

EDUCATIONAL MATERIAL DEVELOPMENT ON MOBILE SPATIAL DATA COLLECTION USING OPEN SOURCE GEOSPATIAL TECHNOLOGIES

B. Anbaroğlu ^{1,*}, İ. B. Coşkun ¹, M.A. Brovelli ², T. Obukhov ³, S. Coetzee ⁴

¹ Dept. of Geomatics Engineering, Hacettepe University, Turkey – (banbar, ihsan.coskun)@hacettepe.edu.tr

² Dept. of Civil and Environmental Engineering, Politecnico di Milano, Italy – maria.brovelli@polimi.it

³ United Nations, United States of America – obukhov@un.org

⁴ Dept. of Geography, Geoinformatics and Meteorology, University of Pretoria, South Africa – serena.coetzee@up.ac.za

Commission IV, WG IV/4

KEY WORDS: United Nations, Sustainable Development Goals, open source, e-learning, web GIS, mobile GIS

ABSTRACT:

Mobile spatial data collection is one of the major tasks carried out under the United Nations (UN) to quantify targets of various Sustainable Development Goals (SDGs). Even though there are readily available proprietary solutions to ease mobile spatial data collection, there is often limited educational resources that rely on Free and Open Source Software for Geospatial (FOSS4G). The ongoing efforts of UN OSGeo Committee are to satisfy the requirements of UN operations in terms of identifying and developing open source geospatial software and services. The aim of this paper is to describe and discuss the educational material (tutorial) that is prepared to address the 2019 UN OSGeo Committee Educational Challenge entitled ‘Open geospatial data and software for UN SDG 16, Peace justice and open institution’. The educational material utilised various technologies, including QGIS, QField, PostgreSQL/PostGIS and NodeJS, by relying on a simple mobile spatial data collection scenario, which is collecting information about trees. The scenario serves as an analogy for many different UN operations that might fall under SDG 16, such as interviews with a victim or a vulnerable person or estimating to what extent decision-making is inclusive and responsive. The developed educational material addresses some of the practical requirements of mobile spatial data collection, including handling multiple users, offline data collection, attaching photos to recorded events, editing of spatial features in the field and displaying the collected data on the internet using Heroku. Even though the educational material intends to be self-explanatory, quantitative and qualitative measures are needed to evaluate its efficacy. Therefore, a group of geomatics engineering students were trained with the educational material and their feedbacks were collected through a satisfaction questionnaire as well as the completion time of the tutorial. The outcomes of this paper will be useful in terms of guiding researchers and practitioners who develop online educational material, especially in the geospatial domain.

1. INTRODUCTION

United Nations (UN) identified 17 Sustainable Development Goals (SDGs) to address the most pressing issues of our times. This agenda is entitled ‘Transforming Our World: The 2030 Agenda for Sustainable Development’, and it was agreed by the 193 member states. These SDGs aim, amongst others, to end global poverty, provide universal access to healthcare, education, water and sanitation, and ensure equality, peace and sustainable economic growth. Different targets are defined under each SDG, and one or more indicators are used to assess each target (Barbier and Burgess, 2019). In order to measure the progress on these SDGs, the importance of ‘data’ is evident.

The necessity of a ‘data revolution’ was highlighted in the report entitled ‘A New Global Partnership: Eradicate Poverty and Transform Economies through Sustainable Development: Sustainable Development Knowledge Platform’ (UN, 2013). Use of mobile technology and crowdsourcing are encouraged to collect better data and statistics. This would also pave the way towards governments keeping track of progress of each target. SDG 16 is about promoting just, peaceful and inclusive societies. Developing effective and efficient means to collect and share data is a crucial component of a transparent government. In this way, government decisions will be evidence-based. Furthermore, promoting open access to the collected data will further increase

the credibility of the whole decision making framework, which is a substantially important component of SDG 16.

