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The Technological Aspect in Cultural Heritage Research: the Application of a Methodological Model of 3D Technologies and Spectroscopy

SUMMARY OF DOCTORAL DISSERTATION

Social Science,
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VILNIAUS UNIVERSITETAS

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ŽIŽIŪNAS

Technologinis veiksnys kultūros paveldo tyrimuose: 3D vaizdo ir spektroskopijos taikymo metodologinis modelis

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RELEVANCE OF THE TOPIC

Digital research is a relatively new approach in information gathering, analysis, and communication. It may provide the foundations for us to present new technologies and methodologies, which in turn may enrich the way new knowledge is developed in science. In this context, digitalization no longer describes the possibilities of making information and communication processes better by converting something stored in an analog format into a digital copy, but rather that digitalization can produce new methods for the analysis of digital content.[1] Cultural heritage is not an exception; therefore, new information-communication technologies (ICT) create new ways of digital research.[2] As a result, scholars working within the fields of humanities and social sciences (HSS) regard digital research as a new scientific subject. The implementation of new technological solutions and methodologies in the field of heritage studies is a fine goal of this dissertation. According to K. Kardelis, "the goal of scientific research – to explore and understand the essence and origin of the processes, and to implement new methods for the rational exploitation of material and immaterial resources."[3]

The essence of this dissertation could be grounded on the following preconditions:

- Lithuania's heritage sector is still facing some problems related to ICT improvements and methodological upgrades.[4] There is the tech-

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1 LAUŽIKAS R., Paveldo skaitmeninimas: nuo duomenų banko iki Second life. *Liaudies kultūra*, Vilnius, 2012, p. 17.

2 KAPLERIS I., Skaitmeninių medijų raiška Lietuvos muziejų komunikacijoje, daktaro disertacija, Vilnius: Vilniaus universitetas, 2014.

3 KARDELIS K., *Mokslinių tyrimų metodologija ir metodai*, Kaunas, 2002, p. 8.

4 KAPLERIS I. Skaitmeninių medijų raiška Lietuvos muziejų komunikacijoje, daktaro disertacija. Vilnius: Vilniaus universitetas, 2014; LAUŽIKAS R., VARNIENĖ-JANSSEN R., Paveldas ir visuomenė: Lietuvos kultūros paveldo skaitmeninimo strateginės plėtros gairės 2014–2020 metų programavimo laikotarpiui. *Informacijos mokslai*, Vilnius 2014; GEČIENĖ I., KUBLICKIENĖ L., MATULAITIS Š.,TAURAITĖ-KAVAI E., ŽALANDAUSKAS T. *HSM nacionalinės kompleksinės programos galimybių studija*, 2012 [interactive]. Link: <http://www.esparama.lt/es_parama_pletra/failai/ESFproduktai/2012_NKP_HSM_GALIMYBIU__STUDIJA.pdf> [last accessed 2017-02-22].

nology transfer factor, where new or updated ICT implementation and application methodologies could actually improve the cultural heritage sector. A related example could be carbon-14 dating, which was a very successful transfer of technology from chemistry and physics toward archaeology. This specific dating method empowered archeology science by making it possible to start measuring facts based not on relative dates of the artefacts but real calendar estimations. Another great example could be a web content management system (CMS). Creating a website was only the matter of professionals in programming until the breakthrough of various user-friendly CMS platforms. It unlocked the possibility to create a website to everyone without needing to have deep knowledge in programing.

- This research is important for broadening communication and information sciences. New technology adaptations and the analysis of such processes are one of the most important fields of study. Communication and information sciences are still lacking some deeper focus on new information-communication technologies that could enrich this area with new methods, techniques, methodologies, and practical application experience.
- Lastly, the relevance of this dissertation comes not from the need of creating fundamental knowledge, but rather from practical problems regarding a lack of ICT application in the humanities and social sciences,[5] where new technological implementation is slower. This demonstrates the need to master new forms of information mediums (e.g., augmented reality, virtual reality). Also, there is a need to reach economic efficiency (e.g., less resources for the same agenda) or precision in research (e.g., seeking objectiveness, particularity) by using artificial intelligence possibilities.

5 Integration of social sciences and humanities in horizon 2020: participants, budget and disciplines, Monitoring report on SSH-flagged projects funded in 2014 under the Societal Challenges and Industrial Leadership, Brussels, 2015 [interactive]. Link: <https://ec.europa.eu/programmes/horizon2020/en/news/integration-social-sciences-and-humanities-horizon-2020-participants-budget-and-disciplines> [last accessed 2015-10-20].

MAIN TERMINOLOGY

- ***3D view*** – three dimensional view (height, width, depth) in a discrete digital environment where the image is manipulated using various software through various screens.
- ***Lidar*** – laser/optical electronical devices measuring actual surroundings in real time, where the results of such measuring are usually exported as x, y, z coordinates of a point cloud and can be followed by additional information, such as albedo and digital color photos. *Lidar* stands for "light detection and ranging," meaning technological systems designed to measure the accurate 3D view of an object.
- Digital research in this work pivots toward the digital humanities field, where the main accent is put on research based on up-to-date digital technologies, digital tools, software, multi-dimensional mediums, and internet access. In other words, digital HSS research is the traditional HSS agenda where analysis and scientific research is based on ICT.
- Spectroscopy – the measurement of various electromagnetic waves' impact from the targeted object. This dissertation's laboratory analysis was performed with a CRAIC PV 308 micro spectrophotometer equipped with a DELL and ZEISS computational device and optical equipment (measured wave length was between 350 and 950 nm). Spectroscopy, in this dissertation, means UV-VIS-NIR reflectance spectroscopy.
- Document authenticity in this work denotes the original document that was made by its author. In this work, the documents' ink colors are the main source of information according to which interpretations are done. Color changes and variations alone cannot predicate falsification facts, but in this dissertation, all ink color changes and variations will be handled as alterations. The investigation of all circumstances of an identified alteration requires a higher level of interpretation, which can only be done by specific field scientists.
- Questioned documents – a discipline of examination of handwritten or printed documents and their ink. These could be paper or parch-

ment objects. Questioned documents analyze all sorts of aspects where authenticity and tangible originality are key points. Various methods and technologies are used in this research field, including chemical and physical testing. Spectroscopy (fluorescence, UV-VIS-NIR, etc.) is one of the methods for examining questioned documents.

State of research. Except for the several articles and practical guide books, *Lidar* as 3D technologies are practically not investigated in Lithuanian scientific papers.[6] These mentioned publications cover mainly practical issues regarding the usage of technologies and its limits at some point. There are more foreign papers on this topic, but there is also the prevailing tendency of case studies.[7] An analysis of such literature suggests that there are almost no instances of a deeper outlook of 3D technologies as a new methodological framework. Such an outlook could be considered, for

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6 GUDRITIENĖ D., ALEKNAVIČIUS A. Skaitmeninė fotogrametrija, ASU, 2007; MELAIKA S. 3D lazerinių matavimo sistemų ypatumai, magistro baigiamasis darbas. Akademija: A. Stulginskio universitetas, 2010; ŠLIKAS D., KALANTAITĖ A. Vietovės trimačių modelių generavimas taikant erdvinius skenavimo duomenis. *AVIACIJOS TECHNOLOGIJOS*, VGTU, Vilnius, 2013; ŽALNIERUKAS A.; CYPAS K. Žemės skenavimo lazeriu iš orlaivio technologijos analizė, *Geodezija ir kartografija*, Vol. XXXII, No. 4, 2006.

