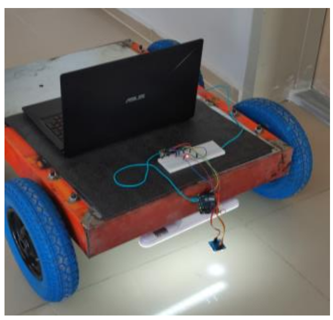


Figure 6. Tile material colour measurements conducted by the colour sensor assembled on the unmanned ground vehicle.

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PARQUET			
Average Value	Obs.1	Obs.2	Obs.3
R	109,89	38,533	128,93
G	111,16	61,222	135,22
B	119,91	60,178	148,4
R'	0,4309	0,1511	0,5056
G'	0,4359	0,2401	0,5303
B'	0,4702	0,236	0,582
MAX(R'G'B')	0,4702	0,2401	0,582
MİN(R'G'B')	0,4309	0,1511	0,5056
Δ	0,0393	0,089	0,0763
H	0,6456	0,4923	0,6128
S	0,0836	0,3706	0,1312
V	0,4702	0,2401	0,582
Meas. Value			
R	140	58	109
G	109	83	127
B	133	65	147
R'	0,549	0,2275	0,4275
G'	0,4275	0,3255	0,498
B'	0,5216	0,2549	0,5765
MAX(R'G'B')	0,549	0,3255	0,5765
MİN(R'G'B')	0,4275	0,2275	0,4275
Δ	0,1216	0,098	0,149
H	0,871	0,38	0,5877
S	0,2214	0,3012	0,2585
V	0,549	0,3255	0,5765
Similarity	0,992	0,9757	0,9886

Table 4. HSV Conversion of Parquet average and measured RGB values

Similarity tests were performed using the cosine similarity scale between the HSV values obtained after the processing steps presented in Tables 2, 3, and 4 and the reference HSV values. Similarity tests performed in the HSV space were found to have higher consistency and could be used more reliably in building material colour acceptance testing.

5. Conclusion

In this study, reference colour values and tolerance ranges were determined for specific building materials using numerous measurements. This dataset will provide a valuable dataset for comparison, making it an important resource for both literature and practice. Comparing the obtained data with the measurements and calculating cosine similarity values, it was observed that the HSV colour space yielded more consistent results compared to RGB. By separately evaluating hue, saturation, and value (brightness) components in HSV calculations, it was determined that it was less sensitive to changes in ambient lighting conditions. This enabled more accurate results in the material procurement process through colour similarity analysis. A system was developed that can consistently determine the colour conformity of building materials to technical specifications with a low computational load and data size using an economical colour sensor. This will reduce disputes between stakeholders in the construction projects. The developed system has been an important application for integrating remote sensing methods with smart contracts. As a further development, the small-scale ground vehicle shown in the case study could autonomously navigate the construction site and collect data, minimizing human labour.

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Appendix

Raw data of the measurements can be obtained from the link given below. The data is allowed to be utilized if the user cites this research.

https://drive.google.com/file/d/1J5ja43wPZRRIvEM3dPlwX-sLej7Xtmb1/view?usp=drive_link