Geographic data collected by remote sensing or crowd sensing can be used for monitoring the progress of SDGs (Avtar et al., 2019; Flückiger and Seth, 2016). Even though geospatial information is largely available in developed countries, it might not be the case for developing countries. Therefore, researchers identified existing freely available data sources and ways in which to utilise them for calculating indicators of, for example SDG 9, which is about resilient infrastructure, promoting inclusive and sustainable industrialization (Ilie et al., 2019). Even though there are readily available platforms to crowdsource data, there is limited research on educational material preparation that relies on Free and Open Source Software for Geospatial (FOSS4G) to create a mobile spatial data collection framework.

The aim of this paper is to describe and discuss the educational material that was prepared to address the 2019 UN OSGeo Committee Educational Challenge entitled ‘Open geospatial data and software for UN SDG 16, Peace justice and open institution’ (OSGeo, 2019). Various FOSS4G solutions were utilised and the effectiveness of the developed material was evaluated by training a group of geomatics engineering students and obtaining their feedback through a usability questionnaire.

* Corresponding author

The structure of the paper is as follows. The second section describes the existing solutions that can be used to collect mobile spatial data. The third section describes the developed educational material. The fourth section evaluates the efficacy of the tutorial by introducing the usability questionnaire, and presents the outcome of the questionnaire. The fifth section critically discusses the current pedagogic approach and suggests ways in which to improve the current tutorial. Finally, conclusions are presented.

2. MOBILE SPATIAL DATA COLLECTION

There are different software solutions to collect mobile geospatial data. Even though it is difficult to provide a comprehensive list, some representative ones are compared in Table 1. These solutions are: Ushahidi¹, wq², Geopaparazzi³, QField⁴ and Input⁵. Some of these platforms are already quite advanced and offer different licensing options, such as Ushahidi, and some of them require coding knowledge, such as wq.

	Ushahidi	wq	Geopaparazzi	QField	Input
Development languages	Python, PHP	Python, JavaScript	Java, HTML, XML, PHP, JavaScript, Python	C++, Java	C++
Database	MySQL	Any Django-supported database (usually Postgres)	sqlite (MBTiles and Mapbox)	Not applicable	Not applicable
Web Interface	✓	✓	✗	✗	✗
Upload photos/videos	✓	✓	✓	Photo	Photo
Offline storage	✓ (SMS)	✓	✓ (SMS)	✓	✓
Language support	✓ (40+)	?	✓ (20+)	✓	✓
Raster data support	✓	?	✓	Should be converted to GeoPackage	WM(T)S or XYZ layer
Licence	AGPL, LGPL	MIT	GPL 3.0	GPL 2	GPL 2
GPS track	✓	?	✓	✓	✓
QGIS Integration	✗	✗	✗	✓	✓
OSGeo Project	✗	✗	✓	✗	✗
Setup	Easy	Difficult	Easy	Easy	Easy
Mobile App	✓	✗	✓	✓	✓

Table 1. Mobile spatial data collection platforms

Different open-source programming languages like Python, PHP, Java, JavaScript and C++ are used to implement these technologies. Yet, only Geopaparazzi is an OSGeo project. Most of these technologies support multimedia data in the form of photos and videos, as well as different scripting languages. Two of these platforms can even store data as a Short Message Service (SMS). Raster data support is another important feature of a mobile spatial data collection software and the investigated solutions offer different ways to handle it. Input relies on Web Map (Tile) Service (WMS) to store raster data. Considering that QGIS is one of the commonly used open-source GIS to create and manage projects, some of the solutions, such as QField and Input, provide a direct linkage between mobile and desktop platforms by allowing users to open a QGIS project file.

3. EDUCATIONAL MATERIAL

United Nations (UN) officers require mobile field data collection for various purposes, mainly to provide reliable measures to the indicators of specified targets. It is necessary to prepare a tutorial

that will ease the process of mobile spatial data collection using open source solutions. This section describes the educational material prepared for the 2019 UN OSGeo Committee Educational Challenge entitled ‘Open geospatial data and software for UN SDG 16, Peace justice and open institution’ (OSGeo, 2019). Even though UN officers might directly benefit from the prepared material, volunteers, students or non-governmental organizations might also utilise it to generate and visualise crowdsourced geospatial information.

The developed educational material addresses some of the practical requirements such as support for multiple users, offline data collection, attaching photos to recorded observations, editing of spatial features in the field and displaying the collected data on the web.