7 TAYLOR J., BERALDIN J.-A., GODIN G., COURNOYER L., BARIBEAU R., BLAIS F., RIOUX M. DOMEY J. NRC 3D imaging technology for museum and heritage applications [interactive]. Link: <http://onlinelibrary.wiley.com/doi/10.1002/vis.311/full> [last accessed 2017-01-31]; 118. LERMA J. Luis, NAVARRO Santiago, CABRELLES Miriam, VILLAVERDE Valentin. Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the Upper Paleolithic Cave of Parpallo´ as a case study. *Journal of Archaeological Science*, Valencia, Spain, Vol. 37, 2010; REMONDINO Fabio. Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning. Remote Sens, 2011; HADDAD A. Naif. From ground surveying to 3D laser scanner: A review of techniques used for spatial documentation of historic sites. *Journal of King Saud University – Engineering Sciences* [interactive]. Link: <http://www.sciencedirect.com/science/article/pii/S1018363911000250> [last accessed 2016-11-22]; 61.
FORTEA M., DELL'UNTOB N., ISSAVIA J., ONSUREZA L., LERCARIA N. 3D Archaeology at Çatalhöyük [interactive]. Link: <http://journals.sagepub.com/doi/abs/10.1260/2047-4970.1.3.351> [last accessed 2017-01-31].

example, the investigation and monitoring of architectural cultural heritage areas (old towns etc.) – this topic is presented as the second case study of this dissertation. According to the status of research and the relevance of the topic, a **hypothesis (1)** could be stated: cultural heritage supervision could be performed by implementing a new methodology that is based on up-to-date 3D technologies, which increase monitoring efficiency (financial, time-wise, and data objectiveness factors).

Spectroscopy is usually used in analyzing various issues related to conservation and restoration.[8] In Lithuania, the UV-VIS-NIR reflectance spectroscopy analysis (via its ink's color alterations) concerning questioned historical documents is not widely researched. There are only several papers on this subject.[9] UV-VIS-NIR spectroscopy could be another method used for investigating not only conservation- and restoration-related issues of old paintings, sculptures, etc., but it also could extend to the authenticity research of historical documents. According to the status of research and

8 VANDENABEELE Peter, TATE Jim, MOENS Luc. Non-destructive analysis of museum objects by fiber-optic Raman spectroscopy. *Analytical and bioanalytical chemistry*, 2006; DAFFARA Claudia, PAMPALONI Enrico, PEZZATI Luca, BARUCCI Marco, FONTANA Raffaella. Scanning Multispectral IR Reflectography SMIRR: An Advanced Tool for Art Diagnostics. *ACCOUNTS OF CHEMICAL RESEARCH*, Vol. 43, 2010; GÁL L., ČEPPAN M., REHÁKOVÁ M., DVONKA V., TARAJČÁKOVÁ J., HANUS J. Chemometric tool for identification of iron–gall inks by use of visible–near infrared fiber optic reflection spectroscopy. *Anal Bioanal Chem*, 2013 [interactive]. Link: <https://www.ncbi.nlm.nih.gov/pubmed/24057023> [last accessed 2017-07-10]; RICCIARDI Paola, PALLIPURATH Anuradha. The Five Colours of Art: Non-invasive Analysis of Pigments in Tibetan Prints and Manuscripts. *Tibetan Printing: Comparison, Continuities and Change*, Cambridge, 2016 [interactive]. Link: <http://booksandjournals.brillonline.com/content/books/9789004316256> [last accessed 2017.07.13].

9 SENVAITIENĖ Jūratė. Kultūros objektų charakterizavimas ir cheminių konservavimo procesų įtakos jų degradacijai tyrimas, daktaro disertacija. Vilnius: Vilniaus universitetas, 2006;
SENVAITIENĖ Jūratė, BEGANSKIENĖ Aldona, PADARAUSKAS Audrius, KAREIVA Aivaras. Istorinių rašalų apibūdinimas spektroskopijos metodu. *Lietuvos dailės muziejaus metraštis*, Vol. 10, 2007; SENVAITIENĖ Jūratė, BEGANSKIENĖ Aldona, TAUTKUS Stasys, PADARAUSKAS Audrius, KAREIVA Aivaras. Istorinių rašalų apibūdinimas įvairiais analiziniais metodais. *Lietuvos dailės muziejaus metraštis*, Vol. 10, 2007.

the relevance of this topic, another **hypothesis (2)** could be stated: UV-VIS-NIR reflectance spectroscopy can effectively (concerning saving research time and being not sophisticated), distinguish *de visu* identical inks in a nondestructive manner. This means that an ink's color variations and alterations could be a methodological approach for analyzing various document-related questions like dating, falsification, etc. Having such laboratory results at their disposal, experts and scientists could use them for making higher level interpretations (what certain color alterations could state regarding the issues of the documents' authenticity).

The **research problem** is utilitarian, because the focus of the dissertation is to investigate whether or not geometry and color alterations (measured with spectrometers, 3D laser scanners, etc.) could be a more effective (speed, accuracy factors) method for analyzing traditional HSS problems and how it can be done. The **object of the research** – a proposed methodological model for analysis of tangible cultural heritage by its color and geometry alterations. In this dissertation, a conjoint methodological model (**Table 1**) is created in order to demonstrate the proposed research approach for this sector's professionals: archaeologists, historians, and cultural heritage specialists. It is important to state that a practical implementation serves as a testing case of the proposed methodology. Hence, any specific knowledge of the case studies (Vilnius Old Town digital monitoring and authenticity questions regarding the 16^{th}–18^{th} c. books from the Suprasłė Abbey's office) are not the goal of this dissertation. **The aim of the research** is to develop and test an innovative methodological model based on color and geometry alterations as well as applied techniques dedicated to cultural heritage analysis and the optimization of heritage practice. In the theoretical part of the dissertation, a communication science framework is used to conceptualize the proposed methodology as an innovation. *Diffusion of Innovations*, a well-known and still high-profile work by Everret Rogers, is used for this purpose.[10] This book is fundamental because it is counted to be the second most cited work in the field of social sciences. This dissertation demonstrates that an innovation – what could be understood as an important

