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Technology, Cultural Heritage and Scientific Diplomacy

*Edited by Sabrina Greco, Maurizio Lazzari
and Jorge Carlos Naranjo Alcaide*



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Contributors

Sabrina Greco, Jorge Carlos Naranjo Alcaide, Katherine Ashley, Maurizio Lazzari, Muna Khamis Khamis Birra Ali, Amin Talha Hassan

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Meet the editors



Sabrina Greco, Ph.D. in “Demography and Economy of Great Geographical Areas”. Her research fields include the relationship between population, environment, and development in Mediterranean countries and Sudan, the analysis of human mobility and development dynamics, and the enhancement of human capital in societies in transition. She also held the position of Principal Investigator for the projects “A new Sudan through culture, technology and innovation” (SudanInnovation, 2020-2021) and “Innovation in society: training paths and human capital enhancement in Sudan” (INSO, 2017-2019). In 2014, as a senior foreign researcher, she won an iPOPs fellowship (Individuals, Populations, Societies) at the “Laboratories of Excellence” of the Institute for Demographic Studies (INED) in Paris, offered by the French Ministry of Higher Education and Research. She has been awarded with research fellowships at “Centre d’Études et de Documentation Économiques, Juridiques et Sociales” (CEDEJ - Khartoum, 2011), INED (Paris, 2013), and has extensive scientific experience in Morocco at Mohammed V - Agdal University.



Maurizio Lazzari holds a Degree in Geological Sciences (1993) and a Ph.D. in Earth Sciences (1999). Since 2001, he has been a Senior Researcher in Physical Geography, Geomorphology, and Applied Geology. He has also served as a Professor of Pedology at the University of Basilicata (Italy) and as a Geoarchaeologist at the University of Salento (Italy). Since 2024, he has served as the Book Series Editor of the Earth Science Series, published by IntechOpen Limited. He is also a member of the Scientific Council of the Department of Human, Social Sciences, and Cultural Heritage of the National Research Council. From 2001 to 2024, his research activity has focused on studying natural and anthropic risk factors aimed at safeguarding and conserving the historical and monumental heritage of the Mediterranean area, including the examination of morpho-evolutionary processes in valley floors, reservoirs, and inland Apennine mountainous areas. From 2004 to 2025, he served as the responsible and scientific coordinator of national research projects related to landslides and trigger factors, natural and anthropogenic risks, geological and geomorphological cartography, the preservation of historical and archaeological sites in Southern Italy, the enhancement of degraded areas, and the geotouristic use and protection of the landscape. He is the author of 180 scientific publications in national and international journals, monographs, book chapters, and conference proceedings, covering applied geology, geomorphology, dynamics of artificial reservoirs, soil erosion, climatology, pedology, geoarchaeology, hydrogeological instability, natural hazards, monitoring, cultural landscapes, UNESCO heritage, and geotourism.



Jorge Carlos Naranjo Alcaide was born in Madrid (Spain) in 1974. He is a Comboni Missionary who has worked in Sudan since 2008. He has been the Principal of CCST since 2012. He holds a Ph.D. in Total Quality Management from the Sudan University of Science and Technology, Deanship of Quality and Development, and a Master's Degree in Direction and Quality Management of Educational Centres. He is one of the founders of C-Hub Limited Company, an incubator that supports the creation of digital start-ups by Sudanese and refugee young people in Sudan, as well as the national committee of ICOMOS Sudan.

Meet the authors



Dr. Kate Ashley is an Architect and holds a Doctorate in Engineering with a focus on heritage conservation. Kate's experience has combined architectural practice with heritage consultancy, including work for national and local governments, developers, donor-funded projects, UNESCO, ICCROM, King's College London, and the British Council. Since beginning her doctorate research, "A Stakeholders' Protocol for the Conservation of the Built Heritage of Suakin" in 2010, Kate has had a significant focus on the cultural heritage of the Red Sea of Sudan and the Arabian Peninsula. She has ongoing involvement with projects in Sudan and throughout the MENA region, including projects for several World Heritage Sites. With a special interest in community engagement and digital tools for cultural heritage, Kate is currently working on several publications in this field. Kate's recent work scope includes serving as Project Manager for the Sudan Memory digital archiving project and Heritage Consultant for Red Sea Global, with a focus on the restoration of the historic pilgrimage port town of Al Wajh on Saudi Arabia's northern Red Sea coast.



Amin Talha Hassan is a dedicated lecturer and researcher specializing in Geoinformatics and Photogrammetry. His research focuses on utilizing photogrammetry techniques to document and preserve cultural heritage sites. With a Master of Science in Computer Sciences and an MBA, Dr. Hassan has a strong foundation in both technical and business aspects of his field. Currently pursuing a Ph.D. in Computer Sciences with a specialization in Geoinformatics, he continues to expand his knowledge and expertise. Dr. Amin's research has been recognized internationally, with a published paper in the prestigious International Journal of Applied Sciences. His work on integrating laser scanning and photogrammetry for 3D/4D cultural heritage preservation demonstrates his commitment to advancing the field.



Muna Ali is a Ph.D. student with over 17 years of experience as an instructor in the fields of Computer Science and Information Technology. She is also the head of the Computer Science and Information Technology Department at Comboni College for Computer Science and Technology (Sudan). She was awarded an Award granted by the International Society of Photogrammetry and Remote Sensing (ISPRS) with Integrated Geospatial Innovations, IGI Ambassador Award of Africa in 2015, which allowed her to work for some weeks in the Institute of Photogrammetry of the University of Stuttgart. She has supervised different projects related to photogrammetry and has specialized in machine learning and satellite image processing.

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Preface

As I write this introduction, Sudan is experiencing one of the most challenging periods in its history. A devastating civil war started on April 15, 2023, freezing the fragile path towards democracy, destroying the main cities, the collapse of the public infrastructures, the industrial system, and, most importantly, the loss of a whole generation with a catastrophic humanitarian crisis that the country has never experienced before. Thousands of Sudanese have lost their lives, and millions have been displaced in the region, abandoning their homes and their loved ones.

In such unfortunate circumstances, it is even more important to further promote and support initiatives aimed at preserving Sudan's cultural heritage and richness. The Italian Embassy in Khartoum has consistently done its utmost in this field, and we firmly believe it is still, and even more so, needed now. Younger generations will soon take over the lead, shaping a brighter future for the country by bringing peace through development and culture, and achieving results where politics and diplomacy have not succeeded. We have therefore never stopped co-financing our partners, such as the Comboni College of Science and Technology in Khartoum (now active from Port Sudan), one of our long-standing key players in supporting us in spreading Italian culture and language in Sudanese society, and also a main actor in cultivating innovative minds.

This book stems from this fascinating path, and with the joint effort of various bodies, we are now able to present the main outcomes of the brilliant works done by the students of the SudanInnovation project. The practical applications showcased in the work, such as virtual reality reconstructions, are fascinating examples of how modern technology can bring historical sites back to new life. This project provides innovative solutions to the challenges of heritage conservation in areas affected by war and climate change, ensuring that cultural treasures are preserved for future generations. Moreover, it demonstrates how interdisciplinary efforts and international partnerships can create meaningful impacts, transforming challenges into opportunities for growth and preservation.

The book presents a compelling exploration of how cutting-edge digital technologies can play a pivotal role in preserving and revitalizing cultural heritage, particularly in conflict-ridden regions, such as Sudan. What stands out to me is the innovative approach taken by the project, which not only bridges the gap between technology and cultural preservation but also empowers international scientific cooperation. I therefore believe the book can soon be seen as a significant example of science diplomacy, where the art of bringing together different cultures successfully turns into a tool to foster science, technology, and innovation.

The Sudanese civil society is aware of the power of science and culture in triggering complex transformations for tomorrow's wellbeing. In this regard, Italy is always ready to do its part. Also within the framework of our government's new vision for

Africa (the so-called “Piano Mattei”), we are keen on enhancing new partnerships with the academic and research world. I am therefore sure that through the success of the SudanInnovation project certified by this book, this work can become a model and a best practice for a better scientific cooperation between Italy and Africa, where different synergies come together for a common goal: empowering local young people as agents of sustainable and inclusive development, key ingredients for a peaceful future.

In conclusion, I want to thank, also on behalf of the Italian Government, the contributing institutions, and amongst them notably Dr. Sabrina Greco and Dr. Maurizio Lazzari from the Cultural Heritage Science Institute of the Italian National Research Council – CNR, together with Fr. Jorge Naranjo from the Comboni College of Science and Technology - CCST in Khartoum. Their sincere efforts in this work give hope for maintaining cultural cooperation in the country, which represents, even in the darkest times, the historical core of the Italy-Sudan friendship throughout the years.

Michele Tommasi
The Ambassador of Italy to Sudan,
Addis Ababa
24/06/2024

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The volume “Technology, Cultural Heritage and Scientific Diplomacy” is published with the financial contribution of the Italian Embassy to Sudan (currently in Addis Ababa). Therefore, we extend our heartfelt thanks to the Italian Ministry of Foreign Affairs and International Cooperation, and particularly to H.E. Michele Tommasi, Ambassador of Italy to Sudan, and Mr. Luca Rapone, Deputy Head of Mission, for their direct involvement.

The aforementioned volume originates from the project “A new Sudan through culture, technology and innovation” (SudanInnovation), also sponsored by the Italian Embassy to Sudan. This scientific diplomacy project is part of the programme “Integrated promotion and relaunch of the country system” of the Italian Ministry of Foreign Affairs and International Cooperation.

The facilitators of the various training sessions have played a crucial role in determining the success of the SudanInnovation project. First, we would like to sincerely thank the 20 lecturers, including:

- a) 17 researchers, technologists and technicians of the Italian National Research Council – Institute of Heritage Science (CNR-ISPC): Alberto Bucciero, David Buti, Claudia Caliri, Gianluca Cantoro, Maria Danese, Fiorella De Luca, Immacolata Ditaranto, Ivan Ferrari, Francesco Giuri, Sabrina Greco, Maurizio Lazzari, Donata Magrini, Nicola Masini, Pasquale Merola, Ilaria Miccoli, Emilia Vasanelli, and Giuseppe Scardozzi;
- b) 3 international experts: Nour Al-Din Al-Regeig, Chairperson of the Commission for Cultural Heritage of the African Union of Architects; Hatim Al-Nour, Director of Sudan’s Antiquities and Museums Authority; and Katherine Ashley, British Council and King’s College of London.

Furthermore, we would like to thank the Authorities and Representatives who participated in the inauguration of the SudanInnovation project:

Prof. Intisaar Saghayrun, Minister of Higher Education and Archaeologist; Dr. Faisal Mohamed Salih, Minister of Culture and Information; Dr. Pavel Kroupkin, Director of the UNESCO-Khartoum Office; Dr. Hatim El Nour, Director of Sudan’s Antiquities and Museums Authority; Arch. Nour Al-Din Regeig, Chairperson of the Commission for Cultural Heritage of the African Union of Architects.

We also thank the following Italian Authorities and Representatives:

H.E. Gianluigi Vassallo, former Ambassador of Italy to Sudan, Dr. Costanza Miliani, Director of the Institute of Heritage Science - National Research Council of Italy,

and Dr. Vincenzo Racalbuto, former Director of Italian Agency for Development Cooperation -AICS.

The SudanInnovation project has been made possible thanks to the commitment of the following students from the BSc in Computer Science at CCST, who benefited from the training. Most of them transformed the received information into different graduation projects: Khamis Issa Ismail Said, Linda Fardinato Santo Salvano, Mona Mohamed Hussein Abdalla, FathElrhman Mohamed Ahmed, Idris Abdelrahman Adam Mohamed, Mubarak Eltahir Ahmed Mohamed, Bethlehem Tesfahun Tebeje Kassa, Sarah Molaley Gadamu Dimise, Omer Ibrahim Hamid Osman, Mohammed Mohieldin Mohammed Almaki, Sweet Yohannes Teklay Habtemariam, Sami Hamid Faki Fadlallah, Sara Gabriel Ombela Kuku, Petros Haile Ghebremedhin, and Mahasin Omer Komi Hassan.

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In the end, we also thank the IT Director of CCST, Wisdom Asungaga Fatur, who facilitated the necessary logistics for the project's development, including collaboration with facilitators in Italy and London, as well as students in Khartoum.

The Editors

Foreword

I am delighted to have the opportunity to contribute a foreword to the volume “Technology, Cultural Heritage and Scientific Diplomacy”, promoted by the Italian National Research Council – Cultural Heritage Science Institute, together with the Comboni College of Science and Technology in Khartoum.

The SudanInnovation project builds on the success of the initiative by the same name that the aforementioned institutions carried out in the first half of 2021, with the support of the Embassy of Italy to Sudan, within the framework of the integrated promotion program of the Italian Ministry of Foreign Affairs and International Cooperation. This approach aims to devise joint endeavors that bring together our leading cultural institutions, as well as agencies and businesses at the forefront of innovation, to promote them in an integrated fashion.

Furthermore, we must not overlook that the initiative discussed in the book occurred in early 2021, against the backdrop of the COVID-19 pandemic and its impact on Sudan. Among other things, this phase highlighted to everyone involved the need to rethink the way cultural heritage is managed and how training in this area is delivered.

The project has indeed met this challenge through a methodology that involved:

- a) a considerable use of technology not just as part of the substance of the teaching but as a way of giving the courses despite the limitations of the circumstances of the time;
- b) the active involvement not just of the teachers, but of the students too, who gave the program the benefit of their experience and contributed to making its content relevant to the Sudanese context.

In my view, this experience has therefore been a very successful one: it enhanced cooperation between the Italian top research institute and a Sudanese institution prominent in the field of higher education; it strengthened the interaction between trainers and students, laying the foundations for future common endeavors; it helped promote the use of the latest technology in cultural management.

The importance of such efforts cannot be overstated in a country like Sudan, where, as in Italy, culture is a defining factor of a thousand-year-old national identity and may become an engine of economic growth for the communities to which this vast heritage belongs.

I would like to thank the contributing institutions, notably Dr. Sabrina Greco of CNR and Fr. Jorge Naranjo for CCST, as well as the Sudanese National Corporation for

Antiquities and Museums (NCAM), for their commitment to this project. I hope it will be the first of many initiatives of its kind in an area - cultural cooperation - which lies at the heart of the partnership between Italy and Sudan.

Gianluigi Vassallo
The Past Ambassador of Italy to Sudan,
Khartoum
28/06/2022

Chapter 1

A Symmetric Experience of Bilateral Cooperation through Culture, Technology, and Innovation

Sabrina Greco and Jorge Carlos Naranjo Alcaide

Abstract

This chapter describes the objectives, beneficiaries, the partnership and a short assessment of the project 'A new Sudan through culture, technology and innovation' (SudanInnovation) conducted in 2021 by the National Research Council of Italy—Institute of Heritage Science with students and teaching staff of the Comboni College of Science and Technology in Khartoum (Sudan). The project consisted of online workshops on new digital technologies applied to the cultural heritage sector and represents a model of international scientific collaboration, as it enabled the learners to apply digital technologies to their own cultural heritage for its knowledge, conservation and transformation into an engine of sustainable development for the territory. With the passing of time and the outbreak of the war in Sudan, the project acquired particular relevance for other similar contexts.

Keywords: cultural heritage, computer sciences, scientific cooperation, sustainable development, Sudan

1. Introduction

Sudan is a country that has shown more than others to be a mosaic of different civilisations that have left traces of a unique cultural, historical and architectural heritage in Africa [1]. The country has been the centre of a plurality of civilisations and played a paramount role in the diffusion of cultural, religious and linguistic currents in different directions, like the Mediterranean basin: Central Africa, West-East Africa, the Middle East-Central Africa and North-Central Africa. The intensity of migratory flows and commercial and cultural relations makes it a strategic location and gateway to the rest of Africa.

It is known that the sustainable development of Sudan is necessarily achieved through the valorisation of human resources, specifically the acquisition of inter-sectoral and interdisciplinary skills for the knowledge, protection and valorisation of cultural heritage, which was strategic in the transition phase of the country before the war and will be even more so in the post-war scenario.

The implementation of this path certainly requires scientific projects of exceptional openness. In this regard, the cooperation with Italy has proved indispensable. In fact, starting from the middle of the last century, Italy put in place a particular strategy of Mediterranean relations based on egalitarian economic cooperation with Arab countries and inspired by peacebuilding. At the same time, the National Research Council of Italy (CNR in its Italian acronym), with its numerous research projects and science diplomacy activity on strategic themes, favours the development of an effective model of Italy-Africa scientific collaboration [2].

This model aims primarily to create endogenous development mechanisms based on the search for means of massive job creation and improvement of the living conditions of local populations, which is possible when a primary human right is respected, the right to peace, as Norberto Bobbio used to defend [3].

This book is the output of the project ‘A new Sudan through culture, technology and innovation’ (SudanInnovation) conducted in 2021 by the CNR—Institute of Heritage Science (ISPC in its Italian acronym) in collaboration with Comboni College of Science and Technology in Khartoum (CCST), a Sudanese university college, and consisted of online workshops on new digital technologies applied to the cultural heritage sector [4].

The book has its own intrinsic originality for the specific applications created by Sudanese university students at the conclusion of the advanced training course provided by the project.

The objective of the project fits the framework described earlier as it enabled the Sudanese beneficiaries to apply digital technologies to their own cultural heritage for its knowledge, conservation and transformation into an engine of sustainable development for the territory.

The Italian Embassy in Khartoum sponsored this scientific diplomacy project as part of the ‘Integrated promotion and re-launch of the country system’, funded by the Ministry of Foreign Affairs and International Cooperation (Italy). These activities of scientific diplomacy express a symmetric model of bilateral cooperation that raises the dignity of the non-Italian party, as they enable it to build an inclusive construct of identity, in this case through the Italian expertise in cultural heritage sciences.

This action of scientific diplomacy, as a powerful vector for the development of international relations, networking and the circulation of open-access knowledge, is even more crucial in particularly difficult territorial areas, such as the case of Sudan. In fact, the times elapsed between the end of the SudanInnovation project and the publication of this volume were long because the authors were observing over the course of this 5-year period and, albeit in different ways, the advance of political and economic instability, the background of the crisis, the evolution of hostilities and multiple external interferences, up to the breakout of the war on 15 April 2023. This conflict, in spite of the complexities of the period, was unimaginable at the time of the project execution.

The richness of the Sudanese cultural heritage in the Sub-Saharan context goes along with the poverty of the resources dedicated to its preservation and the fragility of many collections due to extreme weather conditions, lack of appropriate storage or neglect (**Figure 1**). This contrast has pushed some foreign cultural institutes to collaborate with the local authorities in different digitisation projects dedicated to conserving and promoting Sudanese cultural and documentary heritage.

Two of the most relevant projects in the field of applications of technology to the Sudanese cultural heritage were launched in 2022, i.e., 1 year after the SudanInnovation project, which is a sign of the relevance of the initiative.



Figure 1.
One of the authors, Jorge Carlos Naranjo Alcaide, enters the remains of the Meroitic city of Musawarat.

The first of them, ‘Sudan Memory’ [5], also included capacity building, in this case in the fields of scanning, data description and data management. This project was funded by the British Council Cultural Protection Fund and the Aliph Foundation. King’s College was the project lead. The National Records Office (NRO) and the Sudanese Association for Archiving Knowledge (SUDAAK) were the major national partners.

The second one was ‘Turath’ [6], funded by the European Union delegation to Sudan and led by the Regional French Institute of Sudan in collaboration with the French Archaeological Mission, Sudan Antiquities Service (SFDAS in its French acronym), the National Corporation for Antiquities and Museums (NCAM) and Alsoug.com. The project was launched in June 2022 and aimed to promote the archaeological and historical heritage of Sudan to the Sudanese and the international general public. This dissemination project was targeting mainly the youth from 15 to 20 years old as future actors of the awareness of the community on their cultural heritage and main contributors to the development of historical knowledge in Sudan.

The core outcome of this project is a dynamic QR code-based web application developed and hosted by Alsoug.com, accessible via phone, tablet and computer. Al-soug is a Sudanese company that has created a digital platform for buying and selling any kind of goods, including cars, electronics or household items.

2. SudanInnovation partnership

The CNR-ISPC is an interdisciplinary institute of the CNR whose mission is to pursue scientific excellence and encourage innovation in the understanding,

conservation and enhancement of cultural heritage through collaborative research involving humanities, experimental sciences and technological applications [7].

With over 300 researchers, technologists and technicians from various disciplines, the ISPC is the hub of the CNR for research, innovation, training and technology transfer of the cultural heritage strategic area.

The CCST is a university college founded in Khartoum (Sudan) in 2001 with long-standing programmes in the fields of computer science and information technology [8]. On the one hand, their lack of expertise in academic programmes explicitly related to cultural heritage could be understood as an obstacle to a fruitful collaboration between both institutions. On the other hand, the experience shows that in developing countries, most university students may not have touched a computer before reaching tertiary education [9]. Therefore, the best-equipped students, lecturers or scholars for a kind of collaboration that involves online teaching and the advanced application of technology are those specialised in the above-mentioned fields (**Figure 2**).

In the same line, the research by Negla Ahmed Albasheer Osman on the level of acceptance and use of technology by lecturers at public universities in Khartoum revealed that one of the factors hindering a more widespread use is 'the preponderance of English content on the internet' [10]. This is why, along with the technological skills, a training programme of the characteristics of the one provided by this project should also consider the level of English of Sudanese students and lecturers [4].

These principles have already been experienced on the occasion of the project 'Innovation in society: training paths and human capital enhancement in Sudan' (INSO) funded by the Italian Ministry of Interior, Department for Civil Liberties and Immigration-International Relations Unit. In that project that took place



Figure 2.
CCST students dressing in their respective traditional clothes during a cultural week.

between 2017 and 2019, another institute of the National Research Council of Italy, the Institute for Research on Innovation and Services for Development (IRISS in its Italian acronym), and CCST also worked together [11].

3. Project beneficiaries

The SudanInnovation project was open to 30 students of the Bachelor of Science in Computer Science, with priority to finalists who were supposed to prepare their graduation project in 2021 and with a good level of the English language (15 from CCST and 15 from other Sudanese public or private universities selected in collaboration with the Ministry of Higher Education and Scientific Research of the Republic of Sudan (MOHE)).

Similarly, the invited lecturers were supposed to come from the Departments of Computer Science (CS) of CCST and other Sudanese universities. These lecturers were meant to be potential supervisors of the above-mentioned graduation projects.

Nonetheless, at the end, the participants were nine finalists of the 4-year Bachelor of Science in Computer Science and seven third-year students and therefore semi-finalists. As for teaching staff participation, the programme involved two PhD holders in computer science, one from CCST and one from the Sudan University of Science and Technology; one assistant professor of the physics department of CCST; four MSc holders in computer science from the CS department of CCST; one MSc in computer science from the CS department of the University of Khartoum and two assistant teachers from the CS department of the CCST (**Figure 3**).



Figure 3.
CCST students visiting the Meroitic cemetery of Al-Begrawiya.

The SudanInnovation project was inaugurated on 25 January 2021, under the scientific coordination of Dr. Sabrina Greco. The other author of this chapter, Dr. Jorge Carlos Naranjo Alcaide, was the local coordinator in Khartoum. The latter one is now in Port Sudan, where the college had to resettle as a consequence of the war in progress.

The advanced training course consisted of a series of webinars that were conducted from 25 January to 4 February 2021, which was a period of time immediately before the beginning of the academic year and therefore when final-year students were supposed to choose the theme of their graduation project.

4. Project assessment, outputs and relevance

Both lecturers and students were invited to assess the learning contents through the compilation of a questionnaire designed to summarise each training session with a score ranking from 1 to 5.

It is worth mentioning that the students rated in the first place the lectures more related to cultural heritage than to technological aspects, even if these ones were more closely related to their field of studies, computer science. In fact, they especially appreciated topics like ‘Suakin as model of transformation of cultural heritage into engine of sustainable development’, ‘Africa World Heritage Sites: risks and challenges for their conservation’ and ‘Societies in transition and sustainable development’.

Those lessons served as a theoretical framework and as a preparation to introduce later the more technical sessions and to create awareness about the importance of cultural heritage.

As for the teaching staff, their preferences were more related to their academic field and rated in the first place the lesson of ‘Introduction to Geographical Information System (GIS) for Cultural Heritage’ and the one entitled: ‘Polychromy in ancient sculpture and architecture. Study, visualization and virtual reconstruction’. These lecturers, in more informal feedback, identified the GIS sessions as the most applicable for the students’ graduation projects.

As a result of the training, 12 students in 2021 and three in 2022 applied the learnt contents to their respective graduation projects and produced the digital applications that will be described in chapters 4 and 5 of this book (**Figures 4** and **5**). The College also received a request from UNESCO to produce digital applications that may expose Sudanese children to their own cultural heritage or guide them during the visit to the National Museum.

In March 2023, ICOMOS International approved the creation of the national committee of Sudan. One month later, the war broke out in the country and threatened part of the Sudanese cultural heritage. The old building of the Republican Palace, built in 1830; the Catholic Cathedral in the first third of the twentieth century in Khartoum and the minaret of Sultan Ali Dinar Mosque in El Fasher were damaged. The Mudirya (old governorate) of El Obeid was completely destroyed. The Tangasi Tumulus field in Merowe received impacts from artillery.