QField and Input are the two mobile applications that can directly process QGIS project files, which is the widely used open source GIS by UN staff. Therefore, they were the main mobile applications that were considered in this research. Since the latter alternative led to a technical issue during testing (Input, 2019), QField was used.

The educational material (tutorial) is composed of six sections as illustrated in Figure 1. The first section introduces the tutorial by providing the scope, the audience, the required software to achieve it, the scenario utilised and the acquired knowledge. The developed educational material is openly shared with the public through a dedicated wiki page (OSGeo, 2020). In addition, the code required to open the related database tables and to provide the web interface are also openly available in a GitHub repository (Anbaroğlu, 2020). In this way, readers of the tutorial can contribute towards improving its quality by opening an issue.

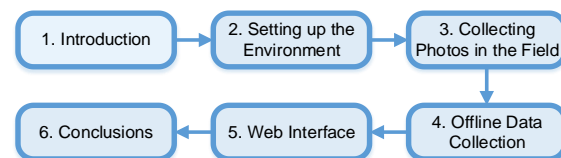


Figure 1. Overall view of the tutorial

The second section sets up the technical environment. Specifically, readers are guided to open an account on Heroku, which is a platform as a service (PaaS) that enables developers to build, run, and operate applications entirely in the cloud (www.heroku.com). By opening an account on Heroku, it is possible to open a PostgreSQL (Postgres) database on the web so that multiple users can effectively collect field data simultaneously. In this way, all the data collected are stored in the same database. Also, Heroku allows deploying readers’ project on the web so that collected data can be displayed in a browser. Heroku offers a server of 512 MB RAM with PostgreSQL/PostGIS installed for free. Even though the free environment is limited in terms of use and performance, it is still convenient to test and learn the materials discussed in the developed educational material. The section then describes the process to open a project in QGIS by linking it to the Heroku database. Finally, in order to ease data collection in the field, *value relations* are set in QGIS. In this way, officers on the ground can select one of the pre-defined event types (i.e. tree type

¹ <https://www.ushahidi.com/>

² <https://wq.io/>

³ <https://www.osgeo.org/projects/geopaparazzi/>

⁴ <https://qfield.org/>

⁵ <https://inputapp.io/>

in the context of the tutorial) from a drop-down menu instead of typing it, which eases user interaction.

Once the prepared QGIS project file, a QGS file, is transferred to QField, a user can start collecting data after a four-step process as illustrated in Figure 2. First, users open the project in QField that is transferred to the mobile device. Second, users choose which layer to edit and toggle the button at the top-right to choose 'You are now in digitise mode'. Third, users can either locate themselves using the GPS of the phone or by panning around the map. Finally, once the add button located at the bottom-right of the screen is touched, a form associated with data collection appears. Drop-down lists to choose the event type or automatically filled thematic attributes such as observation time ease data collection. All of these useful features are set while designing the QGIS project file on desktop.

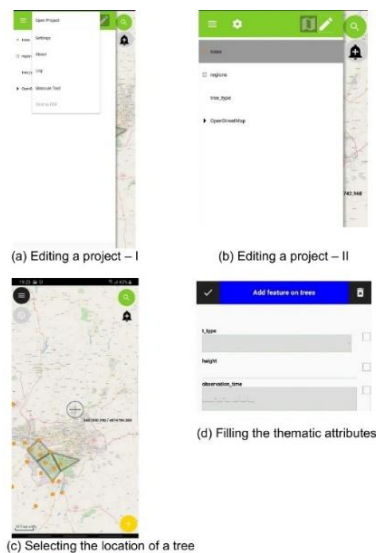


Figure 2. Collecting field data using QField

The third section of the tutorial is about collecting photos in the field, as attaching a photo adds further support to describe a geospatial event. Collecting photos in the field is indeed one of the common approaches in mobile spatial data collection, which necessitates efficient map rendering systems (Guo et al., 2018). However, it is a challenging task to store images in a Postgres database, which might necessitate an additional extension (Guliato et al., 2009). Consequently, Syncthing, an open-source file synchronisation software (<https://syncthing.net/>) was used to sync and share photos between multiple users collecting field data. The first step in this context is to update the QGIS project such that photos can be attached to geospatial observations. Thereon, mobile devices possessing the Syncthing are synchronised with the personal computer possessing the software 'SyncTrayzor'. Finally, whenever a mobile device associates a photo with an observation, that photo is synced with other devices. The QGIS project file holds only the local path to the image, but since that path is identical on all synced devices, collected photos will appear on QField and QGIS as intended.