10 ROGERS M. E. *Diffusion of innovations*, Third edition, London, 1983.

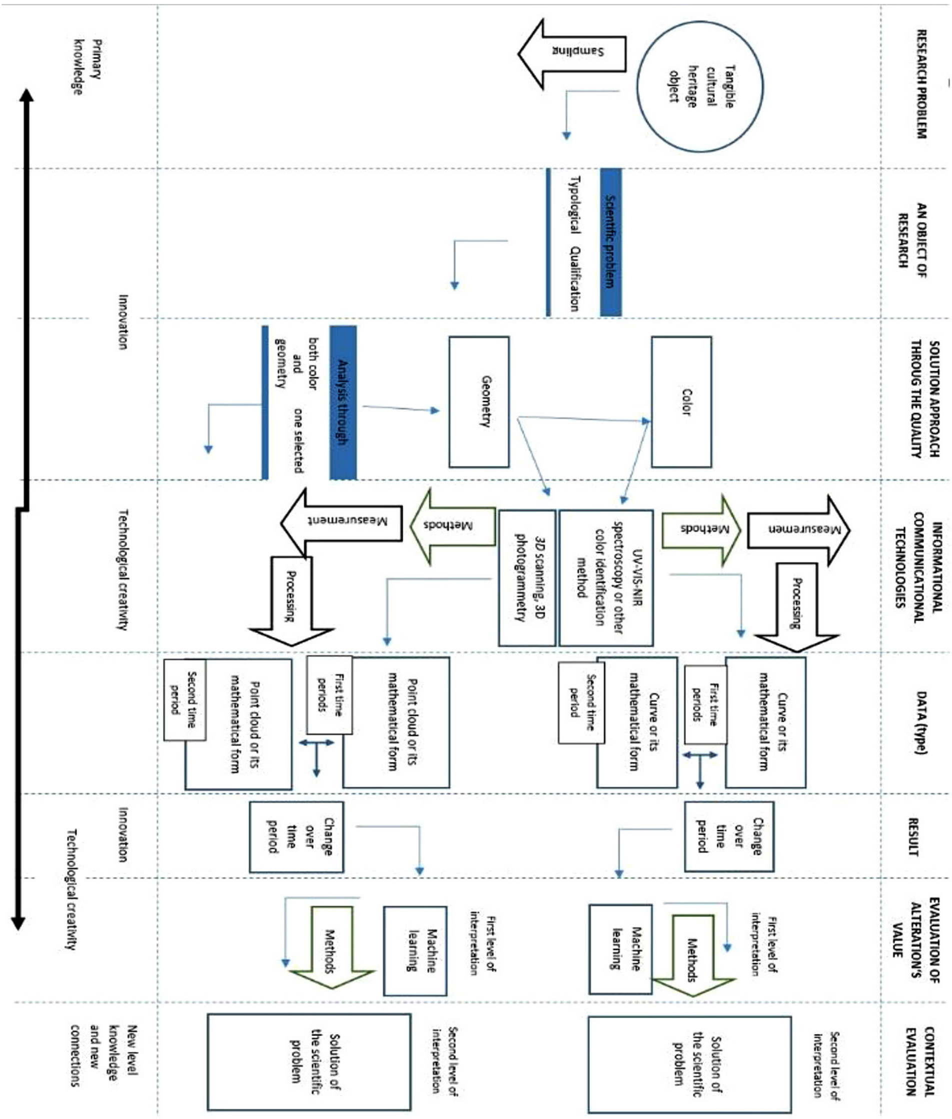

Table 1. *Conjoint color and geometry's alteration methodological model.*
Made by the author.

novelty – is not necessarily something essentially new. To advocate this position, the "3T" theory[11], the innovation management and systemic innovation conceptions are invoked[12] as well.

In order to achieve the aim of the research, the following **objectives** have been defined:

1. To evaluate the implementation of spectroscopy and 3D technologies in cultural heritage studies in the context of the diffusion of innovations theory;
2. To develop a conjoint color and geometry alteration methodological model based on E. Rogers's diffusion of innovations theory.
3. Based on general methodology, to develop applied spectroscopy and 3D technology techniques dedicated to optimizing cultural heritage as well as typological and diagnostical issues.
4. To perform experimental laboratory testing of proposed dedicated techniques with two cases studies using immovable and movable cultural heritage objects in Lithuania.
5. According to experimental results, propose some recommendations and a discussion for HSS specialists and scientists.

The practical relevance of the dissertation lies in developing a practical analytical tools that can indicate some tendencies related to the studied objects' colors and geometry information. Based on the first level of interpretation (tendencies), a higher level of interpretation could be performed (new knowledge). A higher level of interpretation could solve practical issues regarding HSS research objects. In this case, spectroscopy could be used as an analytical tool for the questioned historical documents, where

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11 FLORIDA R. *Cities and the creative class: from City and Community*, 2003; FLORIDA Rrichard, CHARLOTTA P.A. Mellander, STOLARICK M. Kevin. Talent, technology and tolerance in Canadian regional development. *The Canadian Geographer*, Vol. 54, 2010; GOFFIN Keith, MITCHELL Rick. *Innovation Management, Strategy and implementation using the pentathlon framework*, 2nd edition, 2010.

12 ČERNEVIČIŪTĖ J., STRAZDAS R., JANČORAS Ž., KREGZDAITE R., MORKEVIČIUS V. *Kūrybinių industrijų plėtojimo kompleksiniai veiksniai: kolektyvinio kūrybingumo ugdymas*, monografija. Vilnius: Vilniaus Gedimino technikos universitetas, 2015

certain details of a book or a cluster of books are unknown or questioned. These can be questions regarding origin, dating, falsification, etc. it could also serve other HSS areas of interest. For example, in archaeology, spectroscopically measured color variations of an object could suggest some solutions regarding inconsistencies within findings. Spectroscopy could serve as a verification tool as well, where chronological or typological questions are related to historical objects that have color features. 3D technologies can potentially be used as a supervision method for constant changing ur-

METHOD APPLIED	WORKFLOW	CRITERIA AND FUNCTIONS	RESULTS	FIRST LEVEL OF INTERPRETATION
SAMPLING	1	• Filter of authenticity • Filter of consistency, wholeness	• Test examples	• Test examples which corresponding to the criteria
UV-VIS-NIR SPECTROSCOPY	2	• F1 • F2 • F3	• Curves of F1 function • Curves of F2 function • Curves of F3 function	• F1, if $Ax=Ay\neq Az$ or $Ax=Az\neq Ay$, meaning probable word inconsistency or alteration • F2, if $X=Y\neq Z$ or $X=Z\neq Y$, meaning probable whole page inconsistency or alteration. • F3, if Nr. x ≠ Nr. y, and other objects have the same measurements, then it is probable inconsistency
PHOTOFIXATION	3	• macro- • micro-	• In case of F1 at least 3 macro photos ir 9 micro photos. • In case of F2 at least 3 macro photos ir 9 micro photos. • In case of F3 at least 30 macro photos ir 90 micro photos.	• All types of photos are subsidiary information which helps indicate false measurements

Table 2. *An analytical technique for general color alteration.*
Made by the author.

ban architectural heritage where management usually fails to guarantee unbiased and comprehensive monitoring.

Based on a general methodology, applied spectroscopy and 3D technology techniques were developed (**Tables 2, 3**).

METHOD APPLIED	WORKFLOW	CRITERIA AND TECHNOLOGY	RESULTS	FIRST LEVEL OF INTERPRETATION
MEASURE	1	• *Lidar* technologies • Digital camera (digital photogrammetry) • Satellite recipient	• Point cloud • Digital photos • GPS/GLONASS data	• Point cloud data corresponds to real physical characteristics of objects • Digital photos are suitable for processing 3D models. • Coordinates are precise (with a desirable accuracy)
DATA PROCESSING	2	• Data preprocessing (eliminating not eligible information) • Data optimization (connecting data to clusters) • 2D → 3D conversion (digital photogrammetry). Scale rectify. • 3D data merging with coordinates	• Selection and filtration for needed 3D data • Coordinated 3D data scene of real objects	• Data is suitable for machine learning processing
DETECTION OF CHARACTERISTICS	3	• Identifying cultural objects valuable characteristics and x, y, z, position by using static and advanced machine learning algorithms	• Data base with semantic labels (in that case where are different period data of the same object) • Database with results of fitting data with descripted mathematical rules (in that case where are impossible get older data of the object)	• Identified valuable characteristics in the point cloud or photography
COMPUTATIONAL ANALYSI S OF MEASURMENTS	4	• Machine learning algorithms for geometry changes inspection	• Geometrical changes	• Demolished • Sustain • Enlargement • More space/volume • Less space/volume

Table 3. *A geometry alteration technique dedicated to urban architectural cultural heritage monitoring.* Made by the author.

Methods applied in the thesis:

- A critical scientific literature analysis for the development of a theoretical framework;
- The scientific modeling method for the development of a methodological model. Scientific models usually are the essence of every scientific research, and the model typically means various science data forms: physical models, theoretical models, descriptions, equations, etc. In this thesis, the model is perceptible as a schematically simplified reality study contextualized using innovation theoretical framework and based on geometry and/or color information;
- Experiments for testing the methodology and techniques. For laboratory work, a microspectrometer and 3D laser scanner were used.

The experimental part of the thesis was performed in the Digitalization Laboratory of Vilnius University's Faculty of Communication. For ensuring the best possible quality of the practical testing, several projects were performed.[13] This helped to introduce the author's ideas to HSS scientists and specialists. The testing was performed in real life scenarios. Hence, the results were verified by different scientists working in the HSS sector.

