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GIS and Open Data for Sustainable Construction and Risk Analysis: The Case Study of a School in Zambia

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Abstract

GIS and open data are clearly an asset for the construction sector, especially during the planning phase and for logistic. Sustainability is a topic that cannot be disregarded anymore and particularly relevant for the construction sector as one of the most energy and material consuming sectors. In areas where climate change is already a reality and pre-conditions already challenging, the use of available technologies might make a vital difference if properly adopted in projects. This paper presents the result of a preliminary study conducted in collaboration with the Architects Without Borders, Sweden, for a boarding school in Zambia. Results show how GIS and free open data have been used to forecast the project's socio-economic impact on the local population, suggest sustainable materials for construction and foreseen climate change consequences on the project's location and in particular on the natural resources' supply.

Keywords: climate change, GIS, open data, risk analysis, sustainability.

1. Introduction

Creating and managing digital information about the built environment in Geographical Information Systems (GIS) environments is not new, but rather GIS' common applications which bring together spatial data and associated information, and provide a central database to store, update and interrogate these data [1]. The use of GIS in early stages has been confirmed by a great deal of studies. In the last years, new uses of GIS, often integrated with other tools, software or systems, opened for new possibilities. For instance, GIS integrated with Building Information Modelling (BIM) seemed to provide an asset for the construction phase. Zavari et al. (2022) claim that GIS, integrated with Building Information Modelling (BIM), is practical and beneficial for optimizing the construction site layout planning, decreasing the total on-site traveling distance and developing a more realistic model using BIM and GIS together for acquiring the spatial data, navigating dynamically, and considering available indoor and outdoor space continuously [2]. BIM-GIS integration and its applications represent an active research topic for the future development of society, especially in the field of the sustainable built environment [3].

Sustainability issues are well known to the construction sector and the scientific community interest on the topic increased exponentially in the last years. Very similar the trend that sees GIS connected to Sustainability. Usually, while the construction sector's activities are pointed out as the cause for un-sustainable energy and materials consumption, GIS is presented as a tool to analyse, forecast and to support decision-making phases. GIS can be defined as "a system that creates, manages, analyses, and maps all types of data. GIS connects data to a map, integrating location data […] with all types of descriptive information […] used to identify problems, monitor change, manage and respond to events, perform forecasting, set priorities, understand trends" [4].

GIS is indeed a great asset, but data and geodata are needed. In the last years, numerous initiatives have been dealing with the provision of open, and often free, data and geodata. The availability of open data has grown significantly, with pressure being placed on all kinds of public organizations to release their raw data [5]. Finding free and open data and geodata is therefore not difficult, however, information quality issues such as lack of information, lack of accuracy of the information, incomplete information, only part of the total picture shown or only a certain range and obsolete and non-valid data must be taken into serious consideration [5].

The Arkitekter Utan Gränser, Sweden (Architecture Sans Frontières (ASF) Sweden), is a non-profit, religiously unaffiliated, non-political organisation that aims to create and improve access to a safe, sustainable and equitable development of the built environment for all [6]. Once a project idea is approved by the ASF's board, the preliminary study phase can start. This includes the delivery of a report that must comprehend a clear and deep description of: initiative, location, project's sustainability (ecological, social, economic analysis), community needs, analysis, partnerships and collaborations, project's financing, risk analysis, project's effects. Moreover, in order to finalize the preliminary study, a visit to the project's location is considered necessary. From the very beginning of 2022, because of Covid-19 pandemic, travel became from difficult to almost impossible, especially to developing countries, and many of the ASF's projects were set to a pause.

On March the 11th, 2020, the World Health Organization declared Covid-19 a pandemic. To contain the pandemic, most countries took a two-pronged approach. First, they attempted to slow the spread of the disease internally by implementing various non-pharmacological interventions, such as social distancing, using face coverings, and closing businesses and schools. Second, they attempted to reduce the number of imported cases by implementing travel restrictions [7]. While travel restriction measures had some benefits on the already feeble heath system of many developing countries, factors such as restrictions of travel into and within countries, quarantining and other restrictions on group activities and increased bureaucratic hurdles by governments and other actors, have acted against humanitarian access and delivery and international organizations have had to scale back the number of international staff in field locations as they managed travel and quarantine restrictions [8].