The fourth section focuses on offline data collection, as there might be limited or no internet connection while being in the field. Consequently, a mobile spatial data collection platform should allow its users to collect offline data. Therefore, this section is dedicated to users who need to collect offline data. This

process consists of three main steps: i) export the QGIS project using the plugin entitled 'QFieldSync'; ii) data collection; and iii) synchronisation using the same plugin. It should be noted that photos can be collected during this process as well.

The fifth section is about displaying the collected data on the web. It might be possible, and even a required process, to keep track of collected data in real-time. Specifically, collected spatial data can be visualised on the web by using Heroku. In order to effectively follow this section, three different software installations are required. Firstly, 'Visual Studio Code'¹, a free and open source code editor is used to write and edit code. Secondly, NodeJS², an open-source JavaScript runtime environment, is used. Finally, Git, an open-source software development version control system³, is used to deploy the project on Heroku. The web-based project retrieves the data from the database and overlays it on top of OpenLayers. Therefore, whenever a new observation is recorded in QField, the project's website displays it as well. The overall view of the educational material is illustrated in Figure 3.

Finally, the sixth section is the concluding remarks. It critically discusses the content of the tutorial as well as provide future research directions.

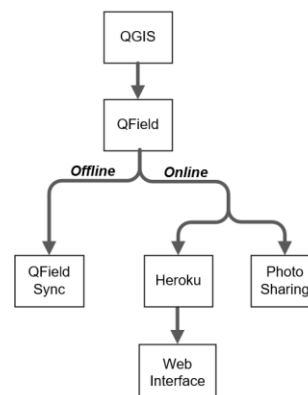


Figure 3. Overall view of the educational material

The educational material relied on is a simple scenario of collecting information about trees in a region. Specifically, a lecturer specifies polygons, assigns one to each student and sends the relevant QGS file to students so that they can open it in QField. Thereon, students collect relevant data in their region. Some of the regions might have limited broadband coverage, which requires students to collect data offline, and some students may capture photos of trees. Finally, it would be interesting to display the collected data on the internet so that decision makers (lecturers) could have a better understanding of over/under mapped regions.

The scenario serves as an analogy for many different UN operations that fall under SDG 16, such as interviews with a victim or a vulnerable person or estimating to what extent decision-making is inclusive and responsive. At the end of the 'online' track of the tutorial, it is possible to display the collected data on Heroku as illustrated in Figure 4. Web-based visualisation consists of only the location of trees without any additional thematic data, such as the type or height of a tree. In this aspect, the educational material acts as a basis for web mapping that is open for further improvements.

¹ <https://code.visualstudio.com/>

² <https://nodejs.org/>

³ <https://git-scm.com/>

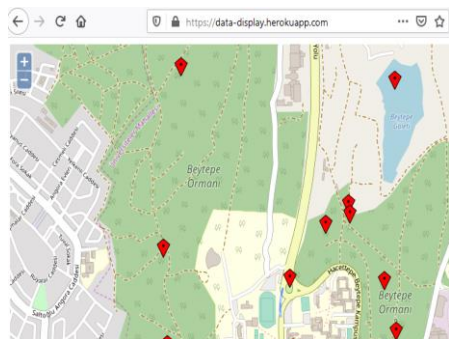


Figure 4. An exemplar output of the ‘online’ track – visualising collected data on the web

4. EDUCATIONAL MATERIAL USABILITY

The tutorial was developed by having regular online meetings with the mentors of the project who are the last three authors of this paper. These regular meetings were invaluable to obtain timely feedback at some important decision points. Once the developed material reached an acceptable level, it was transferred to a dedicated wiki page (OSGeo, 2020). Consequently, the educational material could reach a wider audience, and their feedback can be collected.