EXPERIMENTAL PARTS AND KEY FINDINGS

Concerning the testing of **color** alteration methodology, 20 historical handwritten 16th–18th c. books were examined. A CRAIC PV 308 micro spectrophotometer equipped with DELL and ZEISS computational devices was used. The measured wave length ranged between 350 and 950 nm in reflectance mode (an average of 900 measurements of the place of inter-

13 In 2016, 20 handwritten 16th–18th c. tomes from the office of Supraslė Abbey were investigated. This was done within the framework of the project "Istorinio rašytinio šaltinio kilmės tyrimas: Supraslės vienuolyno atvejis," (lead by Giedraitienė B.); in 2017, a 3D digitalization project of the Gintališkė Wooden Church was performed: "Medinio sakralinio paveldo 3D skenavimo ir panaudojimas edukacijai" (VšĮ Paveldo komunikacija, lead by Žižiūnas T.); the years 2018–2022 will see a team of scholars undergo a high scientific level project "Automated heritage monitoring of urbanized areas implementing 3D technologies" (lead by Prof. A. Kuncevičius).

est). According to the proposed technique (**Table 2**), every measured ink place (~1 mm^2) in the book was catalogued, micro and macro photo-fixed. At least four pages were examined from every book – three pages from the beginning (page A), middle (page B), and the end (page C) – and questioned (page Q). Page Q (the questioned page) is somewhat different regarding the context of the book. The selections of the Q pages were performed before spectroscopy examinations. The selections of Q pages were performed by specialists of the conservation of historical books. Each page (A, B, C, and Q) in each book (1–20) had three measured places: up (1), middle (2), and bottom (3). For example, 15C3 denotes the measurement of book number 15 in the middle of the book (the exact page number placed in the database), while the exact place is at the bottom of the page. The collected database (**Table 4**) consists of coded data in order to perform an analysis by comparing the results between each other. The F1 function denotes a comparison of data in the context of the same page. The F2 function denotes a comparison of data in the context of the same book. The F3 function denotes a comparison of data in the context of several tested books.

4 table. *Part of the database from the laboratory UV-VIS-NIR experiment with historical books from the 16th–18th c.* Made by the author.

Number of book	Identification	Date	Production place	Total page number	Total measurements	Measurement A page	Macro photo (A) no.	Measurement B page	Macro photo (B) no.	Measurement C page	Macro photo (C) no.
1	F19-61	mid. 16th c./ 2nd half	SUPRASLĖ Abbey	368	9	53	1A	189	1B	259	1C
2	F19-52	early 16th c.	Vilnius(?)	271	9	52	2A	190	2B	259	2C
3	F19-238	early 16th c.	SUPRASLĖ Abbey	283	9	58	3A	156	3B	257	3C
4	F19-95	1512	Naugardukas-Vilnius (?)	625	9	93	4A	195	4B	591	4C
5	F19-262	early 16th c.	SUPRASLĖ Abbey	408	9	35	5A	185	5B	343	5C
6	F19-48	16th c. 1st half/ late 16th c.	SUPRASLĖ Abbey	388	10	30	6A	147	6B	325	6C

Number of book	Identification	Date	Production place	Total page number	Total measurements	Measurement A page	Macro photo (A) no.	Measurement B page	Macro photo (B) no.	Measurement C page	Macro photo (C) no.
7	F19-247	early 16th c.	SUPRASLĖ Abbey	159	9	31	7A	90	7B	141	7C
8	F19-239	early 16th c.	SUPRASLĖ Abbey	262	9	25	8A	104	8B	244	8C
9	F19-116	1638–1639/1704–1756	SUPRASLĖ Abbey	291	9	45	9A	165	9B	250	9C
10	F19-115	1662/1704	SUPRASLĖ Abbey	294	9	29	10A	141	10B	221	10C
11	F19-110	16th c.	Žirovičiai	350	9	25	11A	108	11B	347	11C
12	F19-149	1678	SUPRASLĖ Abbey	222	9	32	12A	85	12B	169	12C
13	F19-197	late 17th c.	SUPRASLĖ Abbey	396	9	38	13A	142	13B	329	13C
14	F19-89	from 1631	SUPRASLĖ Abbey	150	10	8	14A	73	14B	148	14C
15	F19-210	1691	SUPRASLĖ Abbey	366	9	79	15A	216	15B	294	15C
16	F19-192	1693	SUPRASLĖ Abbey	396	9	78	16A	248	16B	340	16C
17	F19-160	1667	SUPRASLĖ Abbey	99	9	12	17A	46	17B	84	17C
18	F19-242	1634	Pinsk	429	9	33	18A	255	18B	335	18C
19	F19-84	early 16th c.	SUPRASLĖ Abbey	245	9	62	19A	153	19B	192	19C
20	F19-240	early 16th c.	SUPRASLĖ Abbey	690	9	160	20A	285	20B	588	20C

Four testing groups were configured:

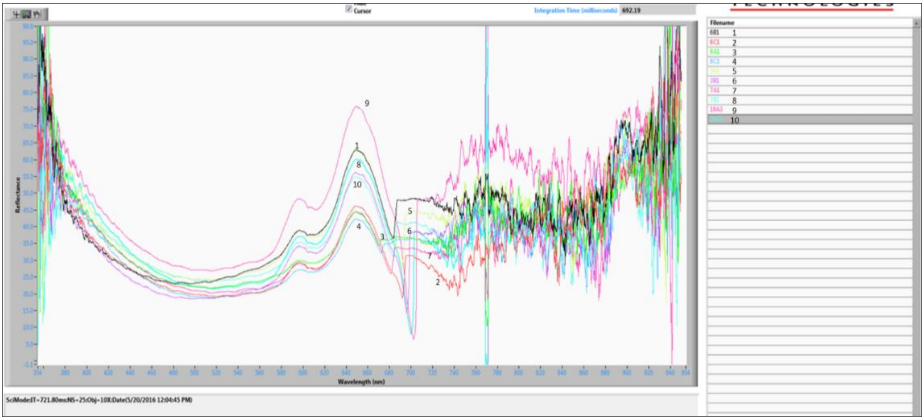
I. A comparison between Supraslė books from the early 16th c.;
II. A comparison of all Supraslė books from the early 16th c. and Supraslė books from the late 17th c.;
III. A comparison of all books of non-Supraslė origin between each other;
IV. A comparison of all Supraslė origin books and non-Supraslė origin books.

These groups were selected in order to answer type F2 and F3 questions: whether or not the same looking books (by defining their ink color) from the same origin and from the same production period can be distinguished. In addition, whether or not the Q pages were targeted correctly (by *de visu*).

One hundred eighty-two measurements were written from the actual non averaged 163 800 measurements.

RESULTS OF GROUP I

From the view of the gathered data, it is considered as a corresponding spectrum except for book No. 5 because of the different peek place onto 580-610 nm and indentation beside 605 nm. After eliminating the data of book No. 5, a general view (**Picture 1**) is generated. This serves as a comparison base.



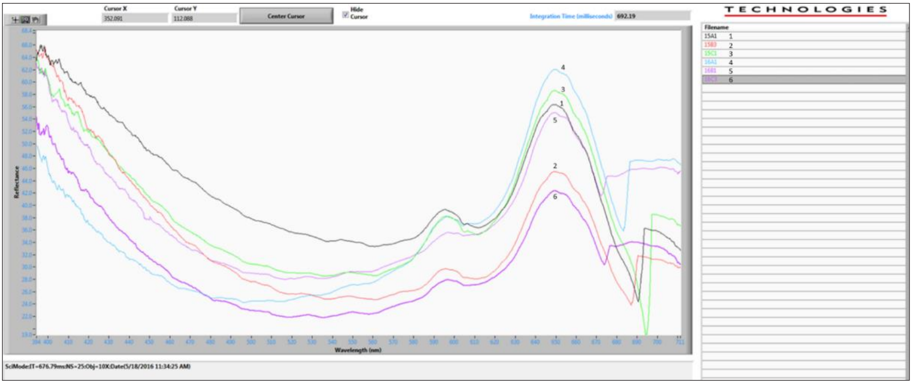
Picture 1. *Relevant spectrum of books Nos. 3, 7, 19, 6, 8, 20.* Made by the author.