Using high-resolution satellite imagery, Cultural Heritage Monitoring Lab (CHML) analysts identified damage to two structures on the National Museum’s campus in Khartoum: a structure containing the ancient Egyptian Temple of Buhen built by Queen Hatshepsut around 1460 BC and another structure containing a section of wall from the ancient Egyptian Temple of Aksha built by Ramesses II around 1250 BC [12]. On 19 May 2023, the same analysts identified significant damage to the Natural History Museum’s main building.



Figure 4.
Student Idris Abdelrahman collecting data at the Museum of Kerma for his graduation project.



Figure 5.
First training session in the Conference Hall of Comboni College of Science and Technology on 26 January 2021.

The list of damaged monuments will increase with the passing of time. Surely, once the situation allows observers to access the areas that became battlefields, new damaged cultural heritage will be identified.

This conflict, which started a few months after the training was completed, is a good example of the importance of, for instance, virtual reconstructions of monuments before being damaged, so that in times of stability, cultural heritage may become an engine of sustainable development. Moreover, as a powerful vector for the development of international relations, the creation of networks and the circulation of open-access knowledge, scientific diplomacy facilitates to jointly address the multiple crises that arise in Sudan, the serious humanitarian crisis first of all, but also the identity crisis, which is at the foundation of peace.

In this new context, the contents of this volume acquire a particular importance as they describe an international cooperation, transfer of knowledge and scientific diplomacy project which can be of reference for other initiatives with low-developing countries and offer clues for the building of a sustainable peace for Sudan.

After more than 2 years since the outbreak of the conflict between the Sudanese Armed Forces (SAF) and the Rapid Support Forces (RSF), peace looks far away (**Figure 5**).

Author details

Sabrina Greco^{1*} and Jorge Carlos Naranjo Alcaide²

1 National Research Council of Italy, Institute of Heritage Science, Lecce, Italy

2 Comboni College of Science and Technology, Port Sudan, Sudan

*Address all correspondence to: sabrina.greco@cnr.it

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References

- [1] Rilley C. Introduction. In: Cabon O, editor. *Histoire et Civilisation du Soudan: De la Préhistoire à nos Jours*. Paris: Africae; 2017. pp. 26-31
- [2] Consiglio Nazionale delle Ricerche. *Mediterraneo. Ricerca e Diplomazia Scientifica*. Roma: CNR edizioni; 2020
- [3] Bobbio N. *Il Problema della guerra e le vie della pace*. Bologna: Il Mulino; 2009
- [4] Naranjo Alcaide JC, Greco S. Online education, international cooperation and sustainable development in Sudan. *Social Education Research*. 2023;4(2):209-226
- [5] Sudan Memory. 2022. Available from: <https://www.sudanmemory.org/> [Accessed: 4 August 2024]
- [6] Turath Connects. 2022. Available from: <https://turath.alsoug.com/> [Accessed: 4 August 2024]
- [7] Istituto di Scienze del Patrimonio Culturale—Consiglio Nazionale delle Ricerche. Available from: <https://www.ispc.cnr.it/en/> [Accessed: 4 August 2024]
- [8] Comboni College of Science and Technology. Available from: <https://www.combonikhartoum.com/> [Accessed: 4 August 2024]
- [9] Naranjo J, Molineri I. La sfida della didattica a distanza in una università sudanese: La valutazione degli studenti e i risultati nei corsi di lingua italiana. *Italiano LinguaDue*. 2021;13(2):748-767
- [10] Ahmed Albasheer Osman N. The Acceptance and use of information and communication technologies by staff members in Khartoum State's universities (Sudan) [PhD thesis]. Dresden: Dresden University of Technology; 2014
- [11] Naranjo Alcaide JC, Greco S, Meyer J-B, Abdalla S. Youth, training and labor insertion in Sudan: Lessons from the INSo project. *Journal of Comparative and International Higher Education*. 2023;15(1):45-60
- [12] Gunter-Bassett M, Bassett HF, Hanson K, Welsh W, Fitzgerald K, Maher A, et al. Cultural Heritage Monitoring Lab Rapid Report: Damage to the Sudan National Museum (18 May 2023). Martinsville, College Park, Penn, Washington D.C.: Virginia Museum of Natural History, Cultural Heritage Monitoring Lab; University of Maryland, Center for International Development and Conflict Management; Penn Museum, Penn Cultural Heritage Center; and Smithsonian Institution, Smithsonian Cultural Rescue Initiative; 2023. DOI: 10.25573/data.22963304

Chapter 2

Sustainable Development and Cultural Heritage in Sudan

Katherine Ashley and Sabrina Greco

Abstract

The chapter analyzes the relation between sustainable development and cultural heritage in a least developed country in transition and applies this analysis to a concrete case, the city of Suakin in Sudan. New digital technologies for recording, documentation, and modeling have immense potential as tools for understanding cultural heritage assets and their values, for evaluating the impacts of risks and other changes, and for enabling cultural heritage as a resource for sustainable development. As part of the Sudan Memory digitization project, a 3D model was developed of Suakin's historic port town, providing an interactive portal for users to engage with Suakin as it was in 1900 CE. Using the Goobi open-source database software application, access is provided via this portal to a wealth of archival resources that document the site throughout its history. Using such digital methods to enable awareness and engage audiences at local and wider levels, and to establish common goals, is invaluable to a site's safeguarding. Furthermore, such approaches and methods are increasingly recognized as tools for planning, conservation, and sustainable development, providing a potential base for future restoration and reconstruction and allowing further interventions that might be integrated to be evaluated accordingly.

Keywords: sustainable development, cultural heritage, digital, tools, awareness, safeguarding, impact

1. Introduction

For many years, Sudan has represented an area of strong territorial mobility of populations where Arab and African cultures have intertwined in a completely original way. On the internal and international front, the country has a strategic role considering jointly its geographical position as an interface between Africa and the Middle East; its oil resources, at least until the independence of South Sudan; and gold extraction, which has fueled trade in the Mediterranean basin since ancient times. Sudan has thus long been a cultural crossroads, connecting trade, religion and pilgrimage, and political links and around which an incredibly rich and unique cultural heritage has evolved. At the same time, it is particularly vulnerable due to the coexistence of extreme poverty, several food crises, and recurrent droughts. Yet above all, multiple high-intensity conflicts have transformed the country into the scenario of the largest humanitarian crisis underway in the world today. Further to the humanitarian impact, this has devastated cultural heritage sites and collections across

the country, as well as the living heritage of Sudan's people through weakening peace and cultural ties, targeted attacks on cultural groups, customs and activities, and the impact on daily life and livelihood.

All of them, and particularly the last war started on April 15, 2023, between the Sudan Armed Forces (SAF) and the Rapid Support Forces (RSF), triggered in the capital and subsequently spread, until now, in the regions of Darfur, Al-Jazeera, Kordofan, and Sennar, have caused the displacement of millions of persons.

According to recent estimates, the conflict that began in April 2023 and the previous ones, starting from 2003, have contributed to Sudan now having the largest population of internally displaced people in the world, almost 11.1 million people [1].

Sudan was in a transitional stage even though slow toward democracy, but the last war has hampered the process, eliminated any sustainable development gain, and caused the destruction of its cultural heritage. In such a context, innovation in society through the development of human capital and a human-centered understanding of development are crucial. This will just be possible through interventions that ensure inclusive and equitable quality education, promote lifelong learning opportunities for all, enable upward socioeconomic mobility, promote gender equality, instill the value of tolerance, and build peace. In a country where diplomatic activities in general have failed to bring such development, scientific diplomacy instead has proved to empower local young people to become agents of sustainable development.

This contribution outlines the relationship between sustainable development and cultural heritage through the lifelong learning of university students in Sudan, which in crisis, emergency, or post-crisis contexts is a tool recognized by the UN as essential to meet social and build peace.

2. Sudan in collapse: The vortex of conflicts

As in Dante's Divine Comedy, at the gate of Hell we read: "Abandon all hope you who enter." In fact, within the complex political history of Sudan, its population overlaps with the vicissitudes of the territory, and the recent conflict should not be considered an isolated event. On the contrary, it is part of a national trajectory full of conflicts that reflect numerous internal political contradictions, the Darfur crisis (theater of violation of human rights) and where even the borders that divide Sudan from neighboring countries do not correspond nor to ethnic divisions, nor to spatial divisions, but are completely artificial, and sometimes functional, as in the rest of Africa [2–4].

As is well known, the "porous" border with Libya was strategic for migratory flows, as Sudan is not only a country of origin and destination but also a transit area for migrants from sub-Saharan Africa and a hub of the route northeast toward Europe [5].

In recent decades, there has been a further increase in armed conflicts and continuous economic crises following the recession of the country after the independence of South Sudan in 2011. The decline in economic indicators, together with particular structural handicaps, has made the territory extremely fragile to the impact of unfavorable external circumstances.

Like other countries in the region, albeit with different times and methods, Sudan has also witnessed frequent economic and sociopolitical instability since its independence in 1956, highlighted by cycles of military coups, popular revolutions, and unstable transition governments, which have reopened the way to new coups d'état.

Between 2018 and 2019, the Sudanese population protested against the government, resulting in April 2019, after numerous demonstrations, the fall of the regime of Omar al-Bashir who had been at the head for about 30 years [6–8].

Once again, when the curtain rises on the democratic transition, the troubled contemporary history of Sudan invites us to peer backstage: the Sudanese population was asking for dignity, freedom, and justice.

In the aftermath, a democratic transition regime took shape, which brought together military and civilians and raised great national and international hopes. These ones, however, were completely dashed with the military coup of October 2021 where the Sudanese political institutions were dissolved, many civilian leaders arrested, and access to the internet and the media was interrupted [9].

Despite this complex history, summarized here, upon closer inspection there remains the “devastating imprint” of the sociopolitical transformations that have followed, the contours of which, however, are mostly to be studied in their many facets.

First of all, the ongoing war has relaunched the spiral of ethnic tensions; it has also damaged some UNESCO world heritage sites and universities, and museums, artifacts, and other cultural collections have been looted and destroyed across the country.

In a multi-ethnic mosaic agitated by conflicts between the different cultural, religious, and economic components that constitute it, “l’éducation est la clé majeure du processus de marginalization dans le Soudan contemporain” [10].

In such a scenario, the transition in Khartoum seems quite arduous, since what is described as an internal crisis actually goes beyond the Sudanese borders, in spite of the coldness of the Western world and the disinterest of international diplomacy.

3. The “specificity of Sudan”: From human mobility to multifaceted identity

If there was a common thread that linked all the cultural diversities of Sudan, unfortunately, that common thread was broken, overwhelmed by the 2023 conflict, marking the beginning of a double post-authoritarian and post-conflict transition.

The case of Sudan is of indisputable interest as it is an expression of cultural diversity.

A pivotal country between the Arab and African worlds has been a carrefour des civilizations, that is, not just one civilization, but a series of overlapping civilizations that have left traces of a unique cultural and historical-architectural heritage.

Khartoum State is made up of three different urban areas, which represent the colonial origin (the capital Khartoum), the indigenous insurrection of the Mahdia (Omdurman), and the industrial development of the Anglo-Egyptian condominium (Khartoum-North). Urban growth has accelerated sharply with the influx of immigrants from rural areas of central Sudan. Specifically, the issue of immigration in Sudan was at the center of a mechanism that, going beyond the traditional framework (country receiving migratory flows from neighboring countries), was essentially attributable to that of having a strategic role for national and international balances [11].

The “specificity of Sudan” is the result of a historical sedimentation of geographical and cultural factors. Before the 2023 conflict, Omdurman’s Libya souq was an important market, an economic crossroads that supplied the capital with goods. It was also a place where new identities were forged through the interaction between migrants and trade. If you walked down any of the main streets in Khartoum, you

would find Chinese products on the roadsides. There was a general awareness of China's preference for importing cheap labor and products at the expense of local labor. As previously mentioned, the progressive modification of immigration in Sudan has been characterized by a growing geographical distance between Sudan and the immigrants' countries of origin and by the absence of historical-cultural relationships between immigrants and the Sudanese population. In addition to the aforementioned incoming flows, for several years Sudan had been a territory of origin and transit of huge migratory movements directed toward Europe. Diplomacy together with foreign policy implemented the so-called Khartoum Process in 2014, which seemed to be a sort of agreement to support the policies of autocratic regimes in open violation of human rights.

These regimes try to impose a certain identity construct to legitimize their position of power. It seems essential to recall Paulo Freire's thoughts on the link between political-social oppression and education to understand the internal Sudanese identity dynamics and the need to make the oppressed aware of their condition and reach awareness. The human person must become aware, and this awareness must lead him to make others, and in particular oppressors, understand that the process of non-recognition of the other, in which they have been mired for years, has as its objective the enslavement of the other [12].

The question of identity has been at the center of the numerous problems of post-colonial politics. In fact, ethnic, religious, and linguistic identity has characterized the country. As Nouredine Satti underlines: [...] the elites of the central power and those of the so-called marginalized regions argued, without arriving at a consensual formula for the political and socio-economic governance of the country [13].

Currently, Sudan is faced with the opportunity to build a "New Sudan" according to the ideological influence of John Garang, founder of the Sudan People's Liberation, where the national identity is inclusive, not linked to Arab or Islamic religious currents and without the exclusion of the populations of the periphery.

4. Sustainable development and enhancement of human capital: Scientific cooperation

The terms of the long debate on the interdependence between population and development have been repeatedly addressed in United Nations speeches, taking on different facets. In particular, the 1994 International Conference on Population and Development, the third 10-year conference of the United Nations, had taken up the emphatic diction "that the necessary basis for the solution of population problems lies in socio-economic transformation." Furthermore, the participants recognized the improvement of the quality of life of individuals as a priority objective in a decisive moment in the history of international cooperation. The participants had recognized the right to development as a fundamental, universal, and inalienable right. Concretely, the international community has agreed on the objective of improving the quality of life for all and the need for sustainable development on a global scale. On the 30th anniversary of the adoption of the Program of Action of the Cairo Conference, we can see significant progress in the implementation of the Program, in particular in the field of poverty reduction, life expectancy, and food security, but progress is uneven, both within and between countries.

Multiple global crises—from climate change to conflicts—have put many of these hard-won gains at risk.

Investing in human capital as a key factor for demographic and socioeconomic change in the Least Developed Countries, harnessing the power of science, technology, and innovation to combat multidimensional vulnerabilities, and achieving the Sustainable Development Goals were the first two key focus areas highlighted in the Doha Program of Action for the Least Developed Countries for the Decade 2022–2031.

There is no doubt that in the case of Sudan, the prospects for sustainable development necessarily pass through:

- The valorization of human resources for the acquisition of strategic skills in the country's transition phase and even more so in the post-war scenario; this should mean the retention of qualified and skilled human capital through income generating activities that do help them stay in the country;
- Strengthening relations with foreign countries whose agenda integrates the prosperity of the country.

The need to link development aid to the necessary action to encourage the country's transition treasures a successful experience of scientific cooperation between Italy and Sudan, the project: "Innovation in society: Training paths and human capital enhancement in Sudan" (INSO). The project was made possible by the financial support of the Italian Ministry of Interior and carried out in the years 2017–2019 by the National Research Council of Italy-Institute for Research on Innovation and Services for Development (CNR-IRISS) in partnership with a Sudanese university, Comboni College of Science and Technology (CCST), the Ministry of Higher Education and Scientific Research of the Republic of Sudan (MOHE), and the Center for Lifelong Learning of the Aldo Moro University of Bari (CAP-UNIBA).

The INSO project included various training activities with the objectives of facilitating the professional insertion of 138 university students of technological undergraduate programs, job creation, and digital transformation in the framework of the sustainable development of the country [14].

Subsequently, the Sudan Innovation project was substantially based on the continuity of the INSO project and the resulting startup incubator [15].

In both experiences, the collaboration with the CCST proved to be fundamental, demonstrating the effectiveness of a particular model of relations based on equal cooperation and inspired by a model peace that integrates the cultural diversity of the country beyond the limited definition of Sudan as an Islamic and Arab country. This model has been successfully tested by the schools of the Catholic Church that "have played and play a relevant role in the instruction of the elites of the country and in the provision of education to the displaced and refugee communities..." [16, 17].

On the other hand, this is fully within some of the objectives of the African Union's Agenda 2063, which demonstrate the desire to prioritize inclusive and sustainable social and economic development.

To achieve this, the Agenda 2063 emphasizes that long-term actions must be implemented in the sectors of education, training, research, and innovation and aims for a major transformation of the three dimensions of durability, in particular the pillar of governance, peace, and security. It is underlined that the African Union's Agenda 2063 and the African Development Bank's "High-Five" program define the regional context of the Sustainable Development Goals.

Even if the African continent does not proceed in a homogeneous way, in recent years, the increase in financial commitment to research and development has been

remarkable in some African countries through technological training centers, dedicated funds, or even technology parks. Science, technology, and innovation are perceived as key factors of transformation and progress by African countries, which, consequently, strive to develop new or strengthened partnerships with the academic, socioeconomic, and cultural realms of their continent and with the international scene. The complexity of the issues and the need to address them through plural, systemic, and multidisciplinary approaches make the CNR a key partner for fair and sustainable cooperation, respectful of the diversity of sciences, thanks to the experience and competence in the field of scientific research, interchange scientific, the synergistic development of research projects, the signing of agreements, and so on.

It appears quite clear that specifically the Department of Social sciences and humanities, cultural heritage (DSU) of the CNR, with its interdisciplinary approach, the transfer of knowledge, and the implementation of scientific diplomacy activities on strategic themes, can encourage the development of an effective Africa-Italy scientific cooperation model.

5. Suakin as model of transformation of cultural heritage and an engine of sustainable development

Increasingly, and as demonstrated by the escalating situation in Sudan, cultural heritage is destroyed deliberately as an act of war or of cultural obliteration and through the impact of wider conflicts [18]. Further to this, the impacts of climate are accelerated through climate change, and ever faster-paced changes in lifestyle, globalization, urbanization, and tourism result in both physical sociocultural pressures on cultural heritage. Indeed, rapid development of towns and cities has often engulfed historic sites, including their physical architecture, in addition to intangible culture and heritage values. Collectively, this greatly impacts the multidimensional sense of place [19–21].

While cultural heritage is at risk and must be conserved and protected, it must also be understood that the historic environment is not a static entity. It is continually changing and evolving, so that it is relevant and meaningful to contemporary society and wider development trends and requirements. Therefore, conservation has to be seen as more than simply preserving historic places and buildings but as a process that enables them to be maintained and changed while always recognizing the values these heritage assets stand for. There is great potential for application and development of digital tools for heritage sites in this context. Notably, the historic Red Sea style coral port town of Suakin, where most of the historic buildings have now disappeared, yet is one of Sudan's most significant cultural and religious sites.

A place of such beauty, importance, and meaning to so many throughout Sudan and further afield, Sudan's historic coral port town of Suakin has been represented in artworks, film, literature, song, and scientific study for many years. It is this incredibly rich and unique documentation and research that the 3D reconstruction of Suakin's historic island town by the Sudan Memory project hopes to bring to light. The Sudan Memory digitization project and the Suakin 3D reconstruction address the need for digital preservation of tangible and intangible cultural heritage, especially where there is increasing destruction and further threat from the impacts of conflict, climate change, over development, and disinvestment. Furthermore, these efforts bring meaning and understanding to one of Sudan's greatest cultural heritages, and inspire hope for Suakin's future.

6. The story of Suakin

6.1 Significance and history

As a place, Suakin has a special position in Sudanese culture because of the memory of the beauty of the lost buildings and because it is identified with where Islam entered Sudan. Suakin has been described by the Sudanese as “the place of all our beginnings.”

Suakin is a natural lagoon harbor, backed by the Red Sea Hills, and was formerly Sudan's chief port. In addition to trade, the town provided the gateway between Islamic culture and Eastern Africa as the major pilgrimage route between Africa and Mecca, and the passenger ferry from Suakin to Mecca has long continued up to this day. During Suakin's period of prosperous trade, most of its famous fifteenth to twentieth century coral block buildings were constructed. These buildings are one of the best and now last remaining examples of the Red Sea architectural style, and for which Suakin is famous and was once termed the “Venice of Africa.”

The historic town consists of the main island within the lagoon, approximately 400 by 600 meters, and the adjacent mainland area known as the Geyf. The two areas were connected by a manmade causeway constructed in the late 1800s. The town has grown like most old towns with irregular narrow streets and blocks of houses of different shapes and sizes, and by the early twentieth century, the island contained approximately 200 houses. These island properties consisted of houses for the wealthy merchants, many named after famous families such as Khorshid Effendi and Shennawi Bey, and traders; commercial offices; stores and shops; zawias and mosques; and a number of public buildings. The Geyf was occupied mostly by Hadendowa tribe inhabitants, containing houses, zawias, and mosques, a number of public buildings, the Suakin-Berber Railway installations, shops, shanties, and drinking houses. The Geyf was encircled by fortifications, while the area surrounding this was scattered with outer defenses and a number of shrines and tombs (**Figures 1–3**).

Two further islands occupy the lagoon. The first island is known as Condenser Island, occupied by British and Australian troops during the 1885–1896 Mahdist campaigns, and a tall condenser-chimney (now disappeared) that determined the island's name. The other island is known as Quarantine Island, occupied by previous quarantine installations for pilgrims to Mecca, some early houses, and a Christian cemetery [22].

6.2 Decline

Despite Suakin's prosperity, by the 1920s, the majority of the population had relocated to Sudan's new port, Port Sudan, and the historic town became mostly uninhabited. The buildings therefore quickly deteriorated and fell into ruins without the constant maintenance required, due to the fragile coral block construction and impact of the local climate. Further damage was caused by earthquakes, and many buildings were deliberately pulled down to provide materials for new constructions elsewhere. A new port later opened at Suakin in 1991. This caused the rapid development of Suakin's new town that surrounded the old and encouraged further inhabitation of the historic mainland. Yet, Suakin's historic island remained largely deserted [22–24]. While the return of trade and development is much welcomed to the area, the subsequent growth of the surrounding new town has put increasing pressure on the historic core as it continues to disappear (**Figures 4 and 5**).

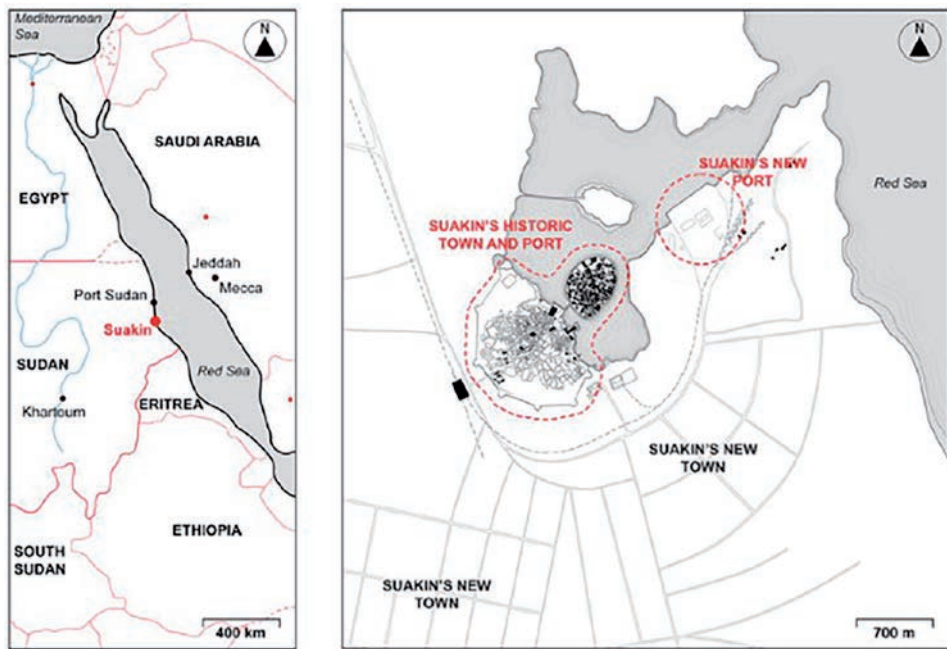


Figure 1.
Suakin's location, historic town and port, new port and expanding new town. Illustration by Katherine Ashley, 2013.



Figure 2.
View toward Suakin island, early twentieth century. Copyright Greenlaw Collection, Sudan Archaeological Research Society.



Figure 3.
A street in Suakin and Beit Mohammed Bey Aboud (house 1), 1914–1930s. Copyright M.E. and G.L. Wolff collection, Sudan Archive Durham SAD.744/1/5.

6.3 Suakin's conservation and documentation

Despite historic Suakin's state of physical decay, the need for this heritage to be saved for future generations has been well recognized. Since the historic town's decline began, the desire for Suakin's revival has been driven by the recognition of its historical and cultural significance and potential for economic development following the opening of the new port. This has encouraged a number of legal measures and sponsored academic research, government-led development plans, and international missions. Included within these efforts are a number of formal proposals for the preservation, restoration, where necessary reconstruction of Suakin's historic buildings, and recognition of Suakin's potential for UNESCO World Heritage status [22–27].