In order to evaluate the efficacy of the developed educational material, a group of geomatics engineering students at Hacettepe University were trained with the tutorial. A total of 58 third year students who were taking the ‘GIS’ course were asked to complete the tutorial. No extra laboratory session was carried out with the students to have a better understanding on how well the educational material was self-contained.

The immediate observation was regarding the mobile operating system. Specifically, students possessing an iOS operating system could not install QField, since the application is not available in App Store. This observation had already been raised as an issue on QField’s GitHub repository. The reason preventing QField’s availability in iOS is related with legal issues on the ‘licensing and publishing open source apps in app store’. Nevertheless, this statement appeared on 31 March 2017, and recent discussions under the same issue suggest that QField would soon be available in iOS as well (QField, 2017).

A survey is then conducted to understand the number of students possessing an iOS or Android device. It is found out that while 23 students possess iOS, the remaining 35 possess an Android device. In other words, almost 40% of the students could not even start the tutorial, which highlights the importance of cross platform open-source software solutions to collect mobile spatial data.

Consequently, students were asked to form groups of two or three so that each group had access to an Android device. This fallback plan did not work either, as it proved to be very difficult for all group members to play with the application and test different parts of the tutorial. Finally, all students were asked to do the web mapping part, since it is possible to open a QGIS project and simulate data as if it was collected in the field, and then visualise it on the web interface.

Two weeks were given to the students, and 26 of them completed the tutorial successfully. Those successful students were then asked to complete the anonymous usability questionnaire illustrated in Table 2.

This questionnaire assessed the strong and weak points of the tutorial, both qualitatively and quantitatively. Specifically, students were asked to evaluate the tutorial based on their personal experience, as well as record the approximate time to complete the tutorial in hours.

ID	Question
1	The tutorial was well-organized.
2	The material was presented in an interesting manner.
3	Various functions in this tutorial were well integrated.
4	The concepts were clearly presented and easy to understand.
5	Figures were helpful to keep track of the tutorial.
6	The tutorial increased my knowledge about mobile spatial data collection.
7	I feel capable of developing a simple mobile spatial data collection application.
8	The length of the tutorial was appropriate.
9	This tutorial was as effective as traditional teaching methods in helping me learn the material.
10	I had to look up the web/ask a friend to be able to follow this tutorial. If 10 is ‘YES’: At what point did you need further support?
11	I would recommend this tutorial to others.
12	Overall, I was satisfied with the tutorial.
13	How do you suggest to improve the quality of the tutorial?
14	How do you think UN operations can benefit from this tutorial?

Table 2. Educational material usability questionnaire

Amongst the successful students, 18 of them filled the web-based questionnaire and the results of the first nine questions are illustrated in Figure 5. Even though the questionnaire is completed by only those who had successfully completed the tutorial, their anonymous feedbacks were valuable in terms of improving the quality of the tutorial.

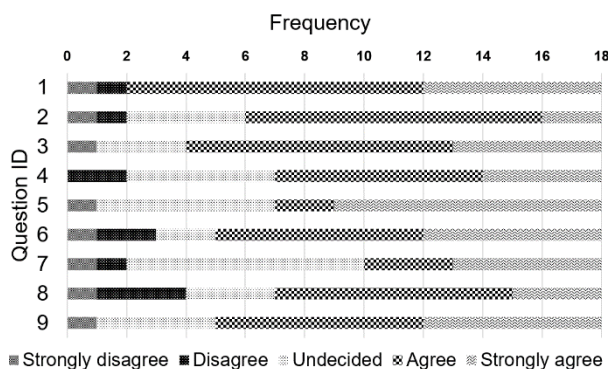


Figure 5. Results of the first nine questions

The results suggest several outcomes. On the positive side, the use of figures was considered helpful, as approximately 61% of the students (11/18) agree or ‘strongly agree’ with question #5. This adds further support to the use of photos, and motivates further use of multimedia, especially videos, a suggestion that was highlighted in responses to question #13. It is evident that inclusion of multimedia enhances legibility of educational material and helps students to better keep track of their progress.