RESULTS OF GROUP II

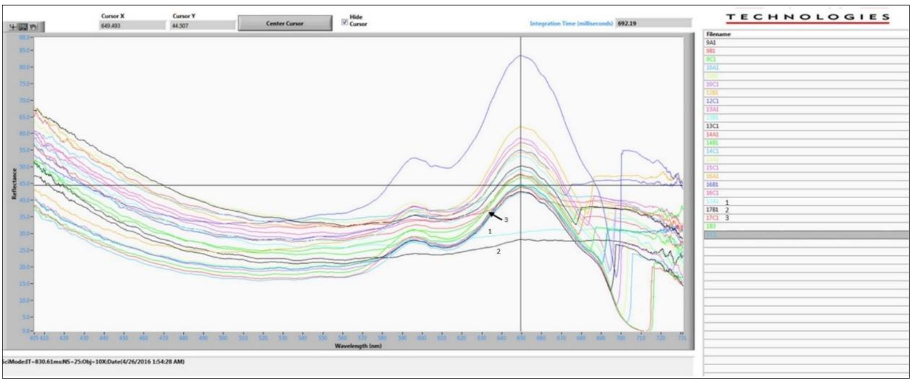
In this group, Supraslė books were compared on a wide chronological base. This means approximately 150 years of production in the same abbey. This comparison could show how ink was changing during the time. In this group there are several accurately dated books: No. 15 from 1691 and No. 16 from 1693. Hence, some additional hypotheses were made here:

- books No. 15 and No. 16 should show the very same spectrum;
- books Nos. 9, 10, 12, 13, 14, 15, 16, and 17 should be approximately corresponding;
- book No. 1 is eliminated because in F1 comparison all measurements demonstrated different results.

Despite the visible differences between books No. 15 and No. 16, a general view (**Picture 2**) demonstrates the same form and places of the peeks



Picture 2. *Books no. 15 and 16 do not show any relevant differences.* Made by the author.

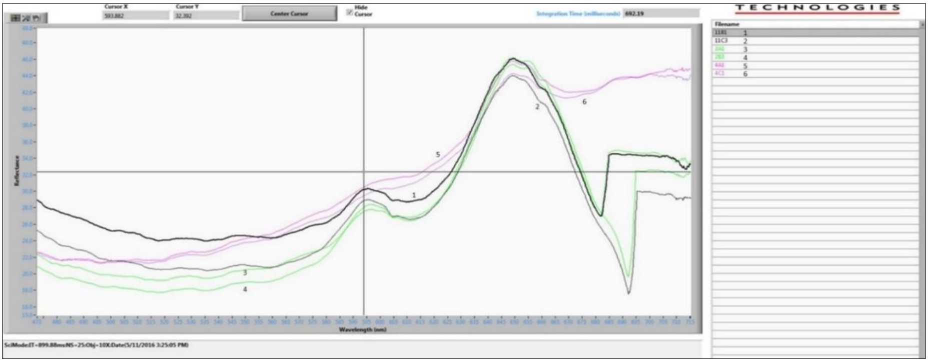


Picture 3. *The spectrum of books Nos. 9, 10, 12, 13, 14, 15, 16, and 17.* Only book No. 17 indicates bigger diferences (1, 2, 3 curves). Made by the author.

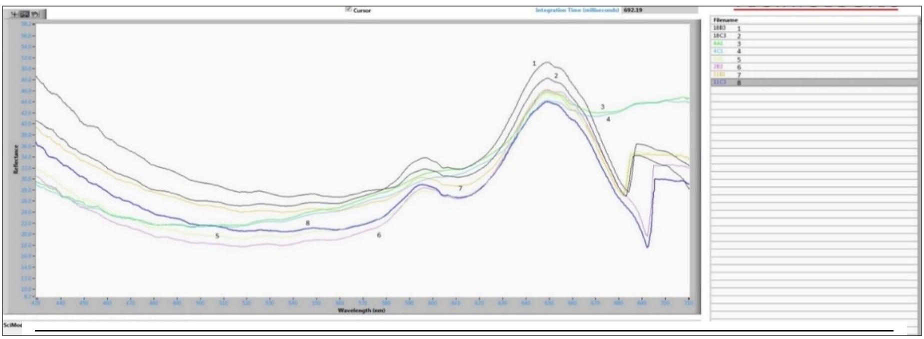
and a specific indentation beside 610 nm. All that indicates that the same recipe of the ink was used. Some small variations could be influenced by different physical state of the books.

Picture 3 shows only that book No. 17 demonstrates some bigger differences (the intensity values do not count as differences). Hence, books Nos. 9, 10, 12, 13, 14, 15, 16 probably are written with the same ink or using ink of the same recipe.

RESULTS OF GROUP III



Picture 4. *Spectrum of books Nos. 11, 2, and 4. All books are from the same chronological frame but of different origin location.* A difference can be seen in book No. 4. Made by the author.



5 picture. *Books No. 11, 2, 4, and 18. All except No. 4 are correspoding.* Made by the author.

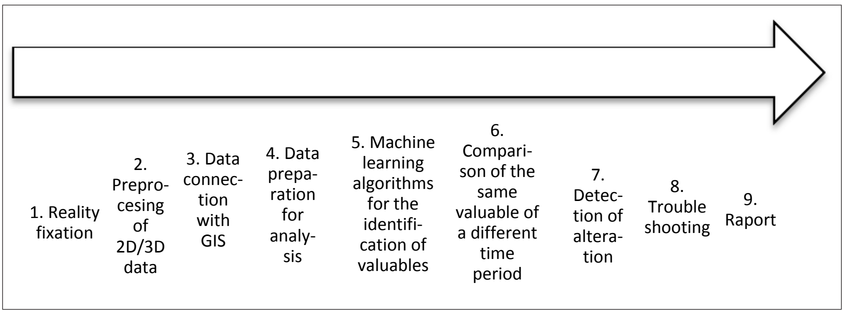
In the third group (**Picture 4**), there are four books that most probably came from different places but that are from the same time period (early 16^{th} century). Book no. 18 should have been more different because of the different time period. However, book No. 4 (**Picture 5**) seems to be tangential, and book No. 18 finely corresponds to book No. 11 and No. 2.

RESULTS OF GROUP IV

In this group, books were compared by place origin criteria without clustering by date. This was done by comparing these pairs because not much could be concluded from the general view. Hence:

- Books Nos. 7, 3, 19 and book No. 18 – no difference;
- Books Nos. 7, 3, 19 and book No. 11 – a difference;
- Books Nos. 7, 3, 19 and book No. 2 – no difference;
- Books Nos. 7, 3, 19 and book No. 4 – a difference.

Lastly, Q page identification by *de visu* was not accurate by 79% of the time. This means that with only a visible analysis some different-looking pages were actually corresponding with other analyzed pages from the books. However, it is recommended that a data analysis be performed using color maps, because comparing many spectrums in one view is a challenging task. An appropriate level of readings was recorded from VIS spectrums; however, readings above ~700 nm could be perspective as well. An additional FTIR analysis with the same test samples was performed but had



Picture 6. *A simplified workflow of the digital monitoring methodology.* Made by the author.

demonstrated no differences at all. UV-VIS-NIR spectroscopy measurements do not require any part of the sample (nondestructive), and measurements take only seconds to perform. Hence, this method could be a primary effective analysis. Second, an additional analytical tool for historical documents could be created by collecting more data into a comparable database.

Concerning a **geometry** fixation and alteration comparison, an innovative monitoring solution (**Picture 6**) was tested with the Vilnius Old Town. The Vilnius Old Town is a UNESCO heritage site with a very complex architectural structure; hence, damages and construction regulations can easily be unobserved. A digital monitoring methodology was created where 3D view technologies are used to perform a *status quo* fixation, and with which machine learning is used to analyze preferred heritage valuables.