During the same period, a close collaboration between ASF, Sweden, and the School of Engineering, Jönköping University, Sweden, was established. The collaboration encompasses the engagement of students in ASF's preliminary studies with the attempt to supply the impossibility to collect onsite data. Students have been involved within GIS and Industrial Placement programs' courses. So far, three successful examples of students' contributions to ASF's preliminary studies have been recorded for: a hospital in Taita–Taveta County, Kenya; Kamakwie hospital infrastructures' improvement, Karene District, Sierra Leone; and a boarding school in Chirundu District, Zambia.

In this paper, the results of the preliminary study conducted in collaboration with the ASF, Sweden, for a boarding school in Chirundu District, Zambia are presented. The aim of the paper is to show how GIS and open data can be used for sustainability and humanitarian purposes and they served as assets to bypass the unforeseen obstacles caused by the Covid-19 pandemic.

Results show how GIS software and free open data have been processed to forecast the project's socio-economic impact on the local population, suggest sustainable materials for construction and foreseen climate changes consequences on the project's location and in particular on the natural resource supply.

2. Research method

For this research, the preliminary study for the project named "Build a classroom", a boarding school in Chirundu District, Zambia, served as case study. "Build a classroom" is a project initiated by the Zambian Children In Crisis, a non-governmental organization registered under the Ministry of Community Development and Social Services in May 2020 and supported by the ASF, Sweden. What started as a "Build a Classroom" initiative, became the project for 500 pupils boarding school on about five hectares land in the village of Kapulurila Chief Sikaongo of Goba village, 10 Km from Chirundu, Chirundu District. The local communities made possible to choose among two plots of land (A and B in Fig. 1) situated few Kilometers from the banks of the Kafue and the Zambezi rivers (Fig. 1). Both plots are still under analysis and a final decision on which has not been taken yet.

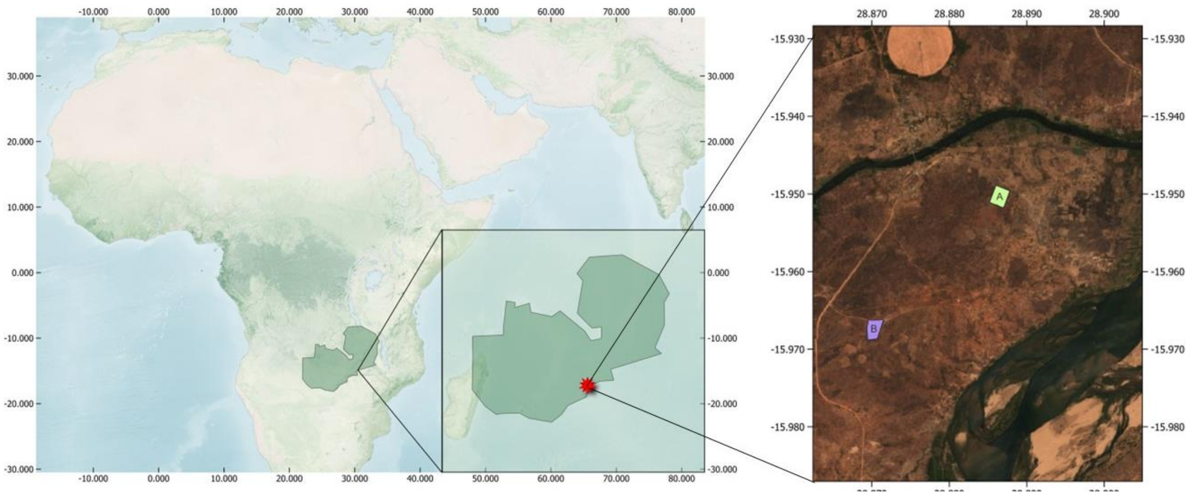

Fig. 1. Project location and the two possible land plots for the school (A and B).

Geodata have been downloaded mainly as Shapefiles, JSON, GeoJSON, Excel, TIFF and geoTIFF from databases that allow free access and downloading such as those showed in Table 1.

Table 1. Used open and free geodatabases.

