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New Enabling Technologies to Observe and Characterize Urban Environments with Big Data from Space - The Urban Thematic Exploitation Platform

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1 ABSTRACT

Modern Earth Observation (EO) satellite missions provide valuable opportunities to support sustainable urban planning and management by delivering dedicated information on the spatiotemporal development of the built environment and its key morphological and physical characteristics such as imperviousness, greenness, built-up density, building volume, albedo – from global down to local scale. However, the transformation of the raw EO imagery into ready-to-use thematic data and indicators for scientist or planners on the one hand and actionable information for decision makers on the other hand requires detailed technical expert knowledge. Moreover, the imagery collected by satellite missions such as the US Landsat program or the European fleet of Sentinel satellites, but also by airborne systems or drones, rapidly adds up to a multiple of the data volume that can effectively be handled with standard work stations and software solutions.

Hence, this contribution introduces the Urban Thematic Exploitation Platform (https://urban-tep.eo.esa.int) that utilizes modern