Some endeavors toward Suakin's conservation and restoration have been successful, and Suakin has been added to Sudan's Tentative World Heritage List since 1994. Yet, many proposals have been prevented by a number of ongoing challenges such as land ownership, financial restrictions, a contrast between legislative and local levels, and a need for effective community and stakeholder collaboration. Consequently, both the physical presence of Suakin's historic buildings and the memory of these, especially among younger generations, is ever faster slipping away [28, 29].

Regardless of the challenges to Suakin's conservation and restoration, the site has been extensively documented and researched for many years. Ongoing archeological and architectural missions since the 1940s continue to reveal more of Suakin's history and the physical properties of the ruined coral block structures. A significant long-term project is the Suakin Project, established by Sudan's National Corporation for Antiquities and Museums in 2000, including ongoing research in collaboration with Cambridge University's McDonald Institute. These long-term efforts have established a wealth of archival resources, dating back to the first recorded mapping of Suakin by the Portuguese in 1517 CE. Since then, further examples include the extensive



Figure 4.
Suakin's expanding new town. Photo by Katherine Ashley, 2012.



Figure 5.
Suakin Geyf (historic mainland town). Photo by Katherine Ashley, 2013.

colonial era collections held by the Sudan Archive Durham, which document Suakin's historic buildings, daily life, and much more, through photographs, film, various documents, and artifacts, and the investigation of Suakin's maritime archeology by Ulster University (**Figure 6**).

Further to more technical scientific study, throughout its existence, Suakin has been recorded through paintings and drawings, as well as film, poetry, and dance.



Figure 6.
Camels entering Suakin island through Gordon's Gate, 1905–1921. Copyright A. Espeland collection, Sudan Archive Durham SAD.1/7/35.



Figure 7.
Suakin island guard Mohammed Bodai, holding his tattered copy of Greenlaw's The Coral Buildings of Suakin, 2012. Photo by Katherine Ashley.

Whatever may happen to the built remains, the structure and spirit of Suakin is forever captured in these works. Some of the earliest of these works date back to early fourteenth century CE Portuguese drawings and Ottoman watercolors, showing how Suakin was when still an island unconnected to the mainland and the much earlier style of the buildings. Artist Jean-Pierre Greenlaw, who established the College of Fine Art in Khartoum, regularly visited and recorded Suakin from the 1940s and initiated an annual field visit by the college students that continued up to recently. Indeed, Suakin's enduring reputation as the "Venice of Africa" may be attributed to the extensive documentation of its buildings that appeared in Greenlaw's 1976 publication, *The Coral Buildings of Suakin*. This publication provides an essential guide for architects, archeologists, general Suakin enthusiasts, and those who wish to hang on to the memory of what Suakin was (**Figure 7**).

7. Sudan memory and Suakin—A 3D immersive archival experience

Sudan Memory is a digitization project dedicated to conserving and promoting Sudanese cultural and documentary heritage. The project has been implemented by King's College London in collaboration with the Sudanese Association for Archiving Knowledge (SUDAAK) and a number of other partners and contributors. A series of grants from the British Council and Aliph Foundation enabled a first phase of major works to take place on the ground from 2018 to 2022. Further smaller funds have since been provided by the Cultural Emergency Response for targeted emergency recording works by Nile Valley University and by King's College London for a series of workshops to facilitate discussion and essential planning for future focus and potential phases of the project, especially in light of the current conflict and its devastating impact on Sudan's heritage sites and collections.

Part of Sudan's Memory objective in the latter first phase of the project in 2020–2021, enabled through a further grant from the British Council's Cultural Protection Fund Impact Round, was to develop the project in new ways. This concerned new archives located also outside of Sudan and explored new ways to use, present, and make available the digitized archival content. One of the major developments that arose from this was the interactive 3D reconstruction of Suakin. This aims to make available some of the vitally important documentation and research about the site through providing an interactive portal. Via this portal, users can engage with Suakin Island as it was in 1900 CE, during Suakin's prosperous trading period, and are provided with direct access and links to digitized content, as well interpretation and navigation of Suakin's historic town. This interaction enables users to have some experience of what was once there, something that for so many years has not been possible (**Figure 8**).

The 3D reconstruction of Suakin was guided by various documentation from a number of archives and key current site survey recordings by drone and other photos during a mission in December 2020. A key reference was the detailed scaled model designed and built by the artist J.P. Greenlaw in the mid-1900s, and that includes a replica of every building on the historic island. Further to this, architectural and archeological plans, diagrams, and photographs that have been captured over many years by Sudan's National Corporation for Antiquities and Museums, by Cambridge University, and by many other institutions and independent researchers. The development of the model also draws on ancient engravings and pictures that show the island in earlier states and on the annual documentation of the site by the College of



Figure 8.
Interactive Suakin 3D reconstruction. Image from www.sudanmemory.org, 2022.

Fine Art in Khartoum. Greenlaw's work to record the coral buildings of Suakin, which contributed to his 1976 publication *The Coral Buildings of Suakin*, resides at the British Museum, much of which has been scanned by Sudan Memory and referred to in the 3D reconstruction. The development of the 3D model also draws on documentation of the site's intangible heritage and stories, in addition to local values and significance of the site determined through community consultation (**Figures 9 and 10**).

To build the 3D reconstruction of Suakin, Sudan Memory collaborated with The Virtual Experience Company. The Virtual Experience Company develops 3D and virtual reality models of heritage sites and museum artifacts across the world, using the latest developments in computer games technologies. Access to the Suakin 3D model is intended primarily for the Sudanese public, meaning access is mostly by mobile phone and often with lower bandwidth. This resulted in some key design considerations, including strict limitations to the model file size and needing to ensure easy navigation with a small screen. The model is therefore restricted to include only the



Figure 9.
Suakin island showing the causeway and Geyf in the background, 2020. Photo by Ibrahim Mohamed Ahmed.

historic island town, rather than also the mainland. Using a 3D software, basic forms of the buildings were first constructed. To keep within the restraints of the model file size, only the exterior was modeled for most of the buildings. A few specific buildings were modeled in further detail, to show details of the interior and finer specific



Figure 10.
Sharifa Maryam's House, Suakin, 2016. Photo by Katherine Ashley.



Figure 11.
Detailed view of Suakin 3D navigation.

details such as finer grained woodwork. By ensuring the accuracy of the model dimensions against previous surveys and recent recordings, the model or parts of it can be developed in further detail as a later phase (**Figure 11**).

The 3D model of Suakin is now accessed via a user interface, available in Arabic and English, located on the Sudan Memory website. Using a mobile phone, tablet, or laptop, users can take a virtual walkthrough of the model. To aid navigation and link users to various archival content, approximately 50 pins are located throughout the model, including information pins and viewpoints. Information pins each open up their own page, including the name of and key information about the specific building or location attached to, ranging from facts about the style and construction of the buildings to histories and stories about the people who lived and visited there. Further to this, archival content to illustrate the history of the various pin locations, such as photographs, film, and audio recordings. The viewpoint pins fix the user camera from a specific point, such as the top of a mosque minaret to enable a 360-degree view of the island, interior views of the more detailed buildings, and various key views of the island elevations and roofline.

8. The Suakin 3D as a driver for sustainable development

The use of online platforms, digital exhibitions, and virtual models of historic sites offer new approaches, methods, and mediums for the documentation and conservation of cultural heritages. This is especially relevant in remote locations, where much of a site's tangible built has disappeared and where access to archives and collections is restricted. For example, while so many people in Sudan, especially Suakin's more deprived local community, know the stories and historical fame of Suakin, very few of them have ever seen an image of the site while most of the historic buildings still stood.

Using a 3D model and other digital visualization tools can enable awareness of a site's tangible and intangible heritage and value, at both local and wider levels. For community consultation purposes, this type of modeling and presentation is extremely powerful. Visualizations such as this, along with various options for building types, textures (such as grass, paving, colors of buildings, etc.), and other, are instantly accessible to everyone, regardless of their technical skills and ability to read specialist drawings. This can be used to convey how a site could be used; to propose specific interventions and gauge their immediate and wider impact, such as visual impact on site and response of the wider community; and to engage these different audiences and establish common goals for a site's future. This is invaluable to a site's safeguarding and future conservation, planning, and development efforts, including impact assessment. Furthermore, this provides essential groundwork for many future opportunities, such as site interpretation, both physical and digital, and scientific modeling.

In terms of using 3D models and other digital tools to enable wider awareness and engagement, this is also extremely powerful to address the issue ownership. The "ownership" of cultural heritage is one of the more immediate challenges faced by cultural heritage conservation and development projects. For example, the development of digital platforms could further enable wider participation through the heritage impact assessment process, especially in demonstrating recognition of wider values of the various communities of a heritage site and likewise enabling awareness of a proposal and facilitating input from these wider groups. One immensely

important feature of this developing international context of digital work in preserving and restoring cultural heritage is the common theme that all cultural heritage is shared, and the heritage of any one culture needs to be seen and recognized as global heritage. There is potential for tension between the “local” and “global” aspects of cultural heritage, but there seems to be a welcome consensus that the groups originally responsible for cultural expression should have a major and decisive role in its preservation. In the Sudan Memory project, for example, a stated aim is to change the world’s perception of Sudan as a country of war and corruption and to show the diversity, richness, and longevity of its heritage [18].

Regarding the future development and application of the Suakin 3D and other digital technologies, this presents great potential to explore new ways to map and link archeology and built heritage with social and cultural components via an inclusive digital platform. Further to this, a new workflow/hybrid prototype model could be developed through innovation in and combination of existing technologies and workflows of digital recording, storage, presentation, and communication visualization methods. This would provide incredibly useful new tool(s), or basis for, for the conservation, management, planning, and development of heritage sites, including impact assessment.

9. Conclusions

Considering both the strategic position of Sudan, a turbulent crossroads between the Mediterranean area, the Arabian peninsula, and the extensive regions south of the great desert, and the economic interests toward its resources by close and far, large and medium world powers, it seems necessary to examine the different issues at stake to understand the events of the current conflict and its deep roots in the political, economic, and social composition of the country in the light of regional and international transformations [30]. Today, the country is isolated and forgotten by the international media, and it would be important for the international spotlight to be turned on to this crisis to relaunch the peace process.

While the conflict in Sudan continues and prevents many actions being taken on the ground, in terms of sustainable development and cultural heritage, it is important to continue to explore and plan for what can be done in the future, which will be so essential to the country’s reconstruction.

The 3D model of Suakin provides an example of an alternative approach toward heritage sites, with many potential applications and that can be developed in various ways. The use of such online platforms, digital recordings, and virtual models of historic sites offers new approaches, methods, and mediums for the documentation, awareness raising, protection, and conservation of cultural heritages. This addresses the need for digital preservation of tangible and intangible cultural heritage, especially where there is increasing destruction and further threat from the impacts of conflict, climate change, over development, and disinvestment. This is especially relevant in remote locations, where much of a site’s tangible built has disappeared and therefore easily overlooked in the development of new plans, and where access to archives and collections is restricted. Using such digital methods to enable awareness and engage audiences at local and wider levels, and to establish common goals, is invaluable to a site’s safeguarding. Furthermore, such approaches and methods are increasingly recognized as tools for planning and conservation, providing a potential base for future restoration and reconstruction and allowing further interventions that might be integrated to be evaluated accordingly.

Italy could become a key player in Sudan, at this particular moment in which the country is totally isolated from the international community, through the consolidation of scientific diplomacy activities. In fact, through the already executed experiences, it emerges that it is a powerful vector for the development of international relations and the circulation of knowledge.

Author details

Katherine Ashley^{1*} and Sabrina Greco²

1 Kate Ashley Studio, London, UK

2 National Research Council of Italy, Institute of Heritage Science, Lecce, Italy

*Address all correspondence to: kate@ka-studio.co.uk

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References

- [1] Office for the Coordination of Humanitarian Affairs. Situation Report. Sudan: OCHA; 2024. Available from: <https://reports.unocha.org/en/country/sudan/> [Accessed: June 27, 2024]
- [2] Marchal R. Le Soudan d'un conflit à l'autre. Les Études du CERI. 2004;**107-108**:1-59
- [3] Casciarri B, Assal M, Ireton F. Multidimensional change in Sudan (1989-2011). In: Reshaping Livelihoods, Conflicts and Identities. New York/ Oxford: Berghahn Books; 2015
- [4] Denis É. Démographie ethnique, modernisation et violence au Darfour. Annales d'Éthiopie. 2005;**21**:93-107. DOI: 10.3406/ethio.2005.1095
- [5] Drozd M, Pliez O. Entre Libye et Soudan: La fermeture d'une piste transsaharienne. Autrepart. 2005;**36**(4):63-80
- [6] Lavergne M. Reconstruire le Soudan? Esprit; 2020. DOI: 10.3917/espri.2007.0039. Available from: <https://esprit.presse.fr/article/marc-lavergne/reconstruire-le-soudan-42828> [Accessed: June 2, 2022]
- [7] Bach J-N, Chevrillon-Guibert R, Franch A. Introduction au thème. Soudan, la fin d'une domination autoritaire ? Politique Africaine. 2020;**158**(2):5-31
- [8] Chevrillon-Guibert R. Les révoltes soudanaises comme miroir de celles du continent? Restauration autoritaire et militarisation d'une démocratisation impossible. Revue Internationale et Stratégique. 2022;**126**(2):127-135
- [9] Mahé AL. Soudan: Après la chute d'Omar el-Béchir, les défis de la transition. Politique Étrangère. 2019;**4**:99-112
- [10] Denis É. Inégalités régionales et rébellions au Soudan. Outre-Terre. 2007;**20**(3):151-168
- [11] Greco S. Migrazioni e globalizzazione: Il caso del Sudan. I diritti dell'uomo. Cronache e battaglie. 2013;**2**:20-23
- [12] Freire P. La Pedagogia Degli Oppressi. Torino: EGA; 2002
- [13] Maillot M, Nicoloso-Beaumé O, Cabon O. Histoire et Civilisations du Soudan, de la Préhistoire à nos Jours. Paris: Soleb. Bleu Autour; 2017
- [14] Naranjo Alcaide JC, Meyer J-B, Greco S, Abdalla SA. Youth, training and labor insertion in Sudan: Lessons from the INSO project. Journal of Comparative and International Higher Education. 2023;**15**(1):45-60. ISSN 2151-0393
- [15] Naranjo Alcaide JC, Greco S. Online education, international cooperation and sustainable development in Sudan. Social Education Research. 2023;**4**(2):209-226
- [16] Greco S, Naranjo Alcaide JC. Innovazione in una società in transizione attraverso la valorizzazione del capitale umano e del patrimonio culturale: Il caso del Sudan. In: Bettini E, Tondini D, editors. Atti del Congresso Allargare gli Orizzonti della Carità per una Nuova Progettualità Sociale. Evento Speciale della Presidenza Italiana del G20. IV Forum Internazionale del Gran Sasso, Partenariato Euro-Africano: III Conferenza, Teramo, 30 Settembre-2 ottobre 2021. Vol. 4, Parte 2. 2022. pp. 289-303. Available from: <https://www.diocesiteramoatri.it/wp-content/uploads/2022/10/>

FORUM_PARTE_I.pdf?_gl=1*154pzipw*_up*MQ.*_ga*NDAzODIiNTQyLjE3NDQxMTIxOTg.*_ga_6N5V58L26F*MTc0NDExMjE5Ny4xLjAuMTc0NDExMjE5Ny4wLjAuMA

[17] Naranjo JC. The development of catholic schools in the Republic of Sudan. *Social and Education History*. 2019;8(1):83-111. DOI: 10.17583/hse.2019.3611

[18] Deegan M, Short H, Ashley K. Cultural Memory & Digital Mediation: Two Case Studies. Unpublished Paper. 2022

[19] Ciftci C, Meshur HFA, Sehrat MY, Yavuz F, Levend S. Urban Regeneration strategies in historical city center of Beysehir-Konya/Turkiye. In: *Proceedings of the 14th IPHS Conference*; 12-15 July 2010; Istanbul, Turkey. 2010

[20] Fadli F, AlSaeed M. Digitizing vanishing architectural heritage; the design and development of Qatar historic buildings information modeling [Q-HBIM] platform. *Sustainability*. 2019;11:2501

[21] Jokilehto J. Definition of cultural heritage, references to documents in history. ICCROM Working Group Heritage and Society. 2005; **January**:4-8

[22] Greenlaw J. *The Coral Buildings of Suakin*. Stocksfield: Routledge & Kegan Paul; 1976

[23] Salim AR. Suakin: On reviving an ancient Red Sea Port City. *Traditional Dwellings and Settlements Review*. 1997;8(2):63-74

[24] Taha S. The value of memory: Suakin's cultural heritage: Significant for whom? *International Journal of Intangible Heritage*. 2014;9:55-56

[25] Hansen E. *Preservation of Suakin*. Unpublished Consultancy Report. Paris: UNESCO; 1972

[26] Lane B. *Suakin Mission Report*. Unpublished Consultancy Report. Paris: UNESCO; 1994

[27] Mallinson M. Nominating Suakin as world heritage site. In: Barnard H, Duistermaat K, editors. *The History of the Peoples of the Eastern Desert*. Los Angeles, CA: The Cotsen Institute of Archaeology Press, University of California; 2012. pp. 372-379

[28] Ashley K, Osmani M, Emmitt S, Mallinson M, Mallinson H. Impact of cultural dynamics on the conservation of Suakin, Sudan. *Proceedings of the ICE - Journal of Engineering Sustainability*. 2014;167(6):264-278

[29] Ashley K. A protocol for the conservation of the built heritage of Suakin [unpublished engineering doctorate thesis]. Loughborough: Loughborough University; 2015

[30] Dazi-Héni F, Le Gouriellec S. La Mer Rouge: Nouvel espace d'enjeux de sécurité interdépendants entre les États du Golfe et de la Corne de l'Afrique. In: *Note de recherche n. 75*. Institut de Recherche Stratégique de l'École Militaire; 2019. Available from: <https://www.irsem.fr/actualites/note-derecherche-n-75-2019.html> [Accessed: June 27, 2024]

Chapter 3

SudanInnovation: Higher Education Training

*Maurizio Lazzari, Sabrina Greco and
Jorge Carlos Naranjo Alcaide*

Abstract

This chapter summarises the aims and the conceptual and practical aspects related to the application of innovative technologies to cultural heritage dealt with in the advanced training programme conducted by the National Research Council of Italy-Institute of Heritage Science, with Sudanese university students and university lecturers. It also describes the context in which the training took place and the students of a Sudanese higher education institution, Comboni College of Science and Technology, applied the learnt contents.

Keywords: Sudan, cultural heritage, digital technologies, sustainable development, computer science

1. Introduction

This chapter summarises the aims and the conceptual and practical aspects related to the application of innovative technologies to cultural heritage, dealt with in the advanced training programme addressed to Sudanese university students and university lecturers in the framework of the SudanInnovation project conducted by the National Research Council of Italy-Institute of Heritage Science (CNR-ISPC).

It also describes the context in which the training took place and the students of a Sudanese higher education institution, Comboni College of Science and Technology (CCST), applied the learnt contents.

2. Development and topics of the training phase

Sustainable heritage management is a multidisciplinary process. Consequently, the SudanInnovation project favoured an integrated approach that combined the protection of cultural heritage with the promotion of cultural diversity and the innovation of digital technologies.

The main aim of the project was to support the sustainable development of Sudan through the application of innovative digital technologies to cultural heritage. This implied the development of the skills and competencies of a group of university students and lecturers in computer science.

The ad hoc training programme allowed those students, with the support of the Sudanese-trained teaching staff, to develop graduation projects in which they applied technology to their own cultural heritage sector and, also, to grow in awareness about their own cultural heritage and its potential to become an engine of sustainable development.

The programme consisted of a series of webinars provided by the CNR-ISPC (with a team of 17 researchers), attended by the Sudanese students and lecturers at the CCST premises. This Sudanese university college and the national institutions responsible for the protection of cultural heritage were involved in the selection of the training content.

In particular, the beneficiaries of the training project, with a total duration of 30 hours, have been:

- 30 students of the BSc in Computer Science with priority to finalists who will have to prepare their graduation project in 2021 and with a good level of English language (15 from CCST and 15 from other Sudanese public or private universities selected in collaboration with the Ministry of Higher Education and Scientific Research of the Republic of Sudan (MOHE)).
- Six university lecturers of CS departments (three from CCST and three from other Sudanese universities). These lecturers will be potential supervisors of the aforementioned graduation projects.

The online workshop proposed content that allowed Sudanese students and lecturers to acquire the knowledge necessary to develop degree projects where new digital technologies are mainly applied to the cultural heritage sector.

The programme included a theoretical framework on sustainable development and cultural heritage (Africa World Heritage Sites: risks and challenges for their conservation; Tourism, Cultural Heritage and Sustainable Development; Societies in transition and sustainable development; Suakin as a model of transformation of cultural heritage into an engine of sustainable development). This introduction aimed to provide technical students and lecturers with the necessary theoretical framework and attitude.

The technical topics covered were the following:

- Techniques for knowledge of the territory: remote sensing, archaeological mapping and topographical survey (high-resolution optical satellite imagery: panchromatic; InSAR and LiDAR for archaeology; photos for the study of landscape transformations; aerial photography and archaeological aero-topography; archaeological mapping for the knowledge and preservation of cultural heritage; mapping ancient roads and agricultural land divisions; cartography aimed at the archaeological research from aerial and satellite data).
- 3D GIS for Cultural Heritage in Sudan (Geographical Information System for Cultural Heritage; GIS for cultural heritage: from data management to spatial analysis).
- Preparing datasets for creating a 3D model.
- Acquisition of data using different resources and pre-processing of data for 3D/4D.

- Augmented reality.
- The creation of software for virtual visits to museums or archaeological sites (virtual reality).
- Digitisation Vanishing Architectural Heritage. The design and development of Sudan's historic building information modelling platform (mapping from UAVs and 3D laser scanning; virtual reconstruction of ancient contexts: some examples from Italy and Egypt).
- Geostatistical applications through GIS (geostatistics, GIS and cultural heritage: theoretical concepts and applied case studies; didactic methods and examples of applications to the knowledge and enhancement of the cultural heritage).
- Understanding, documenting and sharing the materiality of cultural heritage (polychromy in ancient sculpture and architecture; understanding, documenting and sharing the materiality of ancient manuscripts; looking beyond the visible: the use of X-rays to unveil the unknown past of ancient materials).

The lessons were propaedeutic to the practical activities proposed to prepare participants for the final field exercise during the thesis development. In fact, this application phase concluded the training edition.

Course participants played the role of the cultural heritage protection in Sudan, especially in light of the internal conflict that, only a few months later, would explode violently in the country, causing almost irreparable damage to many monuments.

However, this cycle of advanced training, aimed at undergraduate students and teachers, can be replicated in other sensitive contexts where cultural heritage could be at serious risk of conservation due to a lack of maintenance or possible armed conflicts.

Education in the knowledge of the cultural heritage of one's country thus becomes the first weapon available to counter the violation of the human right to preserve the historical memory, tangible and intangible, as an inviolable expression of the identity of a people.

To this end, research and the scientific community can and must play a fundamental role in terms of international cooperation and scientific diplomacy (also known as Third Mission activity, which the CNR-ISPC is committed to [1, 2]), transferring the knowledge of the necessary skills and tools to support other peoples to grow in awareness about their origins, as established since 1954, with the Aja Convention for the protection of cultural property in the event of armed conflict and its two protocols, and in 1972 with the Paris Convention of UNESCO.

3. Projects' contextualisation

The strategic location of Sudan along the Nile River and the junction point of the Blue and White Nile has made this country a site of ancient civilisations that have left a wonderful cultural heritage and a zone of contact among the peoples of Central Africa, the Mediterranean and the Arab world [3]. 'The river Nile and its tributaries served as a corridor through which people, goods and ideas circulated between the south and north' [4].

All these movements of population since Palaeolithic times have left traces that have remained particularly north of Khartoum, thanks to the characteristics of the soil and the climate. Not too much remains south of Khartoum instead, as 'the cultures that have evolved there were using perishable building materials such as wood that did not survive in the acid soil and the rainforest' [5]. The sand of the desert in the north of Sudan has kept stoned and brick architecture for millennia.

These treasures remained almost unknown to Europe until the publication of the illustrated volumes of Frédéric Cailliaud. He 'was the first western scholar to come to Sudan in 1820/1822, as he accompanied Ismaïl Pacha, general military commander of his father Mehemet ali, just like the scholar squad that accompanied Bonaparte in Egypt' [5]. The conquest of Sudan by the Ottoman Egypt of Mehemet ali finished the Funj kingdom of Sennar and reopened the country to the Mediterranean Basin and to European antiquarians, traders, explorers, travellers, etc.

Some years later, in 1842, archaeological activity gained impetus with the expedition 'launched by the king of Prussia under the direction of Carl Richard Lepsius, the best Egyptologist of his time and German successor of Champollion' [5].