Database	Data	Website
AmeriGEOSS	Mineral resources	www.amerigeoss.org/
Humanitarian Data Exchange	Installations, infrastructures, and demographic	data.humdata.org
European Soil Data Centre (ESDAC)	Soil diversity	esdac.jrc.ec.europa.eu
geo7	African geology	geo7.ch
Berkeley Library GeoData	Electricity gris and dams' conditions	geodata.lib.berkeley.edu
Global Solar Atlas	Information for solar energy	globalsolaratlas.info
GRID^3	Social risk indicators, operational points, demography	grid3.org
The Landscapes Portal	Land use, vegetation, crops, soils	landscapeportal.org
Sentinel Hub - Playground	Orthophotos	apps.sentinel-hub.com
FEOW	Hydrographic watershed	www.feow.org/
British Geological Survey	Africa's groundwater	www2.bgs.ac.uk
WorldData.info	Zambia's energy consumption	www.worlddata.info/
World Bank Open Data	Climate	data.worldbank.org/
National Oceanic and Atmospheric Administration (NOAA)	Weather and climate	www.noaa.gov

To visualize and analyzed geodata, both the free and open-source Quantum GIS and Esri's ArcGIS Pro (and its base maps) have been used.

In April 2022, when in Zambia the Covid-19 restrictions have been partially lifted, a visit to the project location was conducted to validate the remotely retrieved data. Onsite surveys and unstructured interviews were conducted. Interviews targeted the main projects' actors: Children in Crisis board, school pupils aged from five to sixteen, teachers, and local communities, and included questions about needs, expectations, and daily issues that the project aims to solve or mitigate. Questions were asked during workshops' activities and answers were gathered differently based on the respondents' age and literacy background: interviews with the NGO border's members and teachers were more formal; school pupils were asked to draw their answers on A4 white paper and post-it; local communities were interviewed with the help of an interpret to overcome linguistic and cultural barriers (Fig. 2).

Fig. 2. Interview with one of the local communities.

3. Results

Free and open sourced geodata have been used to analyze the following aspects: location, topography, climate, geology and hydrology, land analysis, economic analysis, infrastructures in the country and in the project area, social structure, distribution of the population, tribes, languages, equality (classes and castes, household, gender equality), worship, education, sustainability of the project, local materials and construction techniques, renewable energy, community needs and risk analysis including climate change.

While some of the analyses are typically needed to understand the project's location, others such as local materials, renewable energy, and risk analysis, have been specifically conducted for construction purposes. The maps of land use, crops, vegetation coverage, geology and mineral resources provide a great understanding of the materials available for the project in a country where the materials used in rural areas, such as the project area, are and must be local.

During the analysis of the local materials, it was determinate that the site ground consists of conglomerates, sandstones, carbonaceous siltstones, and mudstones. These materials are used in the compressed earth blocks (CEB), a traditional construction technique in Zambia. The use of local materials fulfills all sustainable requirements and enables the employment of local workers who are familiar with traditional techniques.

The photovoltaic power potential average (KWh/m^2) raster was used to calculate the square meters of solar panels needed to support the schools. According to the WorldData.info website, the energy consumption per capita in Zambia is 600.52 KWh per year. Calculating the energy consumption for the 250 people who will reside in the boarding school, an average annual consumption of 150.250 KWh is needed. According to Fig. 4, the photovoltaic power average potential in the sites is 2291.1 KWh/m^2 per year. Dividing the energy needed by the photovoltaic power output (150.250 KWh/2291.1 KWh/m^2), it is reasonable to assume that 65,57 m^2 buildings' surface should be covered with solar panels. To calculate the exact surface area, the actual efficiency of the solar panel must be considered.

Climate change forecasts were made using map algebra by adding the predicted variations for temperature and precipitation for the year 2039. For this, the estimations from the Climate Change Knowledge Portal of the World Bank Open Data were added to the raster data of the current situation obtained from NOAA, using the raster calculations by region.

Fig 3. shows that the most affected areas are those in the southern part of the country where temperatures will increase more drastically, and rainfall will decrease. As a consequence, water in the Zambezi, Kafue and Luangwa River basins will reduce. The results of those analyses must be considered when choosing materials, construction, and the water supply systems during the design phase of the project. Also, buildings' orientation and architectonical techniques will be adopt to favor an appropriate indoor temperature.