The highest number of undecided students occurred on question #7. Specifically, eight students were undecided whether they are capable of developing a simple mobile spatial data collection application. This outcome suggests the necessity to employ further educational material to increase their understanding of the relevant topics, instead of simply asking them to follow what had been done. Though it should be noted that web mapping is an emerging area including many different technologies (Roth et al., 2014).

The highest number of students who either disagree or strongly disagree was for question #8. Specifically, the length of the tutorial might be longer than what students might have expected. This outcome is understandable as students were expected to learn different tools and platforms in short amounts of time without any technical support. Even though 13 students agree that this educational material is as effective as traditional teaching methods to learn new material (question #9), such an experience was novel for both the lecturer and students. Therefore, it is not surprising to observe that a staggering 94% of students had to look up the web or ask a friend while following this tutorial (question #10).

The students who asked for help were then asked an open-ended question to identify the complicated parts of the tutorial. One of the students required further support on 'QGIS plugins and attachments'. Probably, this response is related to the use of QFieldSync; hence, offline data collection. Indeed, the majority of students stated that the 'offline data collection' part was the most complicated part. Thereon, four students found the 'web interface' part complicated. Two of the students further elaborated on this. While one of them had trouble transferring files from command prompt using git, the other one was faced with a more simpler problem; '*Just in the Web Interface/ From cmd going to my project directory (I did not know how to do that)*'; but s/he further added that '*But it just took me seconds to figure it out.*'. This outcome suggests paying attention to all of the seemingly simple details, as the audience might not know them in advance. Finally, one of the students had difficulty to synchronise photos using Syncthing and the other one stated that there were some terms that s/he did not know, though these terms were not specified explicitly. Finally, throughout the process students informed the lecturer about minor improvements, such as updating an image so that it better depicts what needs to be done or identification of problems that had not occurred while drafting the educational material. Most of the requests were taken into account, and the tutorial was updated accordingly.

Completion time of the tutorial was the only quantitative parameter investigated in this study, and the results are reported in Figure 6. The students' self-reported completion times of the tutorial ranged from 5 to 14 hours, with an average of 9.5 hours. This result suggests that the tutorial might indeed be long, which adds further support to the student feedback on question #8. Nevertheless, it would be difficult to develop a simpler and shorter tutorial covering the same content.

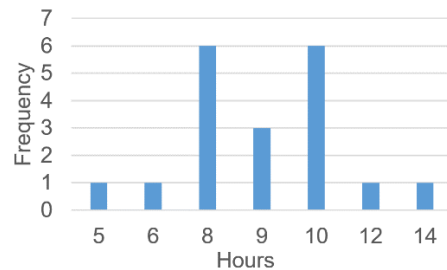


Figure 6. Completion time of the educational material

Students' overall feedback on the tutorial was generally positive, where 12 students would recommend it to others, and 14 of them were satisfied with it. Nevertheless, they suggest various ways in which to improve the quality of the tutorial. Two of the students suggested the use of videos in addition to photos. This is in line with the previous finding (i.e. question #5) that students generally prefer multimedia over text. Another student suggested the use of raw SQL code instead of using an image to describe the process of creating tables. The rationale behind this suggestion is that this will '*make the process for learning faster*', since students are expected to write the SQL code themselves instead of a copy-paste operation. On the other hand, another student suggested that '*this training should focus more on "why we do these steps" than "how we do".' The latter response is surely a more important one to consider, but it should be kept in mind that the tutorial is intended to provide the necessary open source and/or freely available platforms to achieve a mobile spatial data collection framework. Nevertheless, it might be better to consider real-life scenarios while developing such educational content. The last open-ended question was aimed at understanding exactly this issue.*

The students spent a substantial amount of their time on completing the tutorial. Before doing so, they were informed about the SDGs and relevant resources were shared with them. Consequently, their comments could indeed be used to suggest the subsequent versions of this tutorial by focusing on a real-life example from which the UN might benefit. One of the students related the tutorial with the use cases of web GIS and emphasised how volunteers can collect data about natural disasters. Improving capacity to mitigate the recent Covid-19 outbreak is worth to mention. An eloquent example demonstrating the importance of volunteer contributions in such emergencies is shown in Figure 7, which is used to identify Covid-19 test centres in the United States.