While for Egyptologists, Sudan was part of their field of competence, in 1899, the border between Egypt and Sudan was fixed along the 22nd parallel, just north of the second Nile cataract. The great impulse to archaeology in Sudan was given by the salvage campaign launched by UNESCO in 1960 before the inauguration of the dam of Aswan, on the first cataract, that was supposed to create a more than 500 km long lake (called Lake Nasser in Egypt and Lake of Nubia in Sudan). Around 30 archaeological expeditions have uncovered some of the hidden treasures of the cultural heritage of Sudan. Part of those findings were sent to the 21 countries that had funded those expeditions, and part of them were hosted in a new museum that was inaugurated in 1971 in Khartoum. The Sudan National Museum also incorporated the collection of the Sudan Museum, founded in 1904 inside the Gordon Memorial College (today the University of Khartoum) and renamed in 1952.

The extreme weather conditions, the limited resources, the lack of modern equipment, the poor maintenance of the existing ones, sometimes due to the lack of spare parts, and the political agenda of the previous regime put many of the artefacts of these collections and materials at risk. Moreover, that same political agenda did not promote tourism in the country, which would have helped to get funds for the preservation of that cultural heritage and for its transformation into a source of income and sustainable development.

The war that broke out in April 2023 poses a further threat to that heritage and has already damaged part of it.

3.1 Sudanese educational context, cultural heritage and digital transformation

In Sudan, primary and secondary schools are under the competence of the Ministry of General Education. The presence of cultural heritage could be traced in the Sudanese school curricula through subjects like history and geography. Nonetheless, the vision of that history was very politicised, as the Islamist regime configured all the educational curricula since 1991 around two poles: Arab culture and Islamic religion. Just in 2016, these curricula were updated, and the Meroitic Civilisation or the Mediaeval Christian Kingdoms found a place in the books of history of the Basic School.

The transitional government that came out after the 2019 Popular Revolution introduced new curricula for primary, intermediate and secondary schools in a way to better represent the cultural diversity of the country.

On the other hand, the new curricula also included some courses related to technology and computer science. Nonetheless, it is necessary to mention that Sudanese schools usually do not have any computer labs, and therefore, the students reach universities without ever having touched a computer.

3.2 Computer science and IT within humanities programmes in higher education in Sudan

In every undergraduate programme, Sudanese university students were supposed to study the following courses: Islamic Culture, Islamic Religion, English Language, Arabic Language, Introduction to Computer and a course called Sudanese Studies. This last subject is quite a wide umbrella that covers different themes related to the history, the economy, geography and the culture of the country.

It is the main gate through which it was possible to expose Sudanese university students to their own cultural heritage independently of the nature of their academic field of specialisation (Arts, Engineering, Sciences, etc.). It was also typical that the respective lecturer of that course would take the students to the Sudan National Museum. According to the new guidelines for university curricula, universities are not obliged to include the course of 'Sudanese Studies' in new academic programmes.

On the other hand, the study of cultural heritage in Sudanese higher education institutions can be traced through a series of faculties in different universities. The Faculty of Fine and Applied Arts of the Sudan University of Science and Technology is the only one with Departments of Sculpture, Textile Design, Drawing, Ceramics, Calligraphy and Ornamentation, Painting, Printing and Book Binding.

In this university, Information Technology (IT) is applied to the different academic programmes through subjects like Computer-Aided Design in the Bachelor of Arts (BA) in Sculpture, Computer-Aided Textile Design in the BA in Textile Design and Fashion and Computer-Aided Design in the BA in Fashion Design. In this case, we have the use of information technology by students who may not have developed digital skills in depth before.

The Faculty of Arts and Humanities of Dongola, Khartoum and Nilein Universities offer Bachelor of Arts programmes in Archaeology, Documentation and Library Management, and the first one even in Folklore.

3.3 From computer science to cultural heritage

There is another way to link computer sciences and cultural heritage, different from the direction followed by students who come from a cultural heritage-related field and have to learn to use IT tools. It would be the opposite one, that is, to take computer science as a starting point and then introduce within it cultural heritage and its digital transformation.

At CCST, a small university college located in the centre of Khartoum, there are no departments of fine arts or archaeology. The ongoing degree programmes are a Bachelor of Science (BSc) in Computer Science, a BSc in Information Technology, two Diplomas in Information Technology applied to Accounting and Management, a BSc in Nursing, a BA in Education and a BA in English Language and Literature and around 875 students.

One particularity of these students is that 27% are refugees from South Sudan, and 14% are Eritreans and Ethiopians. Just 59% are Sudanese, and many of these come from displaced families from Darfur and South Kordofan.

Some of those refugees and displaced people arrived in Khartoum after 2013, in particular those South Sudanese who fled after their civil war started in December 2012. However, most of them are born in Khartoum and are children of refugees or displaced people, but have never seen their ancestors' homeland. Therefore, the question about their own cultural identity becomes a paramount question.

This is why the college facilitated a reflection on this issue by creating an activity in 2015 called the 'Cultural Week'. Every year, a theme was chosen and was supposed to be dealt with from their cultural perspective and academic field.

This activity led them to discover their own cultural heritage, work on it and present it to others. These cultural activities created a certain sensibility in the students about the importance of cultural heritage as a pillar on which they can build their personal identity in a changing world (**Figure 1**).

After these activities, the students themselves organised some trips to get to know better places they had never seen before, like the pyramids of Meroe, for instance.

In this context, a group of finalists of the BSc in Computer Science asked for a Core i7 computer in order to have their graduation project on the application of photogrammetry to 3D modelling of three artefacts.

The existing computers in the college were not able to respond to the needs of such a kind of project. In addition, this is one of the factors that hinders many universities in Sudan from introducing the necessary theoretical subjects in a computer science syllabus. To have a fully complete lab with 35 computers with a Core i7 processor for a group of students is not affordable for most Sudanese universities. The college bought one to facilitate the first graduation project in this field.



Figure 1.
Students singing and dancing traditional songs during the III Cultural Week in 2017.

3.4 Graduation projects on applications of computer science to cultural heritage

The supervisor of this graduation project was one of the CCST lecturers, Muna Khamis, who was doing her PhD research in this field at the Sudan University of Science and Technology, supervised by Prof. Dieter Fritsch from the Institute for Photogrammetry and Geoinformatics of the University of Stuttgart.

Muna Khamis had benefitted from training in a German company specialised in photogrammetry and was able to teach and supervise a group of three of our students who wished to apply photogrammetry science to draw a 3D model of two monuments of Omdurman, Abdel-Gayoum Gate and a mausoleum at Khalifa's House, and one sculpture of Amon at the Sudan National Museum in Khartoum.

The CCST students used an Olympus camera able to produce 10 MB photos and a Core i7 computer with 16 GB of RAM, even if the ideal would have been at least 32 GB of RAM. This background had created the suitable soil for the SudanInnovation project that developed the skills of some of the college lecturers of the Department of Computer Science and the students of the BSc in Computer Science. Four groups of students chose to have their graduation projects on these applications in 2021:

1. Applying virtual reality for the cultural heritage of ancient Suakin through terrestrial photogrammetry.
2. 3D Reconstruction Documentation Website of Cultural Heritage in Sudan.
3. Ancient polychromy: study and virtual reconstruction using close-range photogrammetry for the Sudan National Museum.
4. Photogrammetric surface/reconstruction from imagery in cultural heritage (Designing Virtual Kerma Museum).

A fifth project was started in 2022 by another group, working on the virtual reconstruction of the mediaeval church of Sonqi Tino.

These efforts reveal the capacity of the students to learn the necessary techniques and apply them to different realities. Nevertheless, they also reveal their limitations in terms of academic background related to cultural heritage or the humanities in general.

3.5 The location of the projects

Two graduation projects were located in Khartoum, the capital of Sudan; one in Suakin (northeast of the country on the Red Sea coast); one in Kerma; and another one in Sonqi Tino (north of the country).

3.5.1 Kerma and its museum

Kerma is located 45 km north of the modern city of Dongola, the capital of the Northern State, near the third cataract. 'The town of Kerma is characterised by well-developed architecture, which included elaborate defences, an important religious quarter located at its heart, and countless domestic buildings, storage magazines, and administrative and industrial complexes. The remains of the capital city surround the Western Deffufa' [6]. This is a large mudbrick temple, currently standing 18 m high and surrounded by a quarter with religious buildings (**Figure 2**).



Figure 2.

Photo of the map of Sudan present in the Sudan National Museum, where you can find Suakin (northeast), Kerma (north) and Khartoum (centre). Songi Tino does not appear. It is located south of Semna West, 150 km south of Wadi Halfa.

The city was the capital of the Kingdom of Kerma, referred to in Egyptian hieroglyphic texts as the Kingdom of Kush, and was founded around 2540 BC. The kingdom extended from the second cataract in the north to the fifth cataract in the south.

Kerma quickly became one of the earliest urban centres in sub-Saharan Africa. The kingdom flourished between 2500 and 1500 BC. In its expansionist operations, it entered into conflict in the North with the Middle Kingdom of the Egyptian Pharaohs. These ones built 10 massive mudbrick fortresses at the beginning of the nineteenth century BC around the second cataract to defend Egypt from Kerma. One of those fortresses was built at Buhen.

In 1700 BC, the Kerma kingdom, taking advantage of the weakness of Egypt, which was fighting the Hyksos in the North, invaded the region, and Buhen became part of it [5]. Nevertheless, after setting their accounts with the Hyksos, the Egyptians conquered Kerma, destroyed the city and built a new one nearby, Dukki Gel, where the famous statues of the 'Black Pharaohs' were discovered in 2003. These

statues are today in the Museum of Kerma, which was one of the locations of the graduation projects.

The Egyptians established themselves over the entire Kerma kingdom under the rule of Thoutmosis I and later on under Thoutmosis III. The whole territory was divided into two provinces, Wawat to the north (Lower Nubia) and Kush to the south (Upper Nubia and Central Sudan).

However, in the eighth century before Christ, a dynasty of Nubian kings invaded Egypt. They are known as the 'Black Pharaohs'. Thus, the 25th dynasty was a line of Nubian pharaohs who reigned in part or all of Ancient Egypt for nearly a century, from 744 to 656 BC [7].

With the goal of protecting and promoting the cultural heritage of the region, in 1999, the High Committee for the Kerma Complex Initiative was created. This regional committee, along with the National Corporation for Antiquities and Museums (NCAM), supervised the construction of a museum in Kerma, which started in 2003, funded by a Sudanese-Swiss partnership. The museum was inaugurated on 19 January 2008 and presents an overview of the region's archaeology from the first human settlements.

3.5.2 The Sudan National Museum, the Buhen temple and the military museum

The Sudan National Museum was built in 1971 after the campaign launched by UNESCO to rescue as much as possible from the Sudanese cultural heritage that would have remained under the waters of the Nubian Lake. Thus, the museum hosted those objects plus the old collection that had been kept in the Khartoum Museum, opened in 1904 inside the Gordon Memorial College, renamed in 1952 as the Sudan Museum.

The museum contains collections from prehistoric sites; the kingdom of Kerma (2500–1500 BC); Napata (660–300 BC) and Meroe (300 BC–350 AC); the periods of Egyptian domination; the Mediaeval Christian kingdoms (550–1500 AC) and the first years of Islamic presence (**Figure 3**).

The main building of the museum is surrounded by a garden which contains the temples of Buhen and Semna West and some mediaeval columns from the Cathedral of St Peter of Faras and artefacts from different temples.

One of the graduation projects has to do with the museum as a whole, and another one with one of the walls of the temple of Buhen built by Hatsheput. She was the fifth pharaoh of the Eighteenth Dynasty of Egypt and the second historically confirmed female pharaoh. She came to the throne of Egypt in 1478 BC. She decided to destroy all the monuments of her father, Thoutmosis I, to build her religious base and legitimacy beyond her position as God's Wife of Amun.

The temple of Buhen is the best-preserved around the second cataract. It was dedicated to the god, Horus. The wall chosen by the students to rebuild its original colours was part of the sanctuary where there was a statue of the main god Horus. The colours changed a little over time and were never restored. Hatshepsut, depicted as a king and not as a woman, is facing Horus. There is a table dressed with all sorts of breads and meat that the pharaoh presents to the god [5]. This reconstruction may be particularly relevant as Cultural Heritage Monitoring Lab analysts identified damage to the structure containing the temple of Buhen that occurred between 17 April and 20 April 2023 [8].

The Military Museum, instead, is located in Khartoum Bahri and documents the history of the Sudanese army and the weapons, equipment and machinery the Sudanese soldier used over different epochs of history.



Figure 3.
Bethlehem Tesfahun Tebeje from Ethiopia and Mona Mohamed from Sudan collect data at the Museum of Kerma. The photo was taken by the third component of the students' team, Idris Abdelrahman.

3.5.3 Suakin

The island town of Suakin, or Sawakin, is located on a flat, oval-shaped island, on the west coast of the Red Sea, inside a narrow inlet that penetrates four kilometres inland and ends in a wide basin about two kilometres across. The island is connected to the mainland by a short man-made causeway (**Figure 4**).

While Kerma was one of the first urban centres in sub-Saharan Africa, Suakin was one of the oldest seaports in Africa with a natural harbour. It was used by African Muslims who set out for pilgrimage to the holy city of Mecca in Saudi Arabia. 'The architecture of the island is the same as that seen at the older Turkish ports of the Red Sea, such as Jeddah and Massowah. At the height its prosperity trade flourished between it and Arabia, Abyssinia, Egypt, India and places as far off as China' [9].

Until the nineteenth century, Suakin was the residential address of the Ottoman Empire's Habesh Province, which included what is today's Eritrea, Djibouti and northern Somalia. The administration of the city was left to the Khedivate of Egypt in 1865 (**Figure 5**).

With the British occupation of Egypt in 1882, the city effectively left Turkish sovereignty and was officially ceded to Egypt under British sovereignty. The Anglo-Egyptian colonial government built a new port between 1905 and 1909, Port Sudan, to replace Suakin. After that, the historical port diminished in importance and accelerated its deterioration until it turned into a ghost town.

3.5.4 Sonqi Tino

An expedition organised by La Sapienza University of Rome started working in 1967 at a Christian site that had been identified at Sonqi West, on the west bank of the Nile, about 150 km south of Wadi Halfa. The site included a small mudbrick church with some wall paintings [10]. The project benefitted from the support of the National Research Council of Italy and the Holy See. The Vatican appointed a



Figure 4.
Aerial view of Suakin Island in 1930 with Condensor Island in the foreground and El Gerf with its enclosing defences behind. Photo credit: www.thearchitecturestore.co.uk



Figure 5.
Screenshot taken from Google Earth.

Comboni missionary specialised in the mediaeval period in Sudan, Fr Giovanni Vantini, who would teach Sudanese Studies at Comboni College of Science and Technology until 2007 [11].

Jorge Carlos Naranjo Alcaide, CCST Principal, contacted Giuseppe Fanfoni, architect and member of the expedition, who had done the architectural designs of the church. Loredana Sist, Egyptologist and former director of the Museum of Near East, Egypt and Mediterranean of Sapienza University of Rome, provided a map of the church where it was possible to identify the location of every fresco that was rescued from the church before being covered by the waters. Most frescoes are kept at the 'Museum of Near East, Egypt and Mediterranean' of Sapienza University of Rome; one single painting is displayed in the Vatican Museum, and a group located in a side chapel of the church was at the National Museum of Sudan before the war that started in 2023. With all this data, the students worked on the virtual reconstruction of a church that the waters had destroyed in 1975.

Author details

Maurizio Lazzari¹, Sabrina Greco² and Jorge Carlos Naranjo Alcaide^{3*}

1 National Research Council of Italy – Institute of Heritage Science, Potenza, Italy

2 National Research Council of Italy – Institute of Heritage Science, Lecce, Italy

3 Comboni College of Science and Technology, Port Sudan, Sudan

*Address all correspondence to: naranjoalcaide@hotmail.com

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References

- [1] Genovese L, Alberti L, Colosi F, Grano MC, Bellia A, Greco S, et al. Cooperation solutions for the local sustainable development of heritage communities: Role and contributions of the Faro Italia network. In: Calabrò F, Madureira L, Morabito FC, Piñeira Mantiñán MJ, editors. *Networks, Markets & People*. NMP, Lecture Notes in Networks and Systems, 1184. Cham: Springer; 2024. DOI: 10.1007/978-3-031-74608-6_33
- [2] Greco S, Lazzari M. Diplomazia scientifica e patrimonio culturale: il caso del Sudan. In: *Volume Conferenza del Dipartimento Scienze Umane e Sociali e Patrimonio Culturale su “La pace: il punto di vista della scienza. Dinamiche di pace positiva”*. Rome; 2024. pp. 42-44. Available from: <https://www.dsu.cnr.it/wp-content/uploads/2024/12/Abstract-Conferenza-DSU-La-pace-il-punto-di-vista-della-scienza-Dinamiche-di-pace-positiva.pdf>
- [3] Mohamed AA, Anderson JR. *Highlights from the Sudan National Museum*. Khartoum: The Sudan National Museum; 2013
- [4] Mohamed AA. *Sudanese Cultural Heritage Sites. Including Sites Recognized as the World Heritage and those Selected for Being Promoted for Nomination*. Khartoum: Sudanese National Corporation for Antiquities and Museums and UNESCO; 2014
- [5] Rilly C. *The Sudan National Museum in Khartoum. An Illustrated Guide for Visitors*. Khartoum: SFDAS; 2013
- [6] UNESCO. *The Monuments of the Kingdom of Kerma and Dokki Geil*. 2022. Available from: <https://whc.unesco.org/fr/listesindicatives/6594/> [Accessed: 3 July 2022]
- [7] Bonnet C. *The Nubian Pharaohs*. New York: The American University Press; 2006
- [8] Gunter-Bassett M, Bassett HF, Hanson K, Welsh W, Fitzgerald K, Maher A, et al. *Cultural Heritage Monitoring Lab Rapid Report: Damage to the Sudan National Museum (18 May 2023)*. Virginia Museum of Natural History, Cultural Heritage Monitoring Lab; University of Maryland, Center for International Development and Conflict Management; Penn Museum, Penn Cultural Heritage Center; and Smithsonian Institution, Smithsonian Cultural Rescue Initiative. 2023. DOI: 10.25573/data.22963304. Available from: https://smithsonian.figshare.com/articles/online_resource/_strong_Cultural_Heritage_Monitoring_Lab_Rapid_Report_Damage_to_the_Sudan_National_Museum_18_May_2023_strong_/22963304
- [9] Bloss JFE. The story of Suakin. *Sudan Notes and Records (University of Khartoum)*. 1936;**19**(2):271-300
- [10] Sist L. *La Chiesa nubiana di Sonqi Tino. Un caso di studio integrato sul patrimonio culturale*. Scienze dell'antichità. Gorgonzola (MI): Edizioni Quasar; 2013
- [11] Tiradritti F, Naranjo Alcaide JC, Giovanni Vantini. *His Life, his Work, his Legacy*. Montepulciano (Italy): CCST & ISPM; 2021

SudanInnovation: Integrating Photogrammetry and Virtual Reality in Cultural Heritage Reconstruction

Muna Khamis Birra Ali and Amin Talha Hassan

Abstract

The chapter describes four concrete graduation projects carried out by students of Comboni College of Science and Technology in 2021 as applications of the training contents of the SudanInnovation project. The first group of projects has to do with Virtual Reality for Cultural Heritage and includes the reconstruction of an old city in view of gamification and the documentation of cultural heritage. The second group of projects has to do with the use of close range photogrammetry and photogrammetric surface.

Keywords: virtual reality, photogrammetry, cultural heritage, 3D reconstruction, ancient polychrome

1. Introduction

Computer science is the study of algorithmic processes, computational machines, and computation itself. Students are introduced into this science at Comboni College of Science and Technology through a bachelor degree in program in 4 years. This degree enhances the student's ability to handle software construction and create digital solutions to problems of social sciences, business, mathematics, engineering sciences, and information technology.

The finalist students are grouped in teams of three or four members who work together on a certain graduation project. In 2021, four groups of finalists chose to apply the learning contents of the SudanInnovation project to their graduation projects:

1. Applying virtual reality for Cultural Heritage of ancient Suakin through terrestrial photogrammetry. The students were Fath-Elrhman Mohamed, Mashair Madrasa, and Mubarak Eltahir.
2. 3D Reconstruction Documentation Website of Cultural Heritage in Sudan. The students were Yohanna Kornelious Kajamity, Linda Fardinato Santo, and Mohammed Elamin Elrashid.

3. Ancient polychromy: study and virtual reconstruction using close range photogrammetry for the Sudan National Museum. The students were Sara Gabriel, Mahasin Omer, and Omron Abdallrazig.
4. Photogrammetric Surface/Reconstruction from Imagery in Cultural Heritage (Designing Virtual Kerma Museum). The students were Bethlehem Tesfahun Tebeje, Mona Mohamed, and Idris Abdelrahman.

In the following batch, a new group of students, who had benefited from the training when they were still in the third year, also chose to apply what they learned during the project training to their graduation project: “Virtual Reconstruction of the medieval church of Sonqi Tino.”

The supervisors of these graduation projects were Muna Khamis (projects 1, 2, and 5) and Amin Talha (projects 3 and 4), both were doing their PhD research in related fields at the Sudan University of Science and Technology.

The chapter presents the four graduation projects executed in 2021.

2. Applying virtual reality to cultural heritage of Suakin

Computer games with complex virtual worlds for entertainment are enjoying widespread use. The popularity of video games, especially among younger people, makes them an ideal medium for educational purposes.

The term “serious games” describes a relatively new concept. It refers to computer games that are not limited to the aim of providing entertainment, but enable the collaborative use of 3D spaces for learning and educational purposes in a number of application domains. Typical examples are game engines and online virtual environments that have been used to design and implement games for non-leisure purposes, e.g., in military and health training, as well as in cultural heritage.

While the widespread use of gaming for leisure purposes has been well documented, the use of games to support cultural heritage purposes, such as teaching and learning history, or for enhancing museum visits, has been less well considered. The state-of-the-art in serious game technology is identical to that of the state-of-the-art in entertainment game technology.

As a result, the field of serious heritage games is related to recent advances in computer games, real-time computer graphics, virtual and augmented reality, and artificial intelligence [1].

The importance of these applications to cultural heritage has to do with the following reasons:

1. In case of pandemic or conflict, traveling would be unsafe, and sometimes it may be restricted.
2. Some cities started disappearing due to geological effects, abandonment, and natural catastrophes.
3. There are many people who are physically disabled due to injuries or old age, and they dream of visiting new places.

The second reason is particularly meaningful for the case of Suakin, which will be the object of our work. Thus, our project aims, through the virtual reconstruction of the city, to:

1. Break barriers that hinder tourists from visiting this historical city.
2. Apply virtual reality (VR) to the cultural heritage of Suakin and preserve it as an electronic version.
3. Increase knowledge about the city in an easy and affordable way for users.
4. Create the foundation for the development of a video game located in that city.

The city of Suakin, located on the coast of the Red Sea in the North of Sudan, has a long filled history as it was an important port and civilizational center. Its history dates back to 3000 BC when it was a port used by ancient Egyptians. Still today, it is Sudan's and Eastern Africa's port that lies closest to Mecca, which makes it the main port for Africa's pilgrims toward the Holy Ka'abah.

Suakin used to be considered the height of medieval luxury on the Red Sea, particularly after its incorporation into the Ottoman Empire in 1517 by Sultan Selim I.

After the opening of sea routes around Africa by Portuguese explorers, local merchants began to abandon the town.

The Swiss explorer Johann Ludwig Burckhardt visited Suakin in 1814 and found two-thirds of the homes in ruin [2]. The Khedive Ismail, Governor of Egypt and Sudan in the name of the Ottoman Empire, attempted to revitalize it from 1865. Egypt built new houses, mills, mosques, hospitals, and a church for Coptic immigrants.

But it became secondary to the city built by the British colonizer at the beginning of the twentieth century, Port Sudan. From that moment on, the Ancient city of Suakin started its total abandonment that has led to the sad situation it shows today.

2.1 Literature review

The success of games that cross over into educational gaming—or serious gaming, as well as games and virtual worlds that are specifically developed for educational purposes, all of which exist within a cultural heritage context, reveals the potential of these technologies to engage and motivate beyond leisure time activities.

A concept extremely related to those games is VR. This term refers to a computer technology that gives the illusion of being immersed in a virtual environment that does not really exist. Initially, in the wide world of Cultural Heritage, the aim of VR is to implement high-impact applications and functional purposes [3]. Recent advancements in VR technologies provide new opportunities for Cultural Heritage (CH) organizations to attract, engage, and support end-users more efficiently and effectively. Uses of such emerging technologies in CH can create unprecedented interactive experiences that scaffold users' learning, foster creativity, and collaboration, often-times through entertainment. However, several user studies have underpinned the necessity to further investigate and improve current approaches and practices related to the design, implementation, and evaluation of VR applications to meet and fulfill the needs and requirements of all involved stakeholders. One possible way to achieve this objective is through the provision of personalized VR user experiences that cater to the diverse characteristics and requirements of stakeholders [4].

Cultural heritage has been hard to be taught due to the lack of educational materials. In this sense, virtual reality has become a customer-ready product. Museums, for instance, can use this new means to enhance their exhibitions.