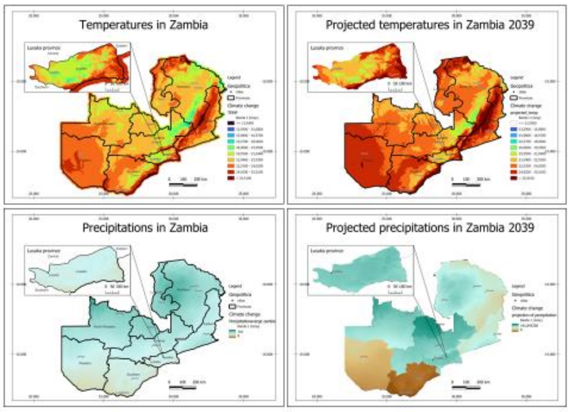

Fig. 3. Climate changes analysis maps.

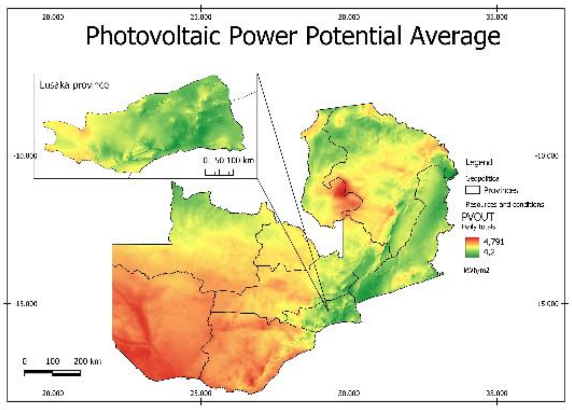

Fig. 4. Photovoltaic power potential average map.

From the analysis of the topography, geology and hydrology geodata was found that the project area is located on the upper Karoo Supergroup formation which is a consolidated sedimentary aquifer with mixed intergranular and Fracture Flow and Karstic Flow, of High to Very High Productivity (CSIF- HV). Therefore, it is necessary to explore the possibility of constructing a borehole. In addition, the high difference from the Zambezi river was used to estimate the upper limit of groundwater and the depth of the well.

The assessment of the need for this project was also evaluated through maps of different social factors such as schooling rate, fertility rate, the Gini Index (which measures inequality in terms of income and wealth) and the WASH Index (measures the access to basic services such as water and communications). These maps were obtained from the Humanitarian Data Exchange website and from the digitization of data included in the Zambian Demographic and Health Survey 2018 [9].

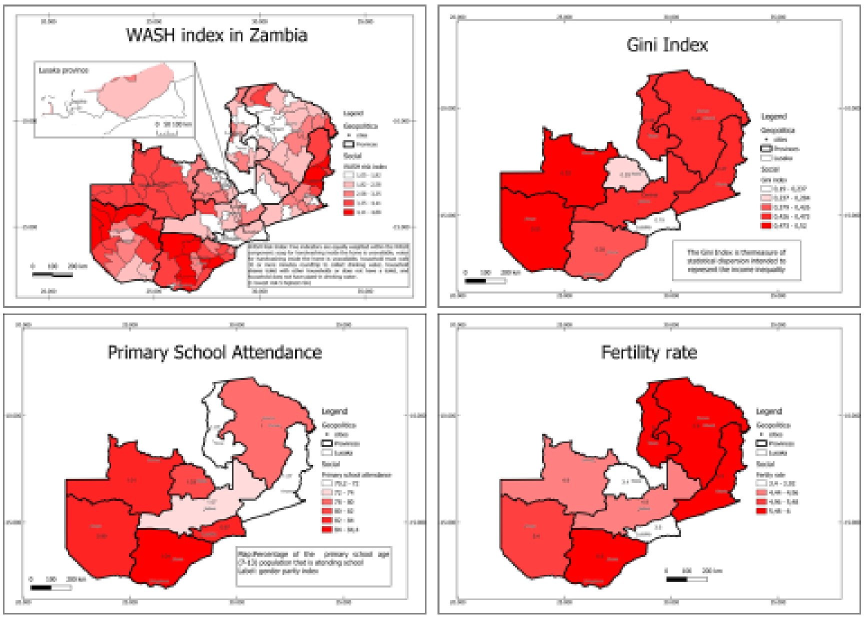

Fig. 5. A selection of the created demographic analysis maps.