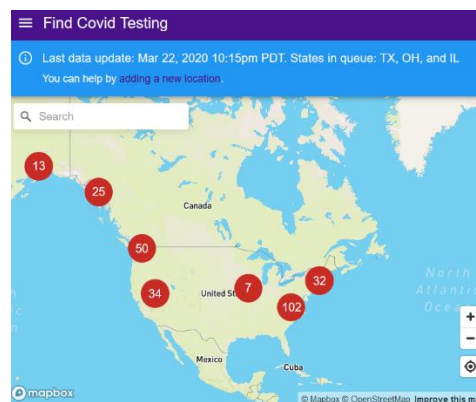


Figure 7. Volunteers developed the 'Find Covid Testing' site <https://findcovidtesting.com/> (access date: 25 March 2020)

Another relevant feedback was related to mapping vandalised buildings and historical monuments. This is also a valuable

suggestion, since SDG 16 aims to promote accountable and inclusive institutions as well as peaceful societies. Monitoring such vandal acts that might be in various forms, including graffiti or looting (Vella et al., 2015), will inform policy makers to develop effective urban regeneration projects (Eyüboğlu et al., 2007).

5. DISCUSSION

The growing technology on web mapping makes it difficult to choose one platform amongst many different possibilities (Roth et al., 2014). Consequently, having simple educational material about mobile spatial data collection that relies on open source and/or freely available platforms to test various ideas is an emerging requirement. As much as any web based service, a dedicated server to run all of the required software costs money. Even though Heroku poses some restrictions on the amount of data collected or that it does not allow creating different types of users, it still proved to be effective to demonstrate the scenario of how multiple users can collect field data about trees. This scenario can be thought of as an analogy to many different mobile spatial data collection scenarios that might fall under the UN operations.

The educational material did not cover some rather important aspects in mobile spatial data collection. For instance, incorporating raster images in offline data collection would be a required operation to identify the correct location of an observation, unless a real-time data collection is in place where coordinates are obtained from the GNSS receivers of the phone. In addition, whoever possesses the QGIS project file would have the means to access the database, as the credentials are stated explicitly in this file. This security breach; however, might not be a decisive limitation since the file is only shared with trusted parties. Furthermore, at the moment, there is no Quality Assurance/Quality Control (QA/QC) processes. For example, a tree might be recorded inside a lake as shown in Figure 4. This necessitates further spatial analysis to identify such incorrect observations. Integrating cloud-based technologies is an ongoing interest, where researchers can integrate further desired features into a mobile spatial data collection project.

6. CONCLUSIONS

The pervasive use of mobile technologies eases spatial data collection. This research developed educational material that is based on open source technologies and/or free platforms so that readers can develop their own mobile spatial data collection framework. The material consists of six sections and demonstrates several important aspects, including multiple users collecting data, attaching photos to observations and offline data collection.

The effectiveness of the developed educational material is evaluated by asking 58 undergraduate students who are taking a GIS course, and 26 of those completed the tutorial. Feedback was sought from these successful students, and 18 of them filled the anonymous usability questionnaire. The responses suggest that the developed educational material can be covered within 8-10 hours. Use of photos to explain steps is appreciated, but there is also room for improvement in terms of utilising videos. Students are asked to follow the educational material, but this strict guidance might have limited their imagination, as well as enthusiasm, to learn on their own; hence, they are undecided whether they would be able to develop a simple mobile spatial data collection application. This outcome suggests the necessity

to employ further educational material and employ assignments to increase their understanding of the relevant topics.

Future research directions include the use of cloud computing to ensure QA/QC steps. In addition, the effectiveness of integrating raster data in offline data collection, again with multiple users, can be investigated. Last, but not least, relying on a real-life mobile spatial data collection scenario would likely improve the overall quality of the developed educational material. In this way, requirements of UN officers can better be understood, and more advanced instructional design frameworks, such as the Analysis, Design, Development, Implementation and Evaluation (ADDIE) model can be practised from the start (Branch, 2009).