Digital monitoring is based on seven conditions. First: all objects in the monitoring process are tangible. Second: physical valuables could be expressed as simple geometrical forms or mathematical expressions. Third: monitored objects could be fully scanned or photogrammetrically processed. Fourth: data from *Lidar* devices and data derived from photogram-

Table 5. *Logical operators of alteration detection*. XYZ – the initial data of X, Y, Z; +1 – the modus of alteration. Importance denotes which operator is higher within the hierachy. By optimizing the analysis, second-level operators could be eliminated. Made by the author.

Logical operator	Earlier data	Later data	Sequence of alteration	Importance
Destruction	XYZ	-XYZ	is → non	first
Creation	XYZ	XYZ + 1	non → is	first
Increase of area/ volume	XYZ	XYZ + 1	is → is (increase)	second
Decrease of area/volume	XYZ	XYZ -1	is → is (decrease)	second
Unchanged status quo	XYZ	XYZ	is → is	first

6 table. *Reference to analytical cases of selected valuables.* Made by the author.

No.	Valuable	Most probable geometrical form	Alteration	"Good experience"
1.	Window	rectangular	Reduction of side, elongation of side, immure, hole	Nguatem W., Drauschke M., Mayer H. 2014.*
2.	Door	rectangular	Reduction of side, elongation of side, immure, hole	Nguatem W., Drauschke M., Mayer H. 2014.
3.	Roof	rectangular, triangle, cone	Reduction of side, elongation of side, immure, hole	Rottensteiner F., Sohn G., et al. 2012.**
4.	Skylight	parallelepiped rectangular, rectangular	Reduction of side, elongation of side, installation	Laužikas R., Žižiūnas T., et al. 2017, Vilnius***
5.	Wall (by the ratio of its height and width)	parallelepiped rectangular, cylinder, polygon	Reduction of side, elongation of side, installation	Yu F., Xiao J., et al. 2015****
6.	Site	rectangular, polygon	Increase of are coverage by 3 meters factor (vehicles are eliminated)	Yu F., Xiao J., et al. 2015
7.	Cornice	triangle	Reduction of side, elongation of side, demolition	Meschini A., Petrucci E... Italy, 2014.*****

* NGUATEM William, DRAUSCHKE Martin, MAYER Helmut. Localization of windows and doors in 3D point clouds of facades, ISPRS Annals of the Photogrammetry. *Remote Sensing and Spatial Information Sciences*, Vol. II, 2014.

** ROTTENSTEINER F., SOHN G., JUNG J., GERKE M., BAILLARD C., BENITEZ S., BREITKOPF U. The ISPRS benchmark on urban object classification and 3d building reconstruction, ISPRS Annals of the Photogrammetry. *Remote Sensing and Spatial Information Sciences*, Vol. I-3, Melbourne, Australia, 2012.

*** LAUŽIKAS R., ŠMIGELSKAS R., KUNCEVIČIUS A., AUGUSTINAVIČIUS R., KURAUSKAS V., ŽILINSKAS E., ŽIŽIŪNAS T. Kultūros paveldo informacijos pusiau automatinis valdymas ir tyrimai naudojant 3D technologijas. *INFORMACIJOS MOKSLAI*, Vilnius, 2017, p. 160–179;

**** YU Fisher, XIAO Jianxiong, FUNKHOUSER Thomas. *Semantic Alignment of Lidar Data at City Scale* [interactive]. Link: <http://gfx.cs.princeton.edu/pubs/Yu_2015_SAO/gsv_align.pdf> [last accessed 2018-03-09].

***** Plg. MESCHINI A., PETRUCCI E., ROSSI D., SICURANZA F. Point cloud-based survey for cultural heritage. An experience of integrated use of range-based and image-based technology for the san Francesco convent in monterubbiano, The International Archives of the Photogrammetry. *Remote Sensing and Spatial Information Sciences*, Italy, Vol. XL-5, 2014.

metry are of the same quality (density, coverage, etc.). Fifth: the detection of cultural heritage could be analyzed using static and machine learning algorithms. Sixth: digitally processed results should be able to check in reality. Seventh: digital monitoring is based on non-destructive and non-invasive 3D view technologies and analytical technologies.

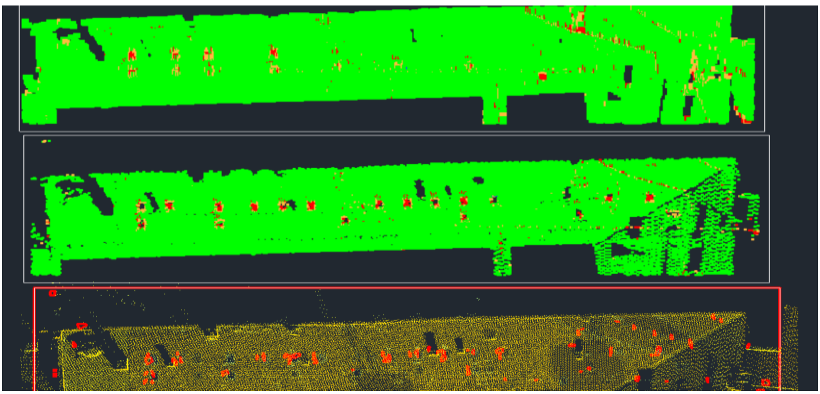
Regarding digital data, there are two possible ways to perform the detection and comparison of selected valuables. The first case scenario mainly means a lack of comparable data of the older *status quo*. This means that there are no earlier 3D data of the selected cultural heritage. New *status quo* 3D data are compared with a set of rules that can be written in coded mathematical form. This set of rules describes the geometrical parameters of the selected valuables of the cultural heritage. In the second case scenario, there are two data sets from different time periods. These data are compared with each other. In both cases, alteration is described as the first level of interpretation (**Table 5**) by logical operators; for example, alteration is described as "status quo unchanged by 90%," "reduction in volume by 65%," etc. The second level of interpretation could be a legal analysis of first-level results, for example, "reduction in volume = illegal demolition works." The second level of interpretation is not an object of this dissertation. For the performance of the analytical part of the monitoring system, some valuable experience could be implemented (**Table 6**).

RESULTS OF SEMI-AUTOMATED MONITORING

In 2014, a semi-automated version was created to test the proposed methodology.[14] For collecting data, airborne *Lidar* technology was used (*UltraCamX*, *Sony ILCE-R7* with a 55mm objective). For ground scanning, *Riegl LMS-Z420i* was used. In this test, skylight detection and alteration

14 The project "Urbanizuotų vietovių paveldo automatinio monitoringo programinės įrangos prototipo sukūrimas panaudojant 3D lazerines technologijas" (Eng. "A Monitoring Prototype of Heritage Urban Areas by Implementing 3D Laser Technologies," lead by Prof. LAUŽIKAS R.). The author of this dissertation is one of the team members of the project.

Picture 7. *The tested area, marked with the red rectangle, is the Vilnius Old Town.* Semi-automated monitoring was tested in 2014. Made by the author.



Picture 8. *Above – June 2011, middle – November 2014, bottom – programmically identified newly installed skylights.*

(is→non and non→is) functionality was developed together with project members from UAB Terra Modus. The buildings' height alteration was also analyzed. Data from 2011 and 2014 were used for comparison. Test algorithms were created in *c#* and *c++* languages as the "Undet" plugin for AutoCAD.

For the analysis, both *Lidar* data and aero photography in the raster form were used. Height differences were calculated using GPS attribute data, and those of the skylights – using albedo. Also, by defining a 1 m alteration's threshold, some new buildings and changes of vegetation were identified.