The main problem, however, is that such a tool was not thought for casual users. In order to adapt this new technology to short experiences such as the ones museums could provide, it is necessary to reduce the adaptation time to the new means. Different authors discuss how removing physical controllers in favor of visually tracked virtual hands could significantly reduce the time needed by casual users to adapt to new experiences, underlying the current technological limitations both in terms of technology and design [5].

Well-designed artificial environments meet three criteria: they permit students to experience high levels of presence, they are interactive, and they are autonomous [6, 7].

The first uses of VR applications focusing on cultural heritage in the classroom employed gamification as a learning technique. Nowadays, there is an abundance of research on educational proposals to work with heritage based on games created *ex professo* making use of pre-existing video games and their historical settings, such as *Assassins Creed* or its educational versions, *Classcraft*, and *Minecraft Education* edition. In the field of heritage education, there is currently a significant increase in the presence of applications based on geolocation, augmented reality (AR), and virtual reality (VR) [8].

First and foremost, while many aspects of applications and uses are explored in current literature, certain important aspects remain understudied, such as the impact of VR on the social experience of museums and the critical analysis of the overall impact of emerging technologies on museological approaches. Moreover, what is usually left out of the equation are the perceptions, needs, and aspirations of museum professionals who are responsible for the objects and narratives of a museum. Museum professionals are also placed in the unique position of being able to observe the interactions of their visitors with VR technologies and how these technologies might change the flow of an exhibition or the social interactions of visitors.

Thus, the emphasis of the study by Shehade and Stylianou-Lambert [9] is to explore and understand museum professionals' experiences, perceptions, and practices rather than to provide an overview of technological solutions used or a discussion of technical challenges. Based on the insights gained, the chapter concludes with particular suggestions on the development of VR applications in museums that can be used as a guiding roadmap by both museum professionals and VR designers.

If we compare our work with the multidisciplinary research project conducted on the Milan Cathedral for 8 years (2008–2015) [3], we will notice that virtual reality and 3D modeling technologies were used in both cases. Furthermore, the cathedral could only be explored like the city in our experiment which means there is no interaction. Both experiments use building modeling systems. On the other hand, this experiment focuses on a certain place, which is the cathedral, while our experiment covers a larger-scale place that is a city. This experiment uses VFD software, which discovers the damages unlike ours.

Moreover, the research carried out by Cantatore, Lasorella, and Fatiguso [10] states that digitalization and interactivity of reality in virtual environments represent the synergic union between current technology potentialities and smartness of users in going beyond the traditional perception of real environment. Starting from the survey of instruments and protocols in previous experiences, the work presents a methodological flow aimed to create a virtual environment using 360° images—Virtual Tour—where the first phase of technical knowledge in historic sites can be

resumed. The protocol has been applied to the undergrounded Cryptoporticus of Egnatia, an archaeological site in Apulia Region (Italy).

VR for Cultural Heritage research presented here aimed at applying new VR immersive techniques to the field of architecture and facility management. The main goal was to evaluate how VR could be used in the sector of Cultural Heritage as a support for conservation and maintenance activities. The work represented the follow-up of the previous research activities of survey and modeling of the main spire of the Milan Cathedral [3]. The research work led to the creation of a complete high-resolution 3D model, currently used as a support of the maintenance activities of the Cathedral.

The main difference between this project and ours is that the Italian project involved just one building, the Cathedral of Milan, while ours has to do with the whole city of Suakin. A Building Information Modeling (BIM) System was used in the above research, while we used virtual reality with Unity.

The research by Cantatore, Lasorella, and Fatiguso [10] concludes that in addition to its promotion through virtual reality, the Cultural Heritage sector represents the main beneficiary of VR tools still in technological growth. The tourist-cultural fruition, the reconstruction of environments or parts of them, as well as the creation of virtual environments as databases of the cultural information in a digitalized version represent the applications already validated in the Architecture and Cultural Heritage fields. This research is similar to ours as both focused on the creation of virtual environments as 3D models.

2.2 System analysis

The main goal of this research is to develop a methodological process based on VR technologies and tools in order to support all the operators involved in the knowledge phase, for any kind of Cultural Heritage. In fact, the proposed methodology aims at the digitalization of knowledge, overcoming the traditional process of knowledge for the state of conservation and decay of a cultural site, as well as the process of cataloging and sharing the collected data.

Finally, the Virtual Tour software that uses panoramic images allows the creation of digital environments. This virtual tour is composed of three classes of elementary unities: the scenes, pro-builder, and first person. The scenes allow the fruition of the single virtual sub-environment and the media with contents in different formats (.jpeg, .pdf, .tiff, .doc).

The researchers collected 3827 photos of the remains of the ancient city of Suakin during 7 days. The photos were taken from 6:00 am to 9:00 am and from 5:00 pm to 6:00 pm with different cameras: Canon EOS 600D 16Pixel, Google Phone-Pixel XL2, Iphone 8 Max, Huawei Mate 10 Pro, and a Fuji FinePix HS30EXR.

These photos were mainly taken from the following sites of the ancient city: Kitchener's Gate, Khorsheed Basha House, Ahli Egyptian Bank, a Private Museum, Al-Shafeai Mosque Center, Mohammed Bek Shinawi House, and Province Entrance (**Table 1**).

When taking the photos, it is important to set the camera to manual mode 1/200, f9.0, ISO 100, and Raw.

It is convenient to take as many photos as possible, because the more photos you get, the more details and clarity you will get, and to take them from every perspective and different locations. There are also some things to avoid like moving light sources or shadows, reflective or transparent surfaces, and capturing your own shadow.

Raw image				
Taken on	21/3/2021	22/3/2021	22/3/2021	22/3/2021
Taken at	7 am	8 am	8:28 am	9 am
Camera model	Google Pixel 2 XL	Google Pixel 2 XL	Huawei Mate 10 Pro	Huawei Mate 10 Pro
IOS speed	61	43	50	50
F-stop	f/1.8	f/1.8	f/1.6	f/1.6
Exposure time	1/4676	1/3906	1/2924	1/3906

Table 1.
Photo collection.

In order to get maximum resolution, it is necessary to set the focus to manual, so that the camera does not autofocus for each image.

As for the processing of images, the researcher team used a Core i7 series Intel processor with the following specifications: 8 GB of RAM memory, Hard drive with 512 GB, Graphics Card—2 GB AMD with Windows 10 Professional as Operating System.

The software the researchers used were: 3DF + Zephyr, 3D Max, Unity Game Engine, and Agisoft (Figures 1 and 2).

After collecting the photos, the researcher team started creating the 3D Models (Table 2).

The phases of the project design the team followed can be summarized in Table 3.

2.3 Design and implementation

The team visited Ancient Suakin to visualize and inspect the urban planning and architecture of the city and look at the island basin from different perspectives. The following photo presents the city in 1970 (Figure 3).

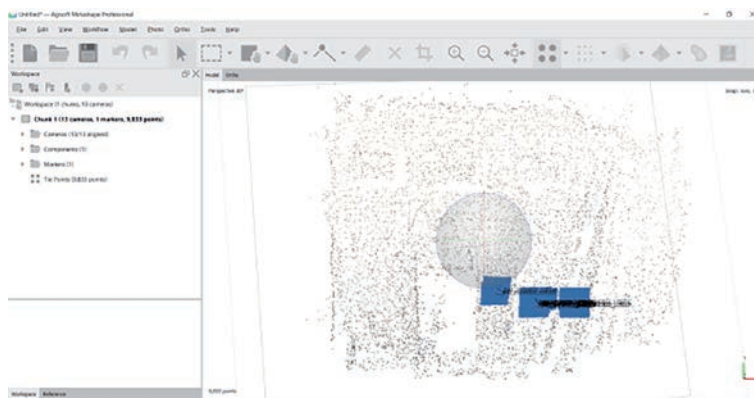


Figure 1.
Aligning with Agisoft.

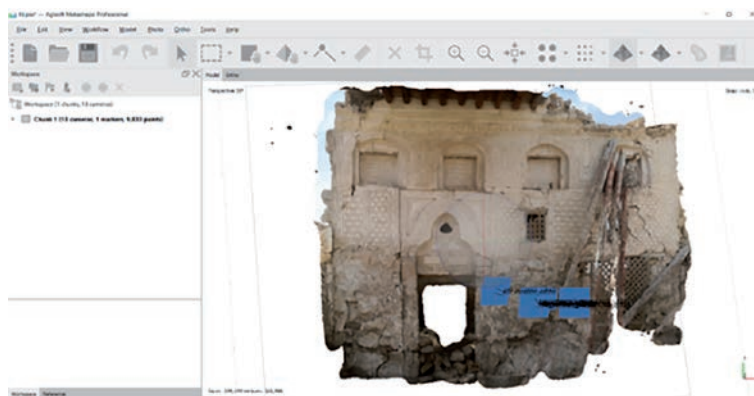


Figure 2.
Exported 3D model.

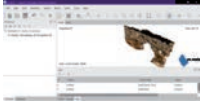
3D image				
Date	1 July 2021	25 May 2021	1 May 2021	2 June 2021
No. of photos	18	16 out of 66	34	20 out of 21
High definition mesh	4	2	2	2
Exposure time	3 hours	8 hours	1 hour	7 hours

Table 2.
Creating the 3D models.

	Activity	Software		Activity	Software
1	Capturing photos	AGISOFT	11	Creating the Unity Hub	UNITY
2	Adding photos		12	Install Post Processing and Pro-Builder from package manager and add it from tools	
3	Aligning photos		13	Install First Person All-in-One package from the asset store	
4	Building dense point cloud		14	Adjust 3D object using Face and Edge Selection	
5	Building mesh		15	Flip object using Flip Normal then add Spotlight and control the feature of light by Inspector	
6	Building texture and saving the object		16	Texture file created in Asset	
7	Building tiled model		17	Textures downloaded from TextureHeaven	
8	3D model export		18	Add Camera, then delete the main camera	
9	Modifying the model	Sketchfab	19	Press Play to test object	
10	Uploading the model to Sketchfab		20	New material created in folder and named Post	
			21	Picture adjusted in Albedo	
			22	Add Camera, then delete the main camera	
			23	Add new plane from 3D object	
			24	Alter light to view the plan	
			25	TextMeshPro used to add text	
			26	Build and run from Build Settings	
			27	Displaying as a model	

Table 3.
Phases of the project.

The following picture instead presents the city as the researchers found it in 2021 (**Figure 4**).

Outdoor photos were taken from various places on the island at different levels. With that material, using Unity software, a virtual reconstruction of the island of Ancient Suakin was produced.

The first step was to create a Unity hub. After starting a new 3D project, from the *package manager* in windows, *Post Processing* and *Pro-Builder* were installed.

The First Person All-in-One package was installed from the asset store. Pro-Builder was added from the tools. A new shape was added. Using Face Selection, the shape was dragged to be modeled as a 3D Object. This 3D Object was partitioned using Edge Selection. More adjustments were made using Face Selection again.

Then the object was flipped using Flip Normal. Spotlight was added by right clicking. Feature of light was controlled by Inspector. A folder was created in Assets and was named Textures. Textures were downloaded from TextureHaven. The material



Figure 3.
Old photo of Ancient Suakin taken in 1970.



Figure 4.
Ancient Suakin in 2021.

was created, and its characteristics were adjusted. Then, using Face Selection, wanted faces were chosen and material was added to them. The SHIFT key is held to select multiple faces.

First Person All-in-One package was added to the theme from the Assets. The feature was unlocked. The Camera was added and adjusted properly. Then the main camera is deleted.

New Post Process Volume was added by right click. More effects mean more CPU usage, which demands a device with high specifications.

The object was tested by pressing on Play. Movement around the object is possible using WSAD keys. You can press “Ctrl + P” to exit testing mode.

A Media folder was created by right click, and assets, pictures, and videos were added to media folder. New material was created in the folder and named Post.

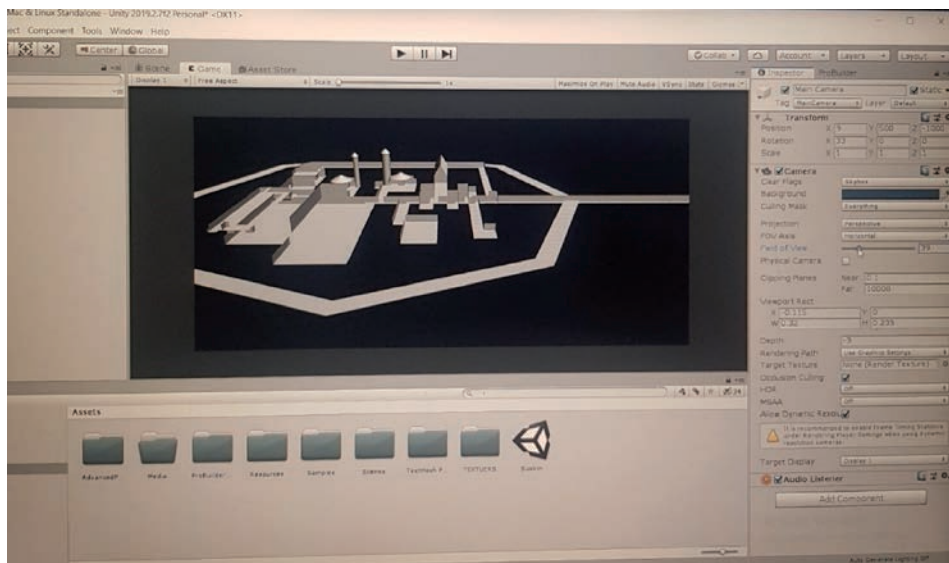


Figure 5.
Designing the Island model.

The picture was put in ALBEDO and then adjusted. A new plane was added from the 3D Object. The object was dragged to the plane. Then the plane was adjusted to fit on the wall. The light was altered to view the plane. The process was repeated using other pictures. Text was added from TextMeshPro by right click and text examples were imported. The text was added, altered, and positioned. Unity Project is built and run from Build Settings.

The entrance of the island was designed first. The entrance led to Kitchener's Gate. Going to the left after the gate, you could find a Catholic church which was designed next. Then, the Shams House, which belonged to a merchant, was also designed. The buildings were dense, yet there were spaces and open areas, so they were designed accordingly. After that, other buildings were successively designed: the houses of Mohammed Bek Al-Shinawai, the admiral Mohammed Bek Ahmed, which was close to the gate, and the merchant Mohammed Saeed Siyam's.

Then the team designed the workers' apartments, the customs building, the site of the Province Gogern, Al-Hanafi Mosque, Al-Shafiei Mosque, Khorsheed Basha House, and Al-Ahli Egyptian Bank (**Figure 5**).

3. 3D reconstruction documentation website of cultural heritage in Sudan

While cultural heritage preservation has not yet become firmly rooted in Sudan, a great number of people and organizations see cultural resources as critical to the nation's economic development through tourism. Cultural heritage is based on the aspects of a nation's past that we want to keep and pass on to future generations and the outside world. However, the economic benefits of preservation are secondary to the intrinsic value of that heritage which has been preserved. The nation's heritage is needed like food, water, and shelter (**Figure 6**).

But in a context where warfare destabilizes states and environmental disasters upend communal order, heritage is often seen as dispensable. That is the wrong



Figure 6.
Ram-headed god Amun protecting King Taharqa (690–664 BC) in front of the gate of the National Museum.

approach. Heritage is not just a link to the past. It is a catalyst that can uplift communities economically, culturally, and spiritually now and for generations to come. This is what people call the world “beyond monuments.” The nation owes its success to everyone from the ancestors. Preserving heritage is one way of giving back to ancestors and making sure the next generations have something to be proud of. Libraries, archives, and museums hold dispersed collections in a variety of media, presenting a vast body of knowledge accumulated over the institutions’ history. The mission of these institutions is to make their collections accessible to intended users.

In particular, the Sudan Military Museum collects diaries, military items, and weaponry used by the Sudan Armed Forces, particularly after the Second World War (**Figure 7**).

Another relevant museum, the most famous one, is the National Museum of Sudan. Its collection includes hundreds of artifacts, statues, temples, and other historical objects that reflect the history and the identity of the nation since its inception. So, the preservation of this museum should be a priority for the whole nation.

Thus, there is a need to document this cultural heritage, particularly that kept in these two museums, by designing 3D models for their objects and features that have a historical importance to be part of the heritage conservation project and to make them available on a rich website for tourism.

These 3D models may also help in the future in the restoration of these pieces, just in case of partial or total damage to the specific artifact (**Figure 8**).

A model can be created automatically (with the help of a 3D scanner) or manually by a 3D modeler (using special computer programs). Quite often, 3D modeling refers to the process when a designer creates a 3D model using software—in this case, the term is related to digital sculpting. The modeling types are polygonal, spline, and non-uniform relational spline (**Figure 9**).

3D modeling is the process of creating a three-dimensional model of an object. Using 3D, it is possible to capture size, shape, and texture of a real or imaginary object. The first 3D models were created in 1960s. Back then, only those professionals in the field of computer engineering and automation who worked with mathematical models and data analysis were involved in 3D modeling. A pioneer of 3D graphics is



Figure 7.
Weaponry at the Sudan Military Museum.



Figure 8.
Granite columns in the garden of the National Museum brought from the Cathedral of St. Peter of Faras.

Ivan Sutherland, the creator of Sketchpad. This revolutionary program helped to create the first 3D objects. Sutherland, along with his colleague David Evans, has opened the first-ever department of computer technologies at the University of Utah.



Figure 9.
3D model of the Stewart Crawler Tank located in the Military Museum.

In this project, we applied these technologies to face a problem: the lack of clear guidelines for visitors and tourists to the different cultural heritage sites in Sudan, such as the National Museum and the Military Museum. Besides that, the maintenance and restoration of archaeological artifacts damaged due to natural conditions or human intervention is a major challenge to the management of the museum because of the lack of clear documentation of these pieces.

Thus, the main purpose of this research is to understand the benefits of utilizing interactive 3D visualization by designing a 3D model for these two museums to assist the visitors, the museum administration, and any eventual rehabilitation project to have easy access to all the resources inside the museum.

3.1 Literature review

The use of 3D information in the field of cultural heritage is increasing year by year, and consequently, the production of scientific literature.

We examined a paper that describes a web-based 3D reconstruction service [11]. The process starts with the user uploading images of an object or scene(s) he wants to reconstruct in 3D. The automatic reconstruction process, running on a server connected to a cluster of computers, computes the camera calibration, as well as dense depth (or range) maps for the images. The researcher keyword in this page is 3D reconstruction web service for Cultural Heritage. The main architecture used in this research of the combined 3D system is a local application that prepares and checks the photos collected by a user and uploads them to a web service.

The second study [12] focuses on using a combination of terrestrial laser scanning and unmanned aerial vehicle (UAV) photogrammetry to establish a three-dimensional model and the associated digital documentation of the Magoksa Temple, Republic of Korea.

An important element for us from this study is the importance of selecting a suitable scan position for the object of interest. In this study, the field scan was performed from 82 positions, considering various factors such as the measurable range and overlap. In addition, the stone pagoda of the temple, a key part of the heritage site, was scanned from 24 positions by dividing the pagoda into lower and upper sections based on its height. The study demonstrates the potential for using the integration of terrestrial laser scanning and UAV photogrammetry in 3D digital documentation and spatial analysis of cultural heritage sites.

The third paper we revised presents a modular software and hardware independent system that can be used for the digitalization of 3D cultural objects, monuments, and sites [13]. The clouds of 2D or 3D scanned points (matrix oriented or scattered), even the 3D wireframe models, are acquired by photogrammetric techniques using different digitizing strategies in various topics of cultural heritage. This input can be processed using an efficient algorithm for the reconstruction of the digitized object. If the digitalization delivers a complete set of scanned 2D or 3D data from all sides of the object, then the volume or so-called solid structure can be calculated.

The fourth paper we revised examines the methodology of the 3D computer reconstruction of cultural heritage and the still unresolved questions of certification, classification, annotation, and visualization, in particular within the digital reconstruction of architecture and interior decoration that have not survived [14].

The fifth paper [15] presents two distinct approaches for 3D reconstruction of the historical city of Nafplio (Greece), by developing 3D models for buildings and monuments, the way they used to be in the nineteenth century. The authors aim (a) to present the importance of reconstructing past cities and (b) to implement gaming technologies in cultural organizations as a means of achieving specific educational goals. Results point out the growing need for close cooperation between the cultural and academic worlds with 3D creators, and, moreover, reveal obstacles and opportunities in reconstructing historical cities and monuments.

Even if 3D modeling technologies have gained importance as tools for the reconstruction and visualization of Cultural Heritage artifacts during the last decade, there is still only little systematic research about how and for which purposes these technologies are used. Further on from a methodological perspective, it would be necessary to understand how 3D modeling is affected by disciplinary boundaries and challenges specific to historical topics. For the investigation of these topics, the authors of the sixth paper we examined have completed a content analysis of 478 conference papers and articles related to 3D reconstruction modeling in the field of humanities. The main objective was to identify current topics, technologies, and institutions involved (**Figure 10**) [16].

After this quick literature review, we can conclude in relation to other studies that ours examines the methodology of the 3D computer reconstruction of cultural heritage and the still unresolved questions of certification, classification, annotation, and visualization, in particular within the digital reconstruction of architecture and interior decoration that have not survived.

3.2 Project planning and data modeling

The objective of this research is to support decisions for the development of virtual museum models by presenting a documentation website of cultural heritage in Sudan and a structured overview of 3D reconstruction that are likely to be *applied in 3D modeling*.

Data modeling is a process used to define and analyze data requirements needed to support business processes within the scope of corresponding information systems in organizations. It includes images captured by scanning buildings for dense image matching, point cloud files (Las data format), files available from point clouds for 3D model construction, documentations related to the Museum information (**Figure 11**).

The project workflow process consists of: Capturing photos, preprocess, filtering of the photos for the generation of a 3D model by using Agisoft application, a photo scan application that has made the complex algorithms necessary for processing



Figure 10.
World War II fighter aircraft at the Sudan Military Museum.



Figure 11.
Artillery piece with a protective shield from the Sudan Military Museum.

photos into 3D reconstruction accessible through a fairly simple to use graphical interface. It offers much greater control of each stage of the process and will let us produce much more accurate result [17].

Building a 3D reconstruction model for different statues located at two museums in Sudan, the National and the Military Museum, used Sketchfab, a platform to empower 3D creators. This software makes it easy for anyone to upload, publish, embed, buy, sell, and find 3D content online. With a community of millions of

creators who have published millions of models, they are the largest platform for immersive and interactive 3D content.¹

Then document them on a website by programming it in JavaScript, a high-level, dynamic, interpreted programming language that has been standardized in environments that are not web-based. They also used cascading style sheet (CSS), a style sheet language describing the presentation of a document written in markup language, and Hyper Text Markup language (HTML).

For this project, they used an Intel(R) Core(TM) i5 CPU processor with 4 GB of RAM, a Hard Disk of 500 GB, an external Hard Disk, and a Fujifilm Finepix EXR camera.

3.3 Simulations and results

A 3D model of two Sudanese museums has been designed using modern photogrammetry techniques. The first step to create this 3D model is getting the images of the targeted place by using available cameras. Then, a set of overlapping images has been collected panoramically using a Fujifilm camera. In order to start with creating the 3D model, first the point clouds of the building and statues are generated from the collection of overlapping photos that have been taken earlier by the camera using dense image matching algorithms.

After that, they uploaded the 3D model in Sketchfab and saved it. Sketchfab software works well for texture mapping and allows customizing and duplicating any shape or repeated pattern. This procedure is useful for creating virtual reality models (**Figure 12**).

The Agisoft PhotoScan prepared 3D model must be exported to a file with (.obj) extension.

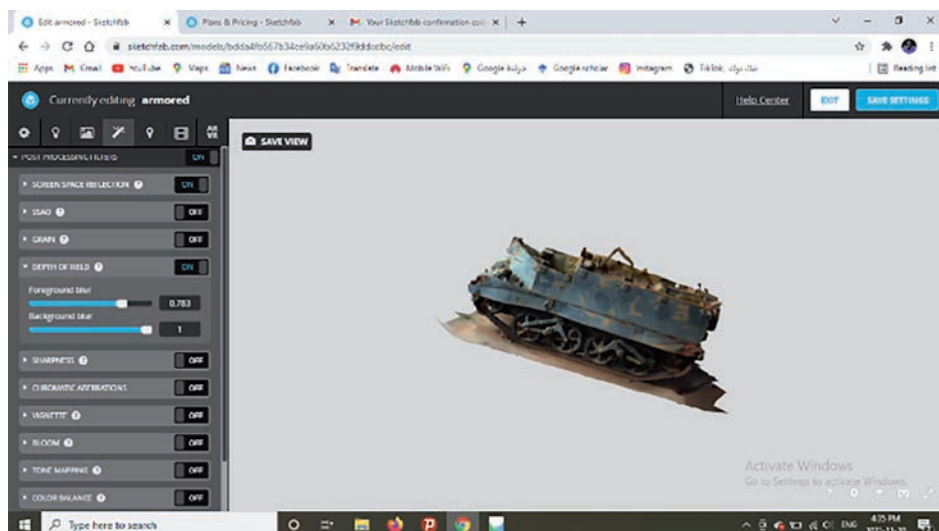


Figure 12.
Model after importing.

¹ Cf. <https://learnbrite.com/academy/using-sketchfab-3d-models-in-webxr/>.