ACKNOWLEDGMENTS

We would like to thank Mohammad Almasri, Agit Oktay and Matthias Kuhn who helped us in various ways to improve the quality of the tutorial. In addition, we would like to thank all students who tried their best to complete the tutorial, and provided feedback to improve it. The 2019 OSGeo UN Committee Educational Challenge has kindly supported the development of the tutorial.

REFERENCES

- Anbaroğlu, B., 2020. banbar/OSGeo-Challenge2-2019 <https://github.com/banbar/OSGeo-Challenge2-2019> (30 May 2020)
- Avtar, R., Aggarwal, R., Kharrazi, A., Kumar, P., Kurniawan, T.A., 2019. Utilizing geospatial information to implement SDGs and monitor their Progress. *Environ Monit Assess* 192, 35. <https://doi.org/10.1007/s10661-019-7996-9>
- Barbier, E.B., Burgess, J.C., 2019. Sustainable development goal indicators: Analyzing trade-offs and complementarities. *World Development* 122, 295–305. <https://doi.org/10.1016/j.worlddev.2019.05.026>
- Branch, R.M., 2009. *Instructional Design: The ADDIE Approach*. Springer US. <https://doi.org/10.1007/978-0-387-09506-6>
- Eyüboğlu, E., Kubat, A.S., Ertekin, Ö., 2007. A New Urban Planning Approach for the Regeneration of an Historical Area within Istanbul's Central Business District. *Journal of Urban Design* 12, 295–312. <https://doi.org/10.1080/13574800701306179>
- Flückiger, Y., Seth, N., 2016. SDG indicators need crowdsourcing. *Nature* 531, 448–448. <https://doi.org/10.1038/531448c>
- Guliatto, D., Melo, E.V. de, Rangayyan, R.M., Soares, R.C., 2009. POSTGRESQL-IE: An Image-handling Extension for PostgreSQL. *J Digit Imaging* 22, 149–165. <https://doi.org/10.1007/s10278-007-9097-5>
- Guo, T., Feng, K., Cong, G., Bao, Z., 2018. Efficient Selection of Geospatial Data on Maps for Interactive and Visualized Exploration, 567–582. <https://doi.org/10.1145/3183713.3183738>
- Ilie, C.M., Brovelli, M.A., Coetzee, S., 2019. Monitoring SDG 9 with Global Open Data and Open Software - A Case Study from Rural Tanzania, in: *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information*

Sciences. 1551–1558. <https://doi.org/10.5194/isprs-archives-XLIII-2-W13-1551-2019>

Input, 2019. Inactive Project Error · Issue #494 · lutraconsulting/input
<https://github.com/lutraconsulting/input/issues/494> (30 May 2020)

OSGeo, 2020. Training Material for 2019 UN Open GIS Challenge 2 - Open geospatial data and software for UN SDG 16, Peace justice and open institutions - OSGeo: https://wiki.osgeo.org/wiki/Training_Material_for_2019_UN_Open_GIS_Challenge_2_-_Open_geospatial_data_and_software_for_UN_SDG_16,_Peace_justice_and_open_institutions (30 May 2020)

OSGeo, 2019. 2019 OSGeo UN Committee Educational Challenge OSGeo: <https://www.osgeo.org/foundation-news/2019-osgeo-un-committee-educational-challenge/> (30 May 2020)

QField, 2017. Question : IOS ? · Issue #122 · opengisch/QField: <https://github.com/opengisch/QField/issues/122> (30 May 2020)

Roth, R.E., Donohue, R.G., Sack, C.M., Wallace, T.R., Buckingham, T.M.A., 2014. A Process for Keeping Pace with Evolving Web Mapping Technologies. *Cartographic Perspectives* 25–52. <https://doi.org/10.14714/CP78.1273>

UN, 2013. A New Global Partnership: Eradicate Poverty and Transform Economies through Sustainable Development.

Vella, C., Bocancea, E., Urban, T.M., Knodell, A.R., Tuttle, C.A., Alcock, S.E., 2015. Looting and vandalism around a World Heritage Site: Documenting modern damage to archaeological heritage in Petra's hinterland. *Journal of Field Archaeology* 40, 221–235. <https://doi.org/10.1179/0093469015Z.000000000119>