The test demonstrated some possible usage of static algorithms, albedo, GPS parameters, but mathematically coded descriptions for all valuables of old towns would be an extremely time consuming task. Hence, the next test is concentrated on machine learning algorithms, where there is no need to manually describe all valuables. Machine learning algorithms could possibly learn themselves to identify and compare the desirable valuables.

AUTOMATED MONITORING EXPERIMENT RESULTS

Regarding the proposed conjoint methodology (**Table 1**), the outlined monitoring process (**Picture 6**) and the proposed technique (**Table 3**) of automated heritage monitoring prototyping, a summary is described below.

According to the most frequent alteration of the Vilnius Old Town's buildings' valuables, a list could be stated:

a) Elements of the roof;
b) Shape of the roof;
c) Cornices;
d) Doors;
e) Gates;
f) The primary height and width of height buildings;
g) The primary housing intensity of site;
h) Windows;
i) Chimneys.

9 picture. *Photo fixation of the facades in Vilnius old town.* Data for segmentation tasks for machine learning. Made by an author.

In order to perform the detection of valuables, we first need to teach the algorithms to identify the desirable valuables from the data – pictures or point cloud. These are semantical segmentation procedures where some already annotated and trained data could be used. However, there are only several such databases, but even these consist of sparse, non-complete, low resolution, and low quantity data.[15] There is even a greater lack of 3D databases with public access.[16] The database semantic3d.com is rather exceptional, with not only 3D annotated data but also some guidance on how to perform calculations with convolutional neural networks that are the best working method for cornering segmentation and other tasks.[17]

15 *The CMP Facade Database* (v. 1.1), *eTRIMS Dataset*, *Ecole Centrale Paris Facades Database*.

16 www.semantic3d.com

17 HACKELA T., SAVINOVB N., LADICKYB L., WEGNERA J.D., SCHINDLERA K., POLLEFEYS, M. Semantic3d.net: a new large-scale point cloud classification benchmark, ISPRS Annals of the Photogrammetry. *Remote Sensing and Spatial Information Sciences*, V. IV-1/W1, 2017.

Picture 10. *Segmentation process using the Labelbox*. Made by the author.

Hence, for performing the digital monitoring processes, a new database was established by the author.[18]

The newly established database consists of collected pictures from the main streets of the Vilnius Old Town (**Picture 9**). For data annotation, Labelbox[19] is used. There are 420 high-resolution photos (approximately 12 megapixels) where the first two classes (valuables) are created: windows and doors. All doors and windows are manually annotated (**Picture 10**) in 420 photos (**Picture 11**). Annotations were performed so that an algorithm could identify the kind of pixels that denote windows as well as what pixels stand for doors. For performing the teaching task, the currently most powerful open data[20] algorithms of Google's Tensorflow were used.

In this case, an XML file is the result of annotation. This means that the annotated information in the c++ language is described according to the standard of Pascal VOC. This standard is one of the most popular and widely used. To sum up, two types of files are exported from Labelbox: XML and JPG. The further process could be described as follows:

1. JPG and XML are converted into RGB. The results are PNG files with segmentation masks – *SegmentationClass*;

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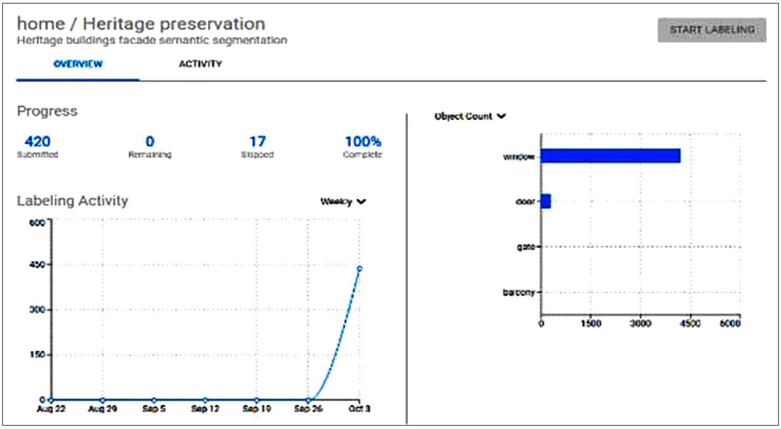
18 „Lietuvos pastatų fasadų rinkinys" (Eng. "Database of Lithuania's Building Facades") (LPFR v. 0.1).

19 www.labelbox.com

20 HALE J. *Deep Learning Framework Power Scores 2018* [interactive]. Link: <https://towardsdatascience.com/deep-learning-framework-power-scores-2018-23607ddf297a> [last accessed 2018-11-10].



11 picture. *Screen from Labelbox. In the left graph, the general number of photos is identified.* The other diagram shows that 282 doors and 4198 windows were manually annotated. Made by the author.

2. Additionally, some PNG raw files with a semantical segmentation object contour are exported – *SegmentationClassRaw*;
3. JPG, PNG files (*SegmentationClass*) and PNG files (*Segmentation-ClassRaw*) are manually separated into two parts: "Train" (for teaching) and "Val" (for validation). The *Train* part is also automatically separated into tech and test parts in order to identify how accurate the teaching results are compared with human manual annotation. Hence, some extra *Train*, *Val* and *Train/Val* index are generated;
4. According to an index of JPEG, PNG, and PNG (Raw) files, we generated files special formats that were required by Tensorflow teaching – *TFRecord* (*Train, Val*, and *TrainVal*);
5. The system is trained using *TFRecord* files.

In order to get the most accurate results, many hyper parameters should be optimized. This process is analyzed in detail by J. Bergstra and Y. Bengi.[21] One of the biggest problems with hyper parameter optimization is *overfitting*. Overfitted data are poor predictors, and machine learning results

21 Plg. BERGSTRA J., BENGIO Y. Random search for hyper-parameter optimization. *The Journal of Machine Learning Research*, Vol. 13, 2012.

are not usable. In the context of heritage monitoring, this would cause that newly presented valuables – windows, for example – could not be identified properly. In order to avoid overfitting, various techniques could be applied. For example, *early stopping* is used to randomly test the prediction results. Once the progress shows that mistakes stopped reducing, all processes are then being stopped. That calculation of the quality of prediction is described as *loss function*. There are various[22] methods on how to calculate the loss function, but in this experiment, a default "cross entropy" is used. The experiment results demonstrated that teaching progress was performed properly because the loss function was (**Table 7**) gradually decreasing and data were not overfitted. However, a powerful computer is needed for finalizing the whole experiment.

7 table. *A fragment of data from the semantical segmentation process*. Global step shows the ratio between the hyper parameter and mistakes. Loss function shows the number of mistakes. Speed shows how fast the values are generated. Made by the author.

INFO:tensorflow. "Global step"	**Loss function**	**Speed (seconds/steps)**
10	0.2524	0.705
20	11.947	0.699
30	45.950	0.705
40	0.5293	0.712
50	0.4267	0.715
60	0.1966	0.711
70	0.2830	0.714
80	0.2486	0.703
90	0.1534	0.717
100	0.6537	0.705
110	0.5362	0.710
120	11.589	0.710
130	37.385	0.700

22 AGRAWAL A. *Loss Functions and Optimization Algorithms. Demystified*, 2017 [interactive]. Link <https://medium.com/data-science-group-iitr/loss-functions-and-optimization-algorithms-demystified-bb92daff331c> [last accessed 2018-12-12].

INFO:tensorflow. "Global step"	Loss function	Speed (seconds/steps)
140	0.7782	0.706
150	0.3307	0.708
160	0.1946	0.703
170	0.4256	0.711
180	0.8429	0.709
190	0.2678	0.709
200	0.3099	0.709
210	0.3719	0.712
220	0.1508	0.707

To sum up, heritage monitoring based on *Lidar*/photogrammetry fixation and data processing using convolutional neural networks demonstrated positive and perspective results.