4. Ancient polychromy: Study and virtual reconstruction using close range photogrammetry for Sudan National Museum

The Sudan National Museum in Khartoum is considered one of the most important Sudanese historical legacies and contains hundreds of artifacts, statues, temples, and some of the twists and turns and historical events that it has gone through since its first inception and until this day, so we find that preserving this museum and its components should be a priority.

This research aims to detect and describe multi-colored artifacts by collecting some pictures from real artifacts whose colors and parts have deteriorated over time, and using the technique of reconstruction and multi-coloring to improve these pieces and display old and new images of artifacts-related pieces to improve their value.

For this purpose, we use the technique of polychrome, which reveals and describes multi-colored artifacts by collecting some pictures of real artifacts that have lost some of their colors and parts over time, and using the reconstruction and multi-coloring technique to improve these pieces and display old and new photos of the relevant pieces to add more of their value.

As traces of colors gradually decay and disappear due to factors such as climatic conditions, light/radiation, etc., these documents will, over time, serve as the only evidence of the original paintwork of sculptures and other objects, which were of crucial importance for their aesthetic appearance in antiquity.

To form the basis for continued research into polychromaticism, as well as to ensure that ancient polychromaticism can be accessed for future research and educational purposes, significant requirements are expected from these documents. Thus, polychromatic research plays a major role in efforts to preserve our cultural heritage for future generations, which is among the museum's most important responsibilities.

Photogrammetry instead enables precise 3D measurements using images. To be able to extract precise measurements, the geometry in which the images are captured, the quality of the cameras and lenses used, and the in situ calibration of the camera are all important [18].

The object of our work was a wall of the temple of Buhen in the Sudan National Museum (**Figure 13**).

The general objectives were to create a website that contains 3D objects using realistic image models with multi-color techniques. In this way, the project will provide a better knowledge of the original polychromy via the production of virtual reconstructions and a better knowledge of ancient color (and gilding).

4.1 Literature review

There are many researches done in the field of Ancient polychromy and virtual reconstruction using close range photogrammetry (3D digitization, visualization, and 3D printing...). These technologies have developed together to the point that they can be merged for different purposes.

This project combines and applies them to cultural heritage. Thus, we examine three case studies: one related to the use of 3D technologies for documenting and presenting artifacts; another one related to 3D collection by the Digital Library of Slovenia; and a third one related to the use of technologies for the restoration of a museum object.



Figure 13.
Buhen Temple.

The first study [19] has to do with Polynomial Texture Mapping, an image capture and processing technique that was developed by HP Labs in 2000. It enables the recording and representation of subtle surface details using a standard digital camera and lighting, and software that is free for non-commercial use.

When compared with our project, we find that in both projects, the images that were captured of the shape in question are relied upon by a standard camera with high specifications, and the images are processed by software.

A difference is that the study of Earl, Martinez, and Malzbender focuses on wood-work wall panels and metals and discusses the possibility of laser scanning, while our project focuses on wall paintings and the pictures are taken and processed by applying the reconstruction technology and by coloring them.

The second study [20] presents a project aimed at the scientific reconstruction of the original polychromy and the realistic rendering of an ancient sarcophagus, obtained with the use of some open source tools. The authors show how the MeshLab tool was used to support the polychrome reconstruction stage and how a combination of MeshLab and Blender was used to achieve a more sophisticated visual presentation of the current and reconstructed ancient color. A central role has been given to the rendering of different and overlapped layers of paint.

In our case, we use a combination of Agisoft and MeshLab. The third study [18] presents projects related to the successful combining of 3D technologies for documenting and presenting artifacts, for 3D collection by the Digital Library of Slovenia, and for the restoration of museum objects. The study included a description of how the Mesh Lab tool was used to support the polychrome reconstruction stage and how a combination of Mesh Lab and 3D Max was used to achieve restoration of a museum object, a stemmed fruit bowl, using reconstructed 3D printed fragments.

4.2 Requirements, specifications, and tools

For our work, we used a computer with the following specifications: Processor Intel (R) Core(TM) i7-4700MQ, CPU@ 2.40 GHz 2.40 GHz, RAM 16 GB, System type 64-bit operating system, x6-based processor.

Our camera was a Canon EOS. For the highest quality of photos, we saved the photos as JPG, set white balance to auto, and self-timer to 2 seconds. We turned the Mode Dial to Av (Aperture value) Mode, set aperture to F9, ISO to 100, and disabled automatic image orientation.

In terms of camera settings, it is important to have consistency between the photos. Focal length, focus, ISO, and aperture should remain consistent for the best results. The lowest aperture setting you should use is f/5.6. If possible, it is better to shoot with a higher aperture, but keeping in mind that the higher the aperture, the slower the shutter speed should be. If the shutter speed slows down, we recommend setting the camera on a tripod.

The camera focus should not be changed after the initial image and the ISO setting should be as low as possible to reduce graininess. We took shots around the subject every 10 to 15 degrees. After completing a 360-degree ring around the object, we checked if there was any part of the object that was not clearly visible from the first set of pictures. If so, it can be necessary to take additional rings of photographs.

The software we used instead was Agisoft Metashape Professional, as it maximizes the possibilities of photogrammetry. It incorporates machine learning technologies for analysis and post-processing to deliver the highest accuracy results.

Metashape makes it possible to process images obtained with RGB or multispectral cameras, including multi-camera systems, and to convert photographs into dense point clouds, textured polygonal models, geo-referenced orthophotomap, and digital elevation/terrain models (DEM/DTM). The ability to export to all external post-processing packages makes Agisoft Metashape Professional a versatile photogrammetric tool.

Another software we used was *Imagej*. It is an image processing program. DStretch is a tool for rock art researchers who wish to enhance images of pictographs. It is a plugin to Imagej. The program contains color space buttons which perform a decoration stretch in the color space.

We have implemented the algorithm in the standard RGB and LAB color spaces. Also in the color spaces we have created: YDS, YBR, YBK, LDS, LRE. These color spaces are modifications of the YUV or LAB color spaces that we have found to give good decoration stretch results on images of rock art. The YDS and LDS color spaces are good for general enhancements and can bring out faint yellow pigments. YBR and especially LRE enhance reds. YBK can help with black and blue pigments and also enhances yellows well.

We also used *MeshLab*, an open-source Windows software for *processing and editing 3D triangular meshes*. It provides a set of tools for editing, cleaning, healing, inspecting, rendering, texturing, and converting meshes. It offers features for processing raw data produced by 3D digitization tools/devices and for preparing models for 3D printing.

We programmed in JavaScript, a high-level, dynamic, and interpreted programming language.

We also used cascading style sheets (css). It is style sheet language used for describing the presentation of the document written in a markup language.

With all these elements, the process could be described as follows (**Figure 14**):

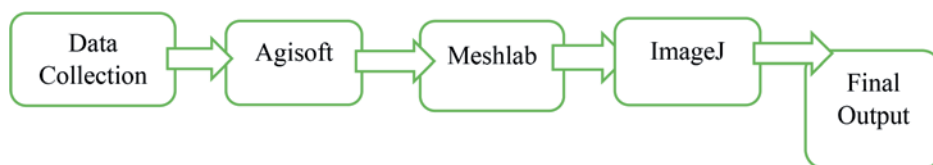


Figure 14.
System workflow.

4.3 Design and implementation

In this section, we present the stages of the process we followed in this research. We took the photos (data collection) using the interlacing technique (**Figure 15**).

Secondly, Agisoft is used, a program in which images are analyzed in a series of steps. Firstly, the photos should be “added” under the “Workflow” tab. Once all photos are loaded, select “Workflow” → “Align Photos.” During this process, Metashape will compare each photo to every other photo (**Figure 16**).

At the end of this process, you will see a series of dots on your screen in the rough outline of what you are trying to model.

For the next step, click on “Workflow” and then select “Build Dense Cloud.” This process is similar to the “Sparse Point Cloud” stage, but it will take much longer because the software analyzes each photo more closely and builds a much denser point cloud. Once this stage is complete, it will look like you have a completed model, but if you zoom in, you will see thousands of individual points.

The final step consists of generating the base model of your object or environment which means to turn the dense point cloud into a mesh. Select “Workflow” → “Build Mesh” and accept the default parameters. At the end of this process, you will have a 3D model that can be exported for printing or loaded to a site like SketchFab for display (**Figure 17**).



Figure 15.
Data collection.



Figure 16.
Overlap of images.

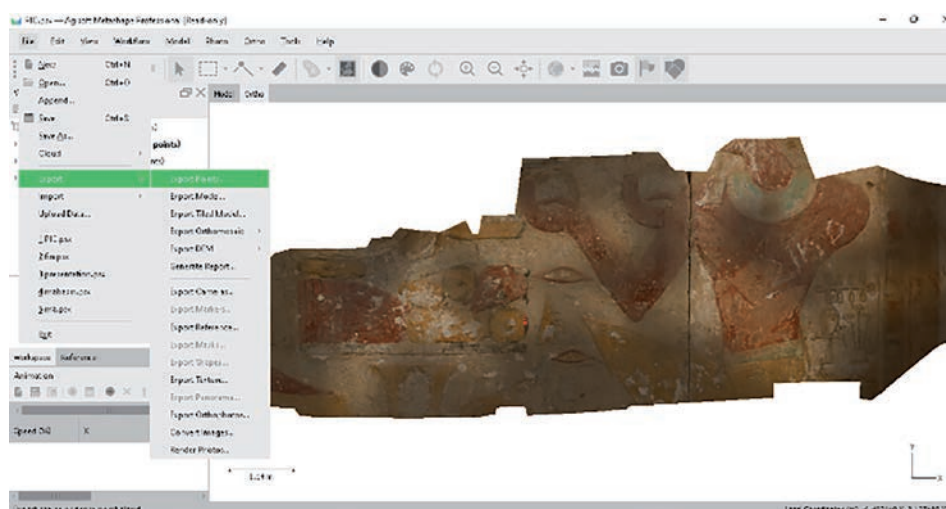


Figure 17.
Model to be exported.

The following step is to build texture. Select “Workflow” → “Build Texture” and apply the default settings. This option creates a texture based on an analysis of the loaded photographs. Once the texture is complete, the software will wrap it around your model, adding a much higher level of detail than the previous model coloring.

Then we build the tiled model. After that, we build orthomosaic, and finally, we export the model. For that purpose, select File > Export Model. If you are going to print the file, select .stl as the file format. If you are going to display the file online, we would suggest exporting as .obj, dae, or .fbx.

After this, we import the file with Meshlab. We select the following options: Filters → Cleaning and Repairing → Remove Isolated (wrt Diameter), and we save the final mesh (**Figure 18**).

From that moment, we shift to ImageJ software. In this software, it is possible to see a considerable difference in what is easily visible out in the field and what DStretch can uncover through sophisticated color manipulation algorithms (**Figure 19**).

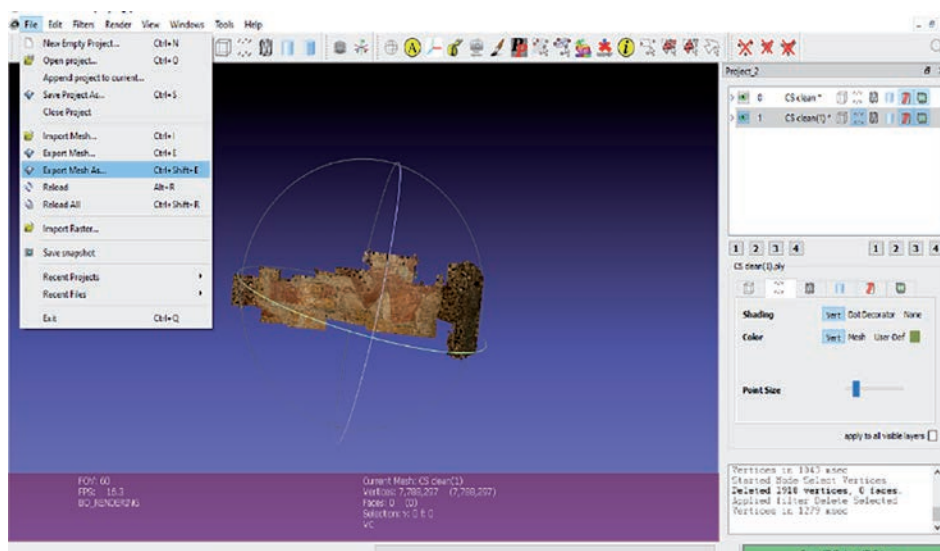


Figure 18.
Final mesh.

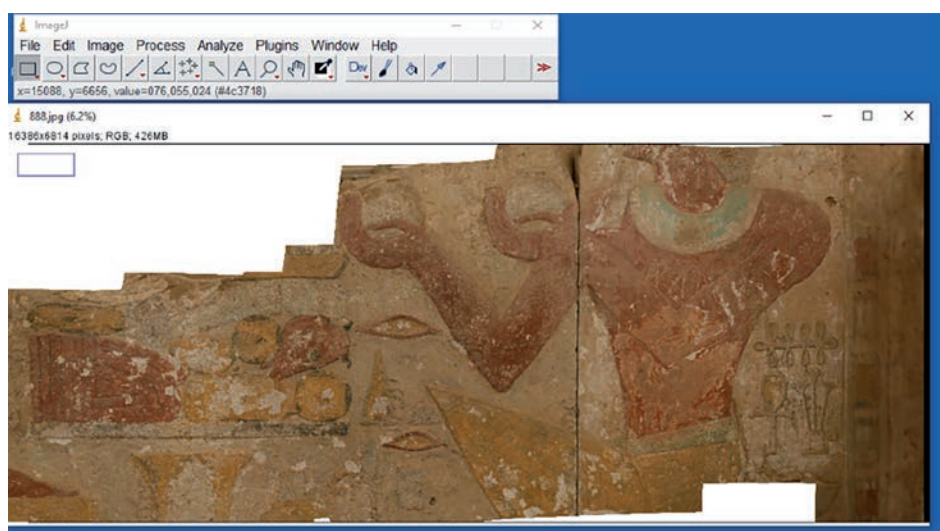


Figure 19.
Image in ImageJ.

DStretch is only a plugin to the modular image application ImageJ.

Thus, we open the photo in ImageJ using the file > open menu, to get a basic enhancement. Then we run DStretch on the image. Do this by selecting the “plugin > DStretch > DStretch Run” menu (**Figure 20**).

We can see different color enhancement options. We just click a different color enhancement type. Examples of default color enhancement options are: LDS, LRE, and CRGB. Finally, we save the DStretch photo.

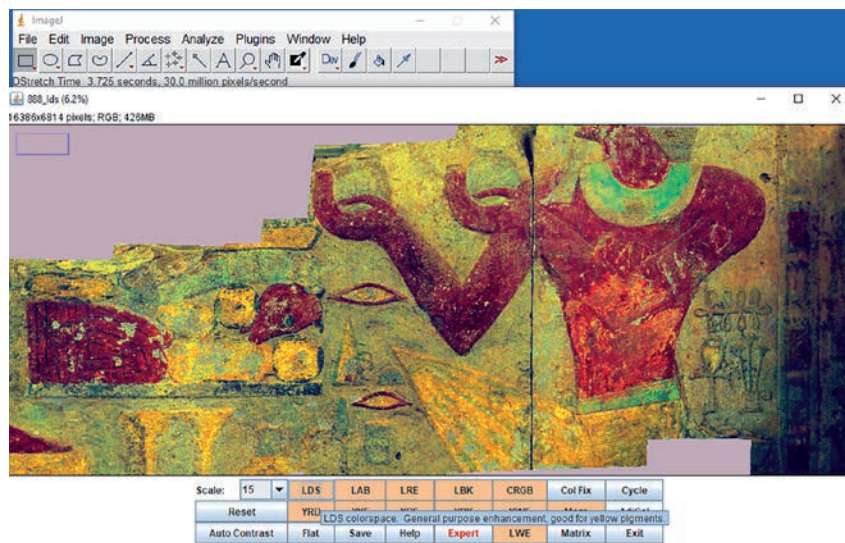


Figure 20.
Color enhancement.

5. Photogrammetric surface/reconstruction from imagery in cultural heritage (designing virtual Kerma museum)

The historical locality of Kerma is 600 km far from Khartoum, the capital of Sudan. Thus its museum, even if located at one of the main archaeological sites of the country, receives few visitors and is not known neither by Sudanese nor by foreign tourists.

This is one of the reasons why it looks relevant to model a virtual visit to that museum. The work will also help documenting, managing, and preserving its patrimony.

Therefore, the project consists of building a virtual visit to Kerma museum using 3D modeling and virtual reality.

Virtual reality is a high-end user interface that involves real-time simulation and interaction through multiple sensorial channels (vision, sound, touch, smell, taste). In other words, it is “a computer-generated, immersive, multi-sensory information program” which tracks a user in real time [21].

3D Modeling is the process of developing a mathematical representation of any surface of an object in three dimensions via specialized software [22, 23].

Photogrammetry is the science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena [24].

Thus, the project aims to develop a process to model the virtual museum visit using photogrammetry, virtual reality, and 3D modeling. This process will produce a website where viewers will be able to perform the virtual visit and find information on the museum.

5.1 Literature review

The students selected three studies that could enlighten the project we wished to develop. The first one is a paper that investigates and evaluates the results of the

photogrammetric methods and 3D surveys that should be used for the development of a virtual museum [24]. Moreover, the paper describes and analyzes the decisions, actions, methodology, and main elements that this kind of application should include. The case presents some similarities and differences with our study. Some similarities are:

- The objective of this case was to highlight the use and exploitation of 3D models in general, which can result from a photogrammetric process and be further used to alternative and innovative products like virtual museums, virtual reconstructions, serious games, etc. The production of 3D models with photogrammetric methods is a procedure that can definitely give precise and realistic results.
- The programming process and the development of the virtual museum in the platform of Unity Software.
- The museum characteristics such as its aim, needs, exhibitions, and collections should be identified and recorded as they are vital to the development of the virtual museum and its content.

The difference instead is that the overall museum structure expands in three dimensions (3D model of the building), while our project concept is to develop a virtual tour that displays a specific selected historical object (tool) in 3D model form.

The second study of reference has to do with the virtual visit to the Maritime Museum of Kotor (Montenegro). In this paper, the authors describe the concept of virtual tourism and present a virtual 3D model of that museum as a concrete example of their theoretical model [25].

The research has some similarities with our case:

- The 3D model of the museum was presented and the opportunity of virtual visiting of this museum was shown with the use of various tools and with application of intellectual technologies.
- The theme of virtual tourism and virtual tours is relevant. This project is important for the development of visualization. It is very significant for the creation of a platform with virtual models of the most significant sights of a historical and cultural orientation.
- It has common points that will help to attract the interest of different social groups of users.
- Visitors in the museum can watch an educational film, mounted from panoramic images of exhibits, which tells about museum, about the collection of different objects, and not only inside the museum but also objects and personalities outside it. Each visitor to the Kotor Museum will be able to download to his smartphone or tablet interactive maps and an application with the virtual thematic routes, as well as providing information about exhibits in different languages.

It has also some differences:

- The project was made for Windows operating system, which is used by most PC users.
- The 3D visual tours do not just refer to inner parts of the museum but also to objects and personalities outside it.

The third paper of reference has to do with the digitization of museums in a non-European context, like the Argentinean one. Virtual spaces for the dissemination of cultural heritage and virtual experimentation were developed, combining 3D image acquisition techniques like digital photogrammetry (captured reality) and computer 3D modeling. This is a novelty in peripheral countries, particularly in Latin America, since there is almost no development of this kind of virtual museums in the region [26].

This project presents the following similarities with ours:

- The case uses virtual software tools to create a virtual environment as model for VR and 3D object for 3D modeling the whole museum.
- Use of 3D image acquisition techniques like digital photogrammetry for 3D modeling collection, process, and representation of objects.

There are also some differences:

- In this case, the recharger is only used to represent the virtual museum in one platform as desktop.
- In photogrammetry, we use tools to process from two-dimensional images into 3D, but the recharger uses 3D image directly from the camera.
- In this work, two types of procedures have been presented to obtain digitized models of objects: CR objects reconstructed by digital photogrammetry and computationally modeled objects.

5.2 About Kerma

Kerma is one of the earliest urban centers of Sub-Saharan Africa. Around 2500 BC, this commercial and trade center that connected the Mediterranean with the interior of Africa “was the capital of a kingdom referred to in Egyptian hieroglyphic texts as the Kingdom of Kush” [27]. The town is made of elaborate defenses, an important religious quarter, and “countless domestic buildings, storage magazines, administrative, and industrial complexes” [27].

In 1700 BC, the Kingdom of Kush was the most powerful state in the Nile Valley. Kerma has produced decades of extensive excavations and research, including thousands of graves and tombs and the residential quarters of the main city surrounding the temple known as Western Deffufa.

5.3 System analysis and project flow

After doing a requirements analysis, we have defined the project flow for both the phases of the project design leading to the 3D model and the phases of the project design for the virtual tour (**Table 4**).

	Phases of the project design for the 3D model	Phases of the project design for virtual reality
1	Capturing image	Capturing photos
2	Adding image	Identifying the museum building as a map
3	Aligning photos	Museum construction map
4	Building dense point	Building the museum architecture
5	Building mesh	Importing (adding) the image sample
6	Building model texture	Exporting model into website
7	3D model export	
8	Modifying the model	
9	Uploading the model to virtual tour	

Table 4.
System analysis and project flow.

5.4 Tools

It is possible to create successful 3D models with any sort of camera going from phone cameras to high-end digital single lens reflex (SLR) cameras. Nonetheless, the better the camera's resolution, the better the photos and resultant 3D model will be. The minimum resolution is 5 megapixels.

In addition to the quality of the camera, it is important to consider that the narrow depth-of-field is a problem for photogrammetry because blurred details confuse the software. Our aim is to have high-detailed, sharp, and flat imagery. This requires closing up the aperture, which means to have a well-enlightened environment.

Optional equipment may be used to simplify or improve the photography. A tripod is perhaps the most useful piece of equipment that is used in photogrammetry since it enables us to take photos with longer exposure times, which is important when trying to get maximum depth of field.

The software specifically related to photogrammetry we used for this project were Agisoft Metashape, Unity, 3DF Zephyr, and Sketchfab.

Agisoft Metashape, known as Agisoft Photo Scan, is a tool for a photogrammetric pipeline. The software is available in Standard and Pro versions. The standard version is sufficient for interactive media tasks, while the Pro version is designed for authoring GIS content [28].

Unity is a cross-platform game engine developed by Unity Technologies, first announced and released in June 2005 at Apple Inc. Worldwide Developers Conference as a Mac OS game engine. The engine has since been gradually extended to support a variety of desktop, mobile, console, and virtual reality platforms.

The engine can be used to create three-dimensional and two-dimensional games, as well as interactive simulations and other experiences. The engine has been adopted by industries outside video gaming, such as film, automotive, architecture, engineering, and construction [29].

3DF Zephyr is a commercial photogrammetry and 3D modeling software. Developed and marketed by the Italian software house 3DFLOW, 3DF Zephyr was first released in January 2014 and has been continuously updated since then. It is a complete photogrammetry pipeline software package that includes many post-processing tools, measurement, 3D modeling, and content creation. It allows 3D

reconstruction from both photos and videos by automatically extracting frames and selecting those most suitable for the computation [30].

Sketchfab is a platform to publish, share, discover, buy, and sell 3D, VR, and AR content. It provides a viewer based on the WebGL and WebXR technologies that allows users to display 3D models on the web, to be viewed on any mobile browser, desktop browser, or Virtual Reality headset [31].

It is also important to consider the necessary languages to develop such a project. JavaScript is a high-level, dynamic, and interpreted programming language. It has been standardized in the ECMA Script language specification; JavaScript is also used in environments that are not web-based.

Cascading Style Sheets (CSS) is a style sheet language used for describing the presentation of a document written in a markup language [32].

Hyper Text Markup Language (HTML) is a markup language for describing web documents (web pages). A markup language is a set of markup tags. HTML documents are described by HTML tags. Each HTML tag describes different document content [33].

Bootstrap is a free and open-source CSS framework directed at responsive, mobile-first front-end web development. It contains CSS- and (optionally) JavaScript-based design templates for typography, forms, buttons, navigation, and other interface components [34].

jQuery is a JavaScript library designed to simplify HTML DOM tree traversal and manipulation, as well as event handling, CSS animation, and Ajax. It is free, open-source software using the permissive MIT License. As of May 2019, jQuery is used by 73% of the 10 million most popular websites [35].

5.5 Design and implementation

This section describes the design and implementation of the project. The process starts from aligning the image, building the dense point, building the mesh, and building texture. Then it will be necessary to export and upload the 3D model into Sketchfab and then embed the model to the website.

5.5.1 Phases of the project design for the 3D object

5.5.1.1 Capturing photos

Before loading your photographs into 3DF Zephyr, it is necessary to take those suitable for 3D model reconstruction. Photographs can be taken by any standard digital camera, as long as you follow some specific capturing guidelines. This section explains the general principles of taking and selecting pictures that provide the most appropriate data for 3D model generation. Camera settings using RAW data loss less converted to the TIF files are preferred, since PG compression induces unwanted noise to the images at the maximal possible resolution.

Aperture value should be high enough to result in sufficient focal depth. It is important to capture sharp, non-blurred photos. Shutter speed should not be too fast. Otherwise, blur can occur due to slight movements (**Figure 21**).

When a digital image is significantly underexposed, certain parts of the image will be simple black, other parts will not express colors accurately, and digital noise will be visible. Overexposure can cause areas to become simple white, without detail. This is known as “blowing out the highlights.” Digital cameras capture a limited range of



Figure 21.
Kerma Museum.

brightness. When starting to take pictures, it is necessary to capture all aspects of the form, which can range from 100 pictures to 400 pictures, according to the size of the object. The bigger the number of images is, the form will become clear (**Figure 22**).

5.5.1.2 Adding photos

Before starting any operation, it is necessary to point out which photos will be used as a source for 3D reconstruction. In fact, photographs themselves are not loaded into 3DF Zephyr until they are needed. So, when loading photos, we only indicate the photographs that will be used for further processing.

3DF Zephyr is the software that enables us to make 3D reconstructions from photogrammetric surfaces through an algorithm that allows us to align photos and create dense points, build mesh, and 3D model texture.

5.5.1.3 Aligning photos

Before starting any operation, it is necessary to point out what photos will be used as a source for 3D reconstruction. In fact, photographs themselves are not loaded into 3DF Zephyr until they are needed. So, when loading photos,



Figure 22.
The Kushite Kings.

only indicate photographs that will be used for further processing. Once photos are loaded into 3DF Zephyr, they need to be aligned. At this stage, 3DF Zephyr finds the camera position for each photo and builds a point cloud model. Once alignment has been completed, computed camera positions and a sparse point cloud will be displayed. You can inspect alignment results and remove incorrectly positioned photos, if any. To see the matches between any two photos, use View Matches command from the Tools menu.

5.5.1.4 Building dense point cloud

3DF Zephyr allows generating and visualizing a dense point cloud model. Based on the estimated camera positions, the program calculates depth information for each camera to be combined into a single dense point cloud. 3DF Zephyr tends to produce extra-dense point clouds which are of almost the same density. A dense point cloud can be edited and then exported to an external tool for further analysis. In the process to build a dense point cloud, in order to adjust the bounding box, it is necessary to use the Resize Region and Rotate Region toolbar buttons. You should rotate the bounding box and then drag corners of the box to the desired positions. The progress dialog box will appear, displaying the current processing status (**Figure 23**).

5.5.1.5 Building mesh

To build a mesh, the model has already been referenced. The bounding box will be properly positioned automatically. Otherwise, it is important to control its position manually. To adjust the bounding box manually, use the Resize Region and Rotate Region toolbar buttons. Rotate the bounding box and then drag cameras of the box to the desired positions. Only part of the scene inside the bounding box will be reconstructed. If the Height field reconstruction method is to be applied, it is important to control the position of the red side of the bounding box. It defines reconstruction

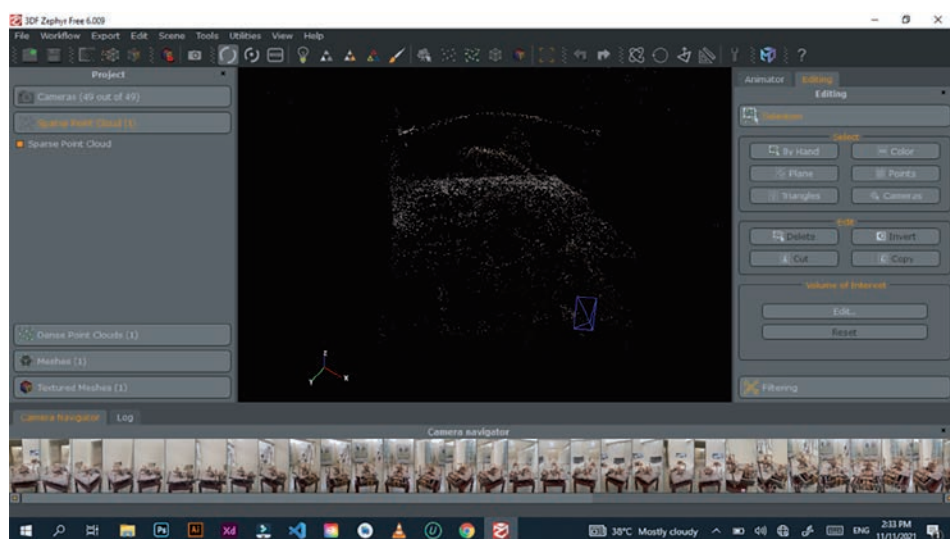


Figure 23.
Building dense points.

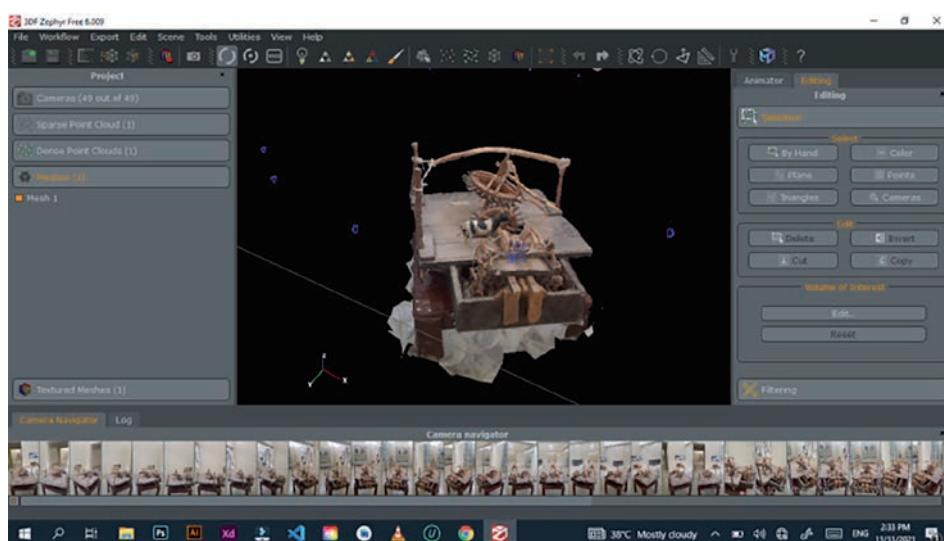


Figure 24.
Building mesh.

plane. In this case, make sure that the bounding box is correctly oriented. The progress dialog box will appear displaying the current processing status (**Figure 24**).

5.5.1.6 Building model texture

The texture mapping mode determines how the object texture will be packed in the texture atlas. Proper texture mapping mode selection helps to obtain optimal texture packing and, consequently, better visual quality of the final model to generate 3D model texture generation parameters in the Build Texture dialog box. The progress dialog box will appear displaying the current processing status.

Agisoft is a software that maximizes the possibilities of photogrammetry. It incorporates machine learning technologies for analysis and post-processing to deliver the most accurate results. We use the software here to make highly competitive photogrammetric processing to make the 3D more realistic. We enter the 3D model and process it for high functional results and resolution for the 3D model, and then we return to 3DF Zephyr.

5.5.1.7 Model export

To export the 3D model, certain stages need to be taken. From *Agisoft*, you save results, go to a project file, browse the destination folder, and choose the file type. 3DF Zephyr supports model export in many formats. In this project, we select the format 3DS and type the file name, after exporting the model in format .play or object. Then you can import to other software easily for other proposes (**Figure 25**).

5.5.1.8 Uploading to Sketchfab

When you finish your 3D modeling, you can upload the 3D modeling using your own account in Sketchfab, which enables people to see the 3D modeling. Viewers can use oculus VR, Gear VR, etc.

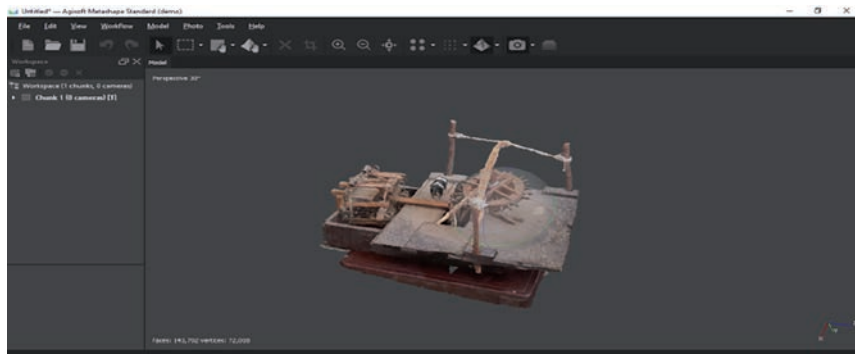


Figure 25.
3D model exporter.

5.5.1.9 Model processing in Sketchfab

Sketchfab is a software that provides utilities to edit the model to enhance color and general view of the model. It also supports sitting of VR viewing and touring virtual environment (Figure 26).

5.5.1.10 Embedded 3D modeling to website

Sketchfab allows to embed the model to a website, which is the gate for visitors and potential tourists who can experience an immersive 3D design. Simply upload your model and create comment cards or an animated walkthrough. Then, generate an embed code and share custom 3D models on your website.

5.5.2 Phases of the project design for the virtual museum

We have used the software Unity 2020 to reproduce the museum following these steps:

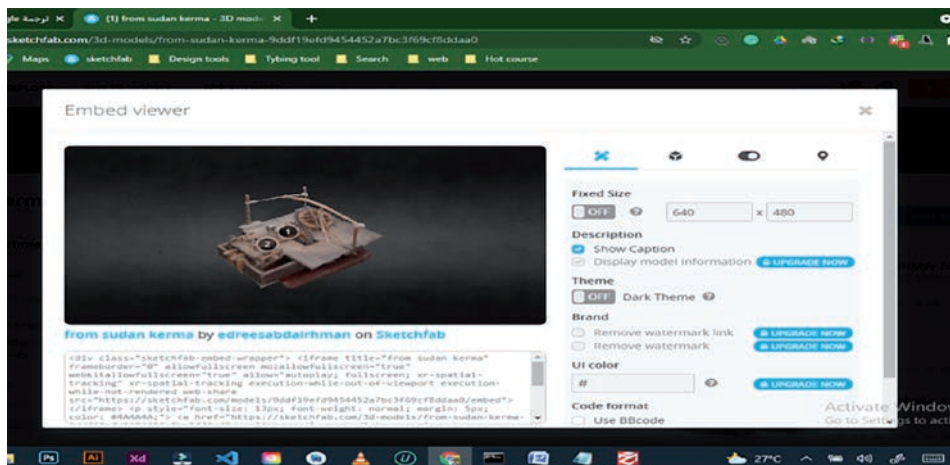


Figure 26.
Embedded 3D modeling to website.

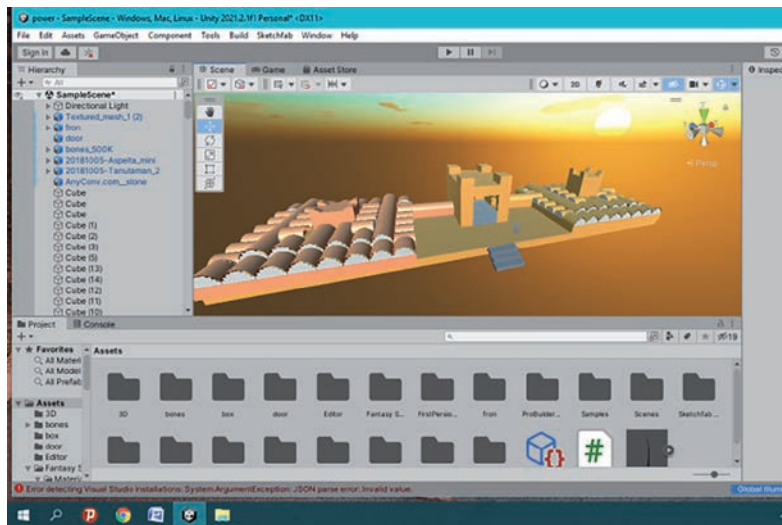


Figure 27.
Designing the model of Museum in Unity.

5.5.2.1 Designing the museum building architecture

Unity is the software used for this task. It provides the most important built-in features that make a game work. That means functions like physics, 3D rendering, and collision detection. From a developer's perspective, the internal and external design has been built from scratch. Every item, picture, and model has been placed in the real-life museum (**Figure 27**).

5.5.2.2 Tour inside the museum

See **Figure 28**.

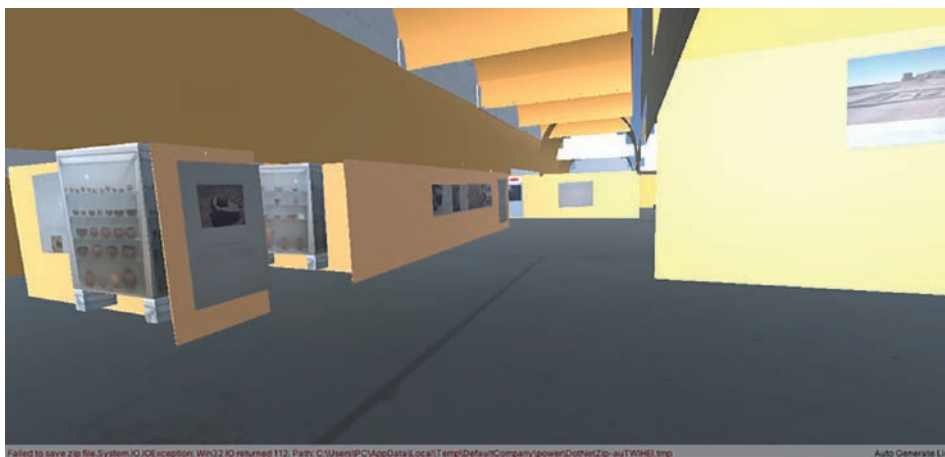


Figure 28.
Tour inside the Museum.

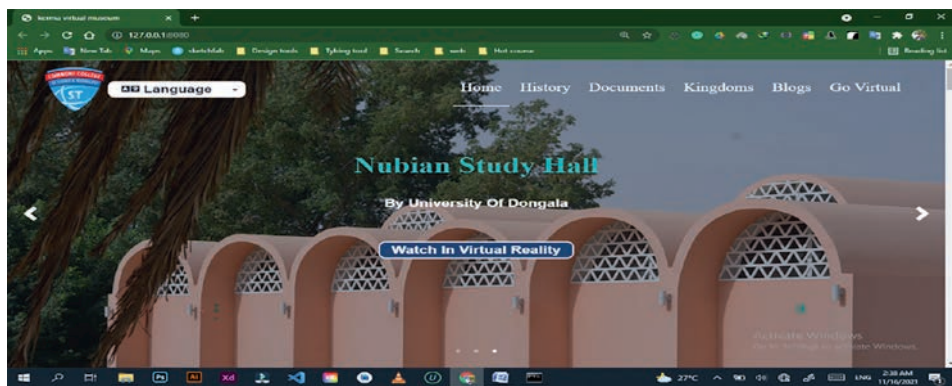


Figure 29.
Home page of the website.

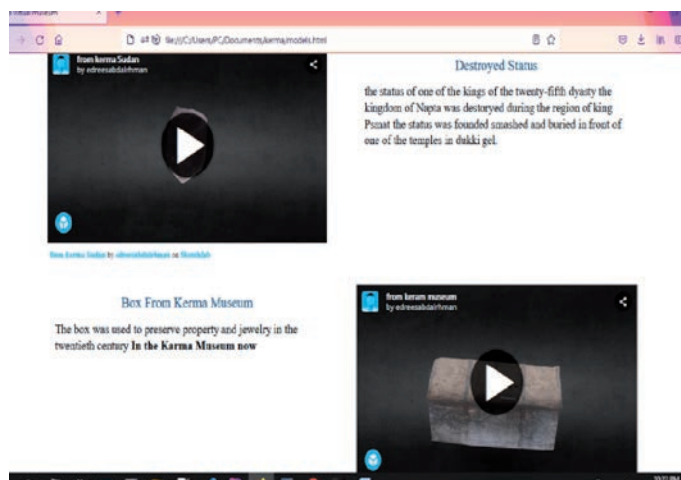


Figure 30.
3D models of some objects.

5.5.2.3 Website

Finally, the tour and all the material are presented in a website (Figures 29 and 30).

6. Conclusion and recommendations

The project “Applying virtual reality for Cultural Heritage of ancient Suakin through terrestrial photogrammetry” produced a virtual model of Ancient Suakin, which was built after visiting the island, visualizing its old streets, taking photos, and using Unity software.

The resulting model becomes a significant reference and basis for the future development of a website with thorough information about Ancient Suakin at hand for the users. In addition, the model will preserve these locations for generations to come, should promote tourism, and could become the basis for a cultural video game that helps local children and young Sudanese people appreciate their cultural heritage.

A similar process could be iterated for other monuments of Sudan that could be presented through websites, applications, or games.

The objective of the project “3D Reconstruction Documentation Website of Cultural Heritage in Sudan” was to support decisions for the development of a website of museum models by presenting a documentation website of cultural heritage in Sudan and a structured overview of 3D reconstructions that are likely to be applied in 3D modeling.

The system provides a 3D design for cultural heritage in Sudan that could be developed to provide information about the cultural heritage of the whole country.

This research reveals that the progresses in 3D geospatial modeling and information technologies have provided the project with building blocks, tools, and methodologies required to create very complex and rich 3D information systems that can be used to improve the information accessibility in Sudan museums, for planning and management.

It was clear that 3D models are increasing the ability to analyze and assess spatial phenomena and support us to make the right decisions based on solid information.

The fundamental technology-related issues and problems that hindered the efficient and regular use of virtual 3D museum models and their applications seem now to be overcome. Indeed, qualified 3D geodata has become available, system solutions have matured, and it is generally possible to create and disseminate complex 3D models and 3D information systems.

To encourage the work on 3D models, it is highly recommended that governments and organizations and governmental bodies should support the adoption and integration of 3D models for planning and management. This project presents simple models to care about the culture and heritage of the country by representing the nation’s history to interested people all over the world in 3D models, which makes them available to a vast audience through desktops, browsers, and mobile devices.

The project “Ancient polychromy: study and virtual reconstruction using close range photogrammetry for the Sudan National Museum” reveals that advances in 3D modeling and polychromaticism have provided the techniques, tools, and methodologies needed for virtual polychromatic construction and 3D creation. These tools can be used to improve access to information in museums.

In this chapter, we present the results of the virtual polychromatic reconstruction of the wall of the Temple of Buhen, moved from its original location in the North of Sudan to the garden of the Sudan National Museum in Khartoum.

This reconstruction of ancient polychromaticism and recreation of realistic color perceptions of the model have been possible with open-source tools like Agisoft. The cleaning up of impurities was made with Meshlab and the color contrast with ImageJ. Polychromatic studies are an important aspect of classical archaeological research because they seek to document, interpret, and preserve rapidly eroding archaeological information.

To preserve the heritage, we recommend using a multidisciplinary approach to take advantage of technology and maximize the processing of archaeological data. It would also be possible to create a high-resolution model using a 3-angle laser scanner and to derive color coordinates from high-resolution calibrated images.

The project “Photogrammetric Surface/Reconstruction from Imagery in Cultural Heritage (Designing Virtual Kerma Museum)” consists of an internet site that shows the historical monuments of Kerma Museum by using photogrammetric technique. Starting from photos taken with a digital camera and the collection of the geometrical information, a 3D model of objects and a virtual visit were produced.

The project is a significant reference about this museum with information available for tourists, potential visitors, and researchers.

The website could be developed by adding information about the contents of the museums and the available hotels and restaurants in the area for tourism purpose. Furthermore, the website was published in English and Arabic, but could incorporate new languages.

Author details

Muna Khamis Birra Ali^{1*} and Amin Talha Hassan²

1 Comboni College of Science and Technology, Khartoum, Sudan

2 Sudan University of Science and Technology, Khartoum, Sudan

*Address all correspondence to: mkbali@hotmail.com

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References

- [1] Anderson EF, McLoughlin L, Liarokapis F, Peters C, Petridis P, Freitas S. Developing serious games for cultural heritage: A state-of-the-art review. *Virtual Reality*. 2010;**14**:255-275
- [2] Burckhardt JL. *Travels in Nubia*. London: Darf Publishers; 1987
- [3] Fassi F, Mandelli A, Teruggi S, Achille C, Rechichi F, Fiorillo F. VR for cultural heritage. In: Ioannides M, Fink E, Moropoulou A, Hagedorn-Saupe M, Fresa A, Liestøl G, et al., editors. *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. Lecture Notes in Computer Science*. Vol. 10058. Cham: Springer; 2016. pp. 139-157. DOI: 10.1007/978-3-319-40651-0_12
- [4] Fidas C, Sylaiou S. Virtual reality and its application. *Applied Sciences*. 2021;**11**(4):1530
- [5] Galdieri R, Carrozzino M. Natural interaction in virtual reality for cultural heritage. In: Mobasheri A, editor. *International Conference on VR Technologies in Cultural Heritage*. Brasov: Springer Open; 2018. pp. 122-131
- [6] Barab S, Kenneth KE, Barnett M, Squire K. Constructing virtual worlds: Tracing the historical development of learner practices. *Cognition and Instruction*. 2001;**19**(1):47-94
- [7] Barab S, Hay KE, Barnett M, Keating T. Virtual solar system project: Building understanding through model building. *Journal of Research in Science Teaching*. 2000;**37**(7):719-756
- [8] Ibañez-Etxebarria A, Gómez-Carrasco CJ, Fontal O, García-Ceballos S. Virtual environments and augmented reality applied to heritage education. An evaluative study. *Applied Sciences*. 2020;**10**(7):2352
- [9] Shehade M, Stylianou-Lambert T. Virtual reality in museums: Exploring the experiences of museum professionals. *Applied Sciences*. 2010;**10**(11):4031
- [10] Cantatore E, Lasorella M, Fatiguso F. Virtual reality to support technical knowledge in cultural heritage. The case study of cryptoporticus in the archaeological site of Egnatia (Italy). *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2020;**XLIV-M-1-2020**:465-472
- [11] Vergauwen M, Van Gool L. Web-based 3D reconstruction service. *Machine Vision and Applications*. 2006;**17**:411-426
- [12] Jo YH, Hong S. Three-dimensional digital documentation of cultural heritage site based on the convergence of terrestrial laser scanning and unmanned aerial vehicle photogrammetry. *ISPRS International Journal of Geo-Information*. 2019;**8**(2):53
- [13] Ioannides M, Stylianidis E, Stylianou S. 3D reconstruction and visualization in cultural heritage. In: *New Perspectives to Save Cultural Heritage: Proceedings of the XIXth International Symposium CIPA*; 30 September–4 October 2003; Antalya, Turkey. Istanbul: CIPA – The ICOMOS/ISPRS Committee for Documentation of Cultural Heritage; 2003. pp. 258-262
- [14] Kuroczyński P, Dworak D, Hauck O. Digital reconstruction of cultural heritage – Questions of documentation and

- p visualisation standards for 3D content.
-
- In: Ioannides M, Magnenat-Thalmann N, Fink E, Žarnić R, Yen A, Quak E, editors.
- Digital Heritage: Progress in Cultural Heritage. Documentation, Preservation, and Protection. 5th International Conference, EuroMed 2014; 3-8 Nov 2014; Limassol, Cyprus. Cham: Springer; 2014. pp. 1-10. Preprint*
- [15] Kargas A, Loumos G, Varoutas D. Using different ways of 3D reconstruction of historical cities for gaming purposes: The case study of Nafplio. *Heritage*. 2019;2:1799-1811
- [16] Münster S, Köhler T. 3D reconstruction of cultural heritage artifacts: A literature based survey. In: *Proceedings of the CHCD2012 Conference; 17-18 Oct 2012; Beijing, China. Beijing: CHCD2012 Organising Committee; 2012*
- [17] Agisoft. Agisoft PhotoScan User Manual. Professional Edition, Version 1.2. 2016
- [18] Antlej K, Erič M, Šavnik M, Zupanek B, Slabe J, Battestin B. Combining 3D technologies in the field of cultural heritage: Three case studies. In: Dellepiane M, Niccolucci F, Peña Serna S, Rushmeier HE, Van Gool L, editors. *Short and Project Paper Proceedings of the 12th International Symposium on Virtual Reality, Archaeology and Cultural Heritage – VAST 2011; Oct 2011; Prato, Italy. Prato: University of Polo; 2011. pp. 1-4*
- [19] Graeme E, Martinez K, Malzbender T. Archaeological applications of polynomial texture mapping: Analysis, conservation and representation. *Journal of Archaeological Science*. 2010;37(8):2040-2050
- [20] Siotto E, Callieri M, Dellepiane M, Scopigno R. Ancient polychromy: Study and virtual reconstruction using open source tools. *Journal on Computing and Cultural Heritage*. 2015;8(3):1-20
- [21] Burdea GC, Coiffet P. *Virtual Reality Technology*. 2nd ed. Hoboken (NJ): John Wiley & Sons; 2003
- [22] Burns M. *Automated Fabrication: Improving Productivity in Manufacturing*. Englewood Cliffs (NJ): Prentice Hall; 1993
- [23] Sparke P, Fisher F, editors. *The Routledge Companion to Design Studies*. London & New York: Routledge; 2016
- [24] Skamantzari M, Georgopoulos A. 3D visualization for virtual museum development. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2016;XLI-B5:961-968. DOI: 10.5194/isprs-archives-XLI-B5-961-2016
- [25] Podzharaya N, Sochenkova A. The virtual museum development with the use of intelligent and 3d technologies on the basis of the Maritime museum in Kotor. In: *Proceedings of the 2018 International Conference on Information Science and Communications Technologies (ICISCT); Nov 2018; Tashkent, Uzbekistan. Piscataway (NJ): IEEE; 2018. pp. 1-4. DOI: 10.1109/SPIT.2018.8350845*
- [26] Loaiza Carvajal DA, Morita MM, Bilmes GM. Virtual museums. Captured reality and 3D modeling. *Journal of Cultural Heritage*. 2020;45:234-239
- [27] Ali Mohamed AR, Anderson JR, editors. *Highlights from the Sudan National Museum*. Khartoum: National Corporation for Antiquities and Museums; 2013
- [28] Agisoft. Agisoft PhotoScan User Manual. Professional Edition, Version 1.4. 2018

[29] Unity Technologies. Unity (Version 2023.1) [Computer Software]. San Francisco (CA): Unity Technologies; 2023. Available from: <https://unity.com> [Accessed: August 26, 2025]

[30] 3DFLOW. 3DF Zephyr (Version 8.005) [Computer Software]. Verona (Italy): 3DFLOW; 2025. Available from: <https://www.3dflow.net> [Accessed: August 26, 2025]

[31] CloudCompare. CloudCompare. Version 2.6.1. User Manual. 2018

[32] Seymour M. EPIC's Unreal Engine Open World: Behind the Scenes [Internet]. 2015. Available from: <https://www.fxguide.com/fxfeatured/epics-unreal-engine-open-world-behind-the-scenes/>

[33] Tim B-L. Information Management: A Proposal [Internet]. 1989. Available from <https://www.w3.org/History/1989/proposal-msw.html>

[34] Otto M. Building Twitter Bootstrap. A List Apart [Internet]. 2012. Available from: <https://alistapart.com/article/building-twitter-bootstrap/>

[35] W3techs. Usage Statistics of JavaScript Libraries for Websites [Internet]. 2022. Available from: https://w3techs.com/technologies/overview/javascript_library

The Impact of the Ongoing Sudanese War on Cultural Heritage and the SudanInnovation Project: Conclusions and Perspectives

*Maurizio Lazzari, Sabrina Greco
and Jorge Carlos Naranjo Alcaide*

Abstract

This chapter describes the impact of the ongoing armed conflict in Sudan on cultural heritage, underlining the relevance of the SudanInnovation project carried out by the Institute of Heritage Science—National Research Council of Italy in collaboration with Comboni College of Science and Technology, a Sudanese institution of higher education. The project opens new perspectives and calls for the protection of cultural heritage, positioning it as medium for reconciliation and the development of a new shared national identity.

Keywords: cultural heritage, digital tools, civil war, cultural identity, Sudan

1. Introduction

Al-Ahlia University in Omdurman once housed an extraordinary library filled with unique books, manuscripts, and historical documents of great value. However, since May 2023, that library no longer exists [1].

In June 2023, the library of the Mohamed Omer Bashir Study Center was consumed by fire, destroying one of the most important repositories of Sudanese history and culture. The fire did not appear to be an accidental incident or a collateral consequence of the exchange of fire between two armies in the streets of Omdurman.

Since April 15, 2023, the Sudan Armed Forces (SAF) and the Rapid Support Forces (RSF) have been engaged in conflict. Prior to the outbreak of violence, both armies has been negotiating a model of integration along with some civilian platforms, aiming for a transition toward a democratic civilian rule. However, hostilities erupted that day, unleashing a wave of destruction that forced the displacement of more than 14 million people (11 million internally displaced persons and 3.1 million refugees) [2].

The RSF claimed to be fighting against the old Islamist regime that resisted this transition, positioning itself as the defender of marginalized cultural groups from the country's peripheries. However, the evolution of the conflict revealed that these

claims were not the RSF's priority, as it does not seem sensible to bring about democratic civilian rule through pillage, looting, killings, torture, "sexual and gender-based violence, rape, sexual slavery, abduction, and recruitment and use of children in hostilities" [3].

2. Targeting cultural heritage

The preceding citation comes from the report prepared by the Human Rights Council on the findings of the investigations conducted by the Independent International Fact-Finding Mission for Sudan. The report examines violations of international human rights law, international humanitarian law, and related crimes committed in Sudan in the context of the conflict that erupted in mid-April 2023.

The same report denounces that "the RSF and its allied militias engaged in a pattern of destruction of objects indispensable to the survival of the civilian population, including through intentionally directing attacks against specially protected objects," as well as the looting and destruction of cultural property [3].

On August 22, 2024, the RSF shelled the El Fasher University Library and the Peace Studies Center in North Darfur with heavy artillery [4].

The targeted destruction of historical archives, university libraries, study centers, cultural centers, and museums [5], as well as institutions connected to the history and culture of the country, has been extensive. In contrast, libraries related to technological and technical fields seem to have been spared. This suggests an intentional effort to undermine the pillars of the traditional cultural identity of the country [6] to replace it with a new one [7].

Similarly, the RSF has reportedly carried out operations to replace inhabitants in areas of Khartoum State with individuals brought from the western regions of Sudan and even from Chad, predominantly belonging to the Rizeigat tribe [8].

The Ministry of Higher Education and Scientific Research of the Republic of Sudan has reported that 104 government and private higher education and research centers have been affected by the war and have been either totally or partially damaged or looted [9].

3. SudanInnovation and the war in Sudan

On September 2, 2024, the *Middle East Eye* published a report on the looting of the National Museum of Sudan and the smuggling of its objects by trucks to South Sudan [10]. The operation was carried out in the territory controlled by the RSF sometime earlier. As of the finalization of this book, it remains unclear whether any artifacts have been recovered.

This museum was the location of one of the graduation projects described in this book. The reported events highlight the necessity of the SudanInnovation project, not just for Sudan but potentially for other neighboring countries that may be facing similar violent experiences. In other contexts, threats to cultural heritage may come from natural disasters, the consequences of climatic change, rapid urbanization, mining activities, irresponsible tourism, and other factors.

The SudanInnovation project demonstrated that the transfer of knowledge from a European research institution specializing in cultural heritage to students and faculty of another institution in a developing country, one with a rich cultural heritage but

few resources to protect and transform it for sustainable development, can be effective and yield meaningful results.

Among the factors that made this transfer successful, the project identified the following:

- English proficiency among trainers and trainees, despite English not being their first language. This aligns with previous studies [11, 12].
- Digital skills among trainees, which facilitated online learning and the application of acquired knowledge. Beneficiaries who are experts in technology-related fields are better equipped for training where technology serves as the primary teaching medium. This also confirms previous experiences [13].
- Immediate application of learning—The timing of training sessions just before students chose their graduations project themes was crucial, ensuring they could directly apply newly acquired skills.
- Adaptability to online education—Only a few universities managed to successfully shift to online learning after the onset of the war [14]. Comboni College of Science and Technology (CCST) was among them. Some factors that may explain this flexibility include the college's small size, the low average age of its teaching staff, previous online education initiatives such as the “Innovation in society: Training paths and human capital enhancement in Sudan (INSO)” project [12], and its ongoing faculty development.

However, the project also showed some limitations. Computer Science students had minimal exposure to the humanities. While they demonstrated technical proficiency in developing applications, they required support from specialists to enhance the presentation of their work and refine the textual content they produced.

4. Perspectives

4.1 Coordination and integration initiatives

As mentioned in Chapter 1, the SudanInnovation project coincided with other initiatives funded by European institutions that were launched a few months after the conclusion of our project. These included “Sudan Memory” [15], a project led by King's College in partnership with the National Records Office (NRO) of Sudan and the Sudanese Association for Archiving Knowledge (SUDAAK); and “Turath” [16], an initiative led by the French Institute in Sudan in collaboration with the French Archeological Unit for Sudanese Antiquities (Section Française de la Direction des Antiquités du Soudan, SFDAS), the National Corporation for Antiquities and Museums (NCAM), and Alsoug.com. The “Turath” project was funded by the delegation of the European Union in Sudan, while “Sudan Memory” was funded by the British Council Cultural Protection Fund and the Aliph Foundation.

The simultaneity of these projects highlights a pivotal moment for Sudan, an opportunity to accelerate the digitization of its cultural heritage and its transformation into an engine of sustainable development while also laying the groundwork for tourism infrastructure.

This potential called for an integrated approach that involved local institutions like the National Corporation for Antiquities and Museums (NCAM) and the Ministry for Antiquities, Tourism, and Wild Life; international institutions with a presence in Sudan, such as UNESCO and European cultural centers; local universities like CCST, as well as others located near key archeological sites such as Dongola and Meroe; local tourism and digital companies, including Al-soug; and local start-up incubators, which could facilitate the transformation of cultural heritage into a sustainable development resource.

Among the tools used by these start-up incubators to solve problems and foster innovation are hackathons. A hackathon is a design sprint-like event where computer programmers, software developers, and other professionals collaborate intensively on software projects. The goal of a hackathon is to create functional software or hardware by the end of the event.

Hackathons bring together young innovators from diverse academic backgrounds, including business administration, marketing, tourism, history, and archeology, within integrated teams. This structure allows them to solve concrete problems without the rigid framework of an academic course.

4.2 Mixed competencies master's degree programs

Another channel to boost the digital transformation of cultural heritage in Sudan is the creation of a master's degree program that integrates digital tools and cultural heritage. Currently, no such program exists in Sudan.

The challenge lies in designing a curriculum that accommodates students from both humanities disciplines (archeology, history, etc.) with a foundation in digital skills, and students from technological backgrounds (e.g., computer science, information technology, engineering, etc.). The teaching staff could include European experts via online instruction, but the plan should prioritize training future local lecturers to eventually replace online instructors.

4.3 Monitoring tools

The destruction of cultural heritage in Sudan could be mitigated through the reconstruction of artifacts using existing 3D virtual models. In addition, the Sudanese experience underscores the need to develop monitoring applications that, with the support of satellite imagery and digital tracking, could support the surveillance of local cultural heritage in collaboration with national and international authorities.

4.4 Cultural heritage, reconciliation, and cultural identity

The ongoing conflict in Sudan is not unprecedented. The country has endured two long civil wars between the north and the south (1955–1972 and 1983–2005) as well as armed conflicts in Darfur (2003–2020), South Kordofan, and Blue Nile State. These conflicts are an expression of severe tensions between the central authority, which imposes a national identity, and the peripheral communities, many of whom identify with non-Arab cultural identities [17].

Surely, the Sudan that will emerge from the war will differ from its past. It will be a “new Sudan,” a term associated with the political vision of the founder of the Sudan People Liberation Movement (SPLM), John Garang. He warned that “it is often forgotten that the Sudan is not just north and south. The Sudan is also west, east, and

center, no matter what definitions you wish to attach to these labels... All patriots must appreciate the reality that we are a new breed of Sudanese; we will not accept being fossilized into sub-citizens in the 'Regions'" [18]. His vision of a new Sudan emphasizes the integration of cultural diversity and the separation of religion and state, prioritizing citizenship over religious identity.

Garang's efforts crystalized in the Comprehensive Peace Agreement (CPA) signed on January 9, 2005, between Omar Al-Bashir, Sudan's ruler from 1989 to 2019, and John Garang himself. The agreement paved the way for a referendum, which led to South Sudan's secession in 2011.

The CPA recognized cultural heritage as a key element for reconciliation and peace, an idea also present in the Addis Ababa Agreement of 1972 that ended the First Sudanese Civil War. President Ja'far Nimeyri at the time spoke of Sudan as an "Afro-Arab entity" [19]. This expression aimed to integrate Sudanese diversity and was in line with the thought of South Sudanese thinker Francis Deng, who stated:

For peace to be genuine and sustainable, it must address the deep-rooted crisis of national identity. This will mean balancing between the rigidity of self-perceptions about identity, which would entail recognizing racial, ethnic, cultural and religious diversities, and building on the fluidity of self-identification to forge a new sense of an all-embracing national identity [20].

The CPA proposed a vision that aimed to create a sense of common ownership while challenging the negative effects of instrumentalizing identity through the promotion of cultural heritage policies [21], which included "strengthening intercultural and inter-religious dialogue and developing protection of the national heritage" [22].

The CPA followed the principle of a single state with two systems, one for the south and another for the north. Within this framework, the Joint Assessment Mission for Sudan detailed cultural heritage initiatives that could help shape a new national identity inclusive of all Sudanese citizens. For Northern Sudan, the report recommended the development of:

joint studies, debates, and discussions about the country's cultural heritage, customary law and traditional structure and [...] capacity building and training, specifically [...] for the conservation of the ancient cultural structures and their preservation and presentation on their original sites or in museums [...] as part of the efforts to promote reconciliation [22].

In line with the CPA's principles, the NCAM developed a plan in 2005 to establish a network of museums across Sudan, leading to the opening of several museums outside Khartoum State. Many of these museums were planned in state capitals affected by violent conflict, such as Nyala, Al-Janeina, Damazin, Fashoda, Kassala, and Jonglei. These institutions were envisioned as instruments of political reconciliation, granting official recognition and visibility to cultural minorities. In fact, the map of the planned location of these museums showed their distribution along two thematic axes: "one axis is devoted to the development in the Northern capitals (Jebel Barkal-Karima, Dongola, Kerma, Wadi Halfa), the second axis concerns the Southern capitals (Juba, Jonglei, Fashoda) and the 'marginal' regions (Nyala, El-Damazin, Kassala)" [21].

Unfortunately, the plan unintentionally reinforced cultural divisions. The report observed: "On the one hand, the Northern Nile valley is devoted to archaeologists; on the other hand, Southern Sudan and regions such as Darfour are relevant for

anthropologists, [so that] the concept of heritage is applied in the peripheries, but is not yet, qualifying any object or artefact” [21].

The development of a truly inclusive Sudanese cultural heritage should not limit or reduce itself to a mere documentation of multiculturalism through exhibitions of costumes, musical instruments, handicrafts, and traditions. Furthermore, heritage cannot be weaponized as a tool for local communities to resist Sudanization or to assert superiority in “sudanity” over others. Instead, Sudan’s multicultural reality should be the platform for intercultural dialog that produces a dynamic and shared concept of identity instead of justification for divisions and comparisons of “sudanity.”

The way to make heritage a source of integrative identity building is through intercultural exchange. This process begins with discovering Sudan’s multicultural nature, then promoting mutual exchange of life and work to shape a global vision of citizenship that builds on what is shared in common rather than erasing individual identity [23].

This means that schools should be places of “initiation to the dialogue of life among young people of different religions and social backgrounds” [23] where cultural heritage is a formative experience, like clay being molded and shaped. According to the intercultural perspective, this clay should remain moldable, allowing for transformation.

The above is supported by [23] and also reflected in the European Faro Convention, which focuses on the importance of participation by citizenship and the values attributed by citizens to forms of cultural heritage, introducing the concept of Heritage Community. The CNR-ISPC Working Group on Heritage Communities supports communities in identifying cooperative solutions for sustainable development based on holistic strategies for protection and enhancement of cultural heritage. This support also extends to educational projects, such as SudanInnovation, which aims to help communities at war or at risk of conflict strengthen their sense of belonging and their cultural identity [24, 25].

This intercultural approach goes beyond the concepts of relativism and assimilation. It is

based on a dynamic idea of culture, which neither is closed in on itself nor celebrates diversity with stereotypes or folkloristic representations. Intercultural strategies function when they avoid separating individuals into autonomous and impermeable cultural spheres; they rather should promote encounter, dialogue and mutual transformation, so as to allow people to co-exist and deal with possible conflict [23].

In addition to intercultural engagement, academic curricula should reflect Sudan’s cultural diversity, integrating local languages into basic education.

In this evolving educational model, digital tools can facilitate access for all children, allowing them to explore the richness of “the other” so that a new “we” may be molded.

Author details

Maurizio Lazzari¹, Sabrina Greco² and Jorge Carlos Naranjo Alcaide^{3*}

1 National Research Council of Italy, Institute of Heritage Science, Potenza, Italy

2 National Research Council of Italy, Institute of Heritage Science, Lecce, Italy

3 Comboni College of Science and Technology, Port Sudan, Sudan

*Address all correspondence to: naranjoalcaide@hotmail.com

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References

- [1] El Zahraa J, Rhodes T. The war raging over Sudan's present—And its past. *The Continent*. 2023;128:11-13
- [2] International Organization of Migrations. Sudan Mobility Update. 2024. Available from: <https://dtm.iom.int/reports/dtm-sudan-mobility-update-10> [Accessed: October 31, 2024]
- [3] Human Rights Council Fifty-Seventh Session. Findings of the Investigations Conducted by the Independent International Fact-Finding Mission for the Sudan into Violations of International Human Rights Law and International Humanitarian Law, and Related Crimes, Committed in the Sudan in the Context of the Conflict that Erupted in Mid-April 2023. 2024. Available from: <https://www.ohchr.org/sites/default/files/documents/hrbodies/hrcouncil/sessions-regular/session57/A-HRC-57-CRP-6-en.pdf> [Accessed: October 31, 2024]
- [4] Al-Aan News. Rapid Support Bombs the Most Import Universities of Darfur Region [Original in Arabic]. 2024. Available from: <https://alaannews.net/%d8%a7%d9%84%d8%af%d8%b9%d9%85-%d8%a7%d9%84%d8%b3%d8%b1%d9%8a%d8%b9-%d9%8a%d9%82%d8%b5%d9%81-%d8%a7%d9%87%d9%85-%d8%ac%d8%a7%d9%85%d8%b9%d8%a7%d8%aa-%d8%a5%d9%82%d9%84%d9%8a%d9%85-%d8%af%d8%a7%d8%b1/> [Accessed: October 31, 2024]
- [5] Isber S, Ismail H, Mohsin Y, Tomomi F, Urralburu A. The Third Report Cultural Heritage Situations in Sudan. Sudan Heritage Protection Initiative [Internet]. 2024. Available from: <https://www.heritageforpeace.org/sudan-reports/> [Accessed: October 31, 2024]
- [6] Reem A. Al-Mahdiya Continues to Haunt Sudan. Bergen, Norway: Chr. Michelsen Institute; 2024. Available from: <https://www.cmi.no/publications/9171-al-mahdiya-continues-to-haunt-sudan> [Accessed: October 31, 2024]
- [7] Berridge W. Western Sudanese marginalization, coups in Khartoum and the structural legacies of colonial military divide and rule, 1924-present. *Journal of Eastern Africa Studies*. 2023;17(4):535-556. DOI: 10.1080/17531055.2023.2280933
- [8] Ibrahim M, Al-Dahni S. Khartoum settlement. With maps and citizen testimonies, How are the rapid support forces demographically changing the sudanese capital? [original in Arabic]. *Arabi Post*. 2024. Available from: <https://arabicpost.net/%d8%aa%d8%ad%d9%82%d9%8a%d9%82%d8%a7%d8%aa/2024/02/20/%d8%a7%d8%b3%d8%aa%d9%8a%d8%b7%d8%a7%d9%86-%d8%a7%d9%84%d8%ae%d8%b1%d8%b7%d9%88%d9%85/> [Accessed: October 31, 2024]
- [9] Abbas R. A War for Sudan's Identity: The Loss and Destruction of Culture and Heritage. Washington, DC: The Tahrir Institute for Middle East Policy; 2024. Available from: <https://timep.org/2024/04/15/a-war-for-sudans-identity-the-loss-and-destruction-of-culture-and-heritage/> [Accessed: October 31, 2024]
- [10] RSF Loots National Museum of Sudan, Says Report. 2024. Available from: <https://www.middleeasteye.net/news/rsf-loots-national-museum-sudan-says-report> [Accessed: October 31, 2024]
- [11] Ahmed Albasheer Osman N. The acceptance and use of information and

communication technologies by staff members in Khartoum State's universities (Sudan) [PhD thesis]. Dresden: Dresden University of Technology; 2014

[12] Naranjo Alcaide JC, Meyer J-B, Greco S, Abdalla SA. Youth, training and labor insertion in Sudan: Lessons from the INSO project. *Journal of Comparative and International Higher Education*. 2023;15(1):45-60. ISSN 2151-0393

[13] Naranjo J, Molineri I. La sfida della didattica a distanza in una università sudanese: La valutazione degli studenti e i risultati nei corsi di lingua italiana. *Italiano LinguaDue*. 2021;13(2):748-767

[14] Sawahel W. Destruction of HE will demand post-war reform of sector. *University World News Africa Edition*. 2024. Available from: <https://www.universityworldnews.com/post.php?story=2024032603345775> [Accessed: October 31, 2024]

[15] Sudan Memory. 2022. Available from: <https://www.sudanmemory.org/> [Accessed: October 31, 2024]

[16] Sudan National Museum. 2022. Available from: <https://turath.alsoug.com/> [Accessed: October 31, 2024]

[17] Greco S, Naranjo Alcaide JC. Il patrimonio culturale sudanese come vittima della guerra e base per la riconciliazione. In: Bettini E, Tondini D, editors. *Atti del Congresso Conoscere per Costruire. Il Ruolo dei Centri Accademici, di Ricerca e della Formazione*, VI Forum Internazionale del Gran Sasso, Partenariato Euro-africano: V Conferenza, Teramo; 28-30 Settembre 2023. Vol. 6, Parte 2. 2024. pp. 225-249. Available from: https://www.diocesiteramoatri.it/wp-content/uploads/2024/10/FORUM_GS_VI_PARTE_II_2023_.pdf?_gl=1*1mevz7*_up*MQ.*_ga*MTIyMzc0NTIuMTcyODU3NTY1NA..*_ga_6N5V58L26F*MTcyOD

U3NTY1My4xLjAuMTcyODU3NTY1My4wLjAuMA

[18] Garang J, Khalid M. John Garang Speaks. London, New York: KPI; 1987

[19] Stevens R. The 1972 Addis Ababa agreement and the Sudan's Afro-Arab policy. *The Journal of Modern African Studies*. 1976;2(14):247-276

[20] Deng F. Tradition and Modernisation, A Challenge for Law Among the Dinka of Sudan. London: Yale University Press; 1971

[21] Leturcq J-G. Heritage-making and policies of identity in the "post-conflict reconstruction" of Sudan. *Égypte/Monde Arabe*. 2009;1(5-6):295-328

[22] Joint Assessment Mission for Sudan. Framework for Sustained Peace, Development and Poverty Reduction. Vol. 3. OCHA. Available from: <https://reliefweb.int/report/sudan/sudan-jam-final-report-volume-iii-cluster-reports> [Accessed: May 28, 2025]

[23] Congregation for Catholic Education. Educating to Intercultural Dialogue in Catholic Schools Living in Harmony for a Civilization of Love. 2013. Available from: https://www.vatican.va/roman_curia/congregations/ccatheduc/documents/rc_con_ccatheduc_doc_20131028_dialogo-interculturale_en.html [Accessed: October 19, 2024]

[24] Genovese L, Alberti L, Colosi F, Grano MC, Bellia A, Greco S, et al. Cooperation solutions for the local sustainable development of heritage communities: Role and contributions of the Faro Italia Network. In: Calabrò F, Madureira L, Morabito FC, Piñeira Mantiñán MJ, editors. *Networks, Markets & People*. NMP, Lecture Notes in Networks and Systems,

1184. Cham: Springer; 2024.
DOI: 10.1007/978-3-031-74608-6_33

[25] Greco S, Lazzari M. Diplomazia scientifica e patrimonio culturale: Il caso del Sudan. In: Conferenza del Dipartimento Scienze Umane e Sociali e Patrimonio Culturale su “La pace: Il punto di vista della scienza. Dinamiche di pace positiva”. Rome: CNR, DSU; 2024. pp. 42-44. Available from: <https://www.dsu.cnr.it/wp-content/uploads/2024/12/Abstract-Conferenza-DSU-La-pace-il-punto-di-vista-della-scienza-Dinamiche-di-pace-positiva.pdf>



*Edited by Sabrina Greco, Maurizio Lazzari
and Jorge Carlos Naranjo Alcaide*

This book is one of the first scientific texts to present technology applied to cultural heritage as a tool of scientific diplomacy, and it serves as evidence of a successful project where technology becomes a means to preserve the memory and identity of countries in conflict, such as Sudan. The last war in Sudan broke out on April 15, 2023. Several months prior, the National Research Council Institute of Heritage Science (CNR-ISPC, Italy), a Sudanese University, Comboni College of Science and Technology, and the Italian Embassy in Khartoum had begun collaborating on the application of technology to Sudanese cultural heritage. Time unfortunately showed that the training project was particularly relevant to protect the cultural heritage that would be threatened and destroyed by the conflict. This scientific diplomacy project, called “SudanInnovation: A new Sudan through culture, technology and innovation,” was part of the “Integrated promotion and relaunch of the country system” funded by the Italian Ministry of Foreign Affairs and International Cooperation. The book analyzes the project and presents it as a point of reference for similar experiences.

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