Fig. 5 shows the results of the need evaluation for this project. In Zambia, children, especially orphans and girls, are vulnerable to many social risks. The majority of Zambians have no or some primary education. Specifically, 60% of females and 54% of males aged 6 years and older have no or only some primary education. The primary school net attendance ratio (NAR) for the population aged 7-13 years is 79% (81%

for girls and 77% for boys). The secondary school NAR drops sharply to 40% (38% for girls and 42% for boys). The variation in the secondary school by place of residence is large, with a 27% difference between urban (56%) and rural (29%) areas. Besides this, the risks derivate from not having proper sanitary installations, limited access to clean water and walking long distance unsupervised can be also mitigated with the realization of a boarding school.

In all the interviews, the need for the School was confirmed. During The interview with the NGO, a list of priorities to be phases during two phases of the project was drafted. Access to electricity and clean water was claimed as the top priority.

From the workshops with the pupils, their needs and challenges clearly emerged. School children need from legal requirements to go to school (for example uniforms and shoes) to the means to reach the school within an acceptable timeframe and in security. At school, basic teaching and learning tools such as tables, chairs, books, pencils, whiteboards, and chalks lack. Basic infrastructures such as toilets are, when existent, deficient. Children don't have proper playgrounds or a safe green areas close by the schools. Food is scarce and for several of the pupils attending Children in Crisis' schools, the meals provided by the teacher is often the only one they will eat during the whole day. The main challenges discussed with the children mirror the needs listed above. Some of them live far from the school and being in classroom every morning is difficult. Some don't have uniforms or shoes, therefore not even supposed to be at school. Difficulties faced home by some of those children have repercussions at school where inappropriate behaviour are sometimes imitated. The classes are full. Following a lesson is very difficult in a crowded, small, hot room. The lack of toilets and other sanitations facilities is indeed a problem.

Interviews were conducted with a number of the communities surrounding the project´s sites. The communities consist of about 100 families of circa 15 members each. Many of the interviewees claimed that that the way to the nearest school is too long. During the path, children encounter dangerous animals that often attack. During the rainy season, roads become very muddy and reaching schools become extremely difficult when not impossible. The boarding school would also be a way for young girls to avoid early pregnancies by avowing sexual assaults that often happen on the way to school, early marriage and indeed by empowering young girls with the knowledge the school can provide.

4. Discussion and conclusions

The aim of the paper is to present how GIS and free and open data have been used for sustainability and humanitarian purposes and how they served as assets to bypass the unforeseen obstacles caused by the Covid-19 pandemic. Despite the luck of some relevant data, those retrievable from online free and open databases allowed to deeply analyse project location, demographic parameters, materials and energy supply and risk analysis, including climate change.

A project's geographical location and topographic analysis are desirable for all construction projects [4], but fundamental for remote locations in developing countries where material supply and access to energy and water sources are, if existing, scarce or difficult to reach. Basic infrastructures are often unreliable, and transit is difficult. Therefore, local materials and material suppliers are the only possibility to build affordably.

Demographic analyses are needed to support the claim of the project's need and to justify the ASF's partnership on it. For this purpose, up-to-date, reliable data are needed.

In projects such as those supported and sponsored by ASF, the risk analysis is an indispensable tool for decision making and this must include climate change effects on the project's location and on the project itself. Especially in southern countries, the increase of temperatures constitutes a concrete danger that can be faced by taking right decisions during the first stages of a project (i.e. choose of materials, architectonic techniques, buildings orientation). Data such as the current climate data from NOAA and the climate projections and analyses in GIS environment, allowed a seventeen years forecast that will influence the above mentions decision matters.

In this project, free and open-source data and geodata played a central role. As underlined by [5], open databases provide many benefits, but the quality of the data must be assured. Furthermore, some data needed for the project do not exist or are not available on the used databases. Data such as animals most used paths were not found but would have been extremely useful for the project as one of the most reported natural problems by local communities is the danger posed by wild animals attacking people, including kids on their very long way to school. The same can be said for walking path used by children on the way to school, which often are through bushes, water streams and other unsafe paths. Finally, the rural and unsettle architecture is not always present in geodata (Fig. 6).

Fig. 6. A Google maps screenshot about the architectonical conformation nearby the project's area.

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