CONCLUSIONS

1. For analyzing tangible cultural heritage, the proposed conjoint methodology of geometry and color alteration could be used. This methodology is based on a three-dimensional view and spectroscopy technologies and is powered using machine learning data processing possibilities. For the practical implementation, separate color and geometry application techniques are proposed. In this dissertation, such technological implementation is perceived as an innovation. Innovation is perceived in the context of the innovation diffusion theory (E. Rogers). Hence, there are defined criteria and communication process in order for an innovation application to be successful. The application of the described technologies is an interdisciplinary research related to digital humanities.
2. The proposed conjoint methodology, if considered within the framework of E. Rogers's theory of diffusion of innovations, has to reach a higher innovativeness level by impelling early adopters (HSS scientists and specialists in this case) in a certain system. The proposed conjoint methodology should reduce the uncertainty about the implication possibilities of color and geometry in HSS. By referring to Rogers's terminology, in this thesis, the most important part is software – meaning both the proposed general methodology and the dedicated techniques for color and geometry measurements with the first level of interpretation. Techniques are dedicated to the target audience and communicated using the most appropriate channel – a scientific paper (thesis). This should ensure the high level homogeneity of the methodology as an innovation.
3. The color and geometry alteration approach can evaluate the physical features of tangible cultural heritage. Geometry can be captured in a 3D digital environment, and the selected spectral area (UV-VIS-NIR) can measure spectral reflectance values. In both cases, digital values are compared in order to identify tendencies as the first level of interpretation. The development of new knowledge is performed by applying a second level of interpretation by scientists and specialists in accordance with the research question.

4. Conjoint methodology and the techniques therein are tested by two experiments with two different case studies. Selected case were separated, but the conjoint methodology can be applied for the analysis of the same object by color and geometry at once. In this thesis, for the case of geometry, a study of the Vilnius Old Town was selected (problems of poor monitoring). For color techniques, a testing of 20 tomes from the 16^{th}–18^{th} centuries of handwritten books from Supraslė were selected (the authenticity problem).
5. Some findings were done in the case of color alteration. Spectroscopy can be a useful tool for easily and accurately distinguishing very similar (for the naked eye) colors of ink. This means that gall ink, which was used last 2000 years, could be examined more precisely. In the context of the performed experiments, the VIS spectrum part demonstrated best results (~400–~700 nm). Other parts of the spectrum (from about 700 nm) demonstrated a lot of noise information, which was not interpreted due to technological limitations. Other parts of the spectrum can be perspective, but the VIS data were enough to state reliable results. According to the proposed technique, some proposed functions (F1, F2, and F3) demonstrated that it is possible to distinguish which word (F1), page (F2), or whole book (F3) are questioned and which parts of the text can be cases of fraud or inconsistency. The performed Q page analysis (color inconsistency by *de visu* and analysis by spectroscopy) demonstrated that the naked eye, in the absolute number of cases, was not correct. Hence, VIS spectroscopy, in evaluating relative comparisons of the spectrum, can at least be a nondestructive, easy to use, and quick method for the primary inspection of a document (or other object that has color features). A big, systematic collection of data of the spectrum could be a valuable source of information for investigating questioned historical documents and various artefacts.
6. The geometrical analytical tool was created for the effective monitoring of urban architectural tangible heritage. Digital monitoring is based on effective 3D laser scanners and digital photogrammetry. Collected information from different time period measurements

could serve as data for artificial intelligence analysis, which can automatically identify needed valuable elements and its changes during the time period. Such monitoring can be performed in a remote, non-destructive, and cost-effective way. The first level of interpretation is in demonstrating some facts of geometrical change. The second level depends on the particular legal status and local legislation for managing cultural heritage. Artificial intelligence today can perform extremely precise calculations, where convolution neural networks are the best possible choice. Experimental testing with the Vilnius Old Town demonstrated that convolution neural networks perfectly fit the requirements of effective digital monitoring. The best way of collecting data are drones with digital cameras and stabilization or using *Lidar*.

Recommendations and Discussion

Before implementing the proposed methodology, it is necessary to analyze the research object's color and geometry features. The main aspect of using the color and geometry alteration approach is the ability to verify the same object with the same methods in different time periods. Hence, it is necessary to make sure that such a possibility will exist in the future. All tangible objects can be analyzed with the proposed techniques and methodology, but for smaller cultural objects, more precise technologies are needed.

In every case study, a new technique should be created in order to underline how data collection, storage, and interpretation procedures will be done. The interpretation of color and geometry digital information can be and should be performed using artificial intelligence algorithms.

For all analyses, a nondestructive approach should be taken into account. After describing the final goal of the research, the economical part of the analysis should be calculated in order to the choose best technological pipeline. For instance, for small objects like books, archeological findings, or alike, 3D photogrammetry should be used to cut some financial costs of the research. Instead of building a local machine – a computation workstation – internet-based solutions could be used.

The proposed conjoint methodology suggests that both information types (color and geometry) can be used at the same time for the same object. For example, in the case of urban heritage and area monitoring, not only geometry but spectroscopy as well can be applied in order to track the changes of vegetation. In the case of historical book analysis, the 3D technological part could be also applied. Historical books usually have expressive geometrical features, like their covers, size, trimming, etc.

One of the most important motives of this dissertation was the efficiency that can be reached by implementing new technologies. In such a context, it would be important to discuss open data (big data) possibilities in the particular kind of research that requires huge amounts of data. For example, the tourists in daily visiting the Vilnius Old Town, taking a lot of pictures of the various places and buildings. Such information, if made public, could serve as additional data for the monitoring process.

Concerning machine teaching, 3D and 2D semantical segmentation is very different. Therefore, hybrid techniques are recommended: for data classification, 3D data should be used, and for semantical segmentation, 2D high resolution photos should be used. In both cases, deep learning is the best option for operating desirable functionality. Considering the monitoring efficiency factor, for 3D data deep learning procedures, photogrammetrically processed 3D models are not recommended because of the difficulty in acquiring quality results.

Papers Published by the Author

Scientific, reviewed publications:

- ŽIŽIŪNAS T. Išmanusis kultūros paveldas: genius loci ir papildytoji realybė. *Vietos dvasios beieškant*. Vilnius, 2014, p. 156–183;
- LAUŽIKAS R., ŠMIGELSKAS R., KUNCEVIČIUS A., AUGUSTINAVIČIUS R., KURAUSKAS V., ŽILINSKAS E., ŽIŽIŪNAS T. Kultūros paveldo informacijos pusiau automatinis valdymas ir tyrimai naudojant 3D technologijas. *INFORMACIJOS MOKSLAI*, Vilnius, 2017, p. 160–179;
- ŽIŽIŪNAS T. SPEKTROSKOPIJA DOKUMENTINIO PAVELDO AUTENTIŠKUMO TYRIMUOSE: SUPRASLĖS VIENUOLYNO RAŠTINĖS ATVEJIS. *KNYGOTYRA*, t. 70, Vilnius, 2018, p. 193–218.

About the author

Tadas Žižiūnas was born on March 6, 1989, in Panevėžys. In 2012, he graduated from the Faculty of History of Vilnius University with a bachelor's degree in archaeology. In 2014, Tadas graduated from the same faculty with a master's degree in heritage studies. In 2010, he was selected to go to Aarhus University in Denmark for a half-year exchange program. During 2014–2018, Tadas was enrolled in doctoral studies and was lecturing at the Faculty of Communication of Vilnius University. Tadas has been working as a technician in the digitalization laboratory of the Faculty of Communication from 2014. Also starting in the same year, he has been performing various projects regarding the implementation of augmented reality in museums, virtual reality, 3D scanning, 3D photogrammetry, UV-VIS-NIR spectroscopy, and machine learning projects for the HSS sector.

From 2014, Tadas Žižiūnas is a member of the LAD (Lithuanian Archaeologist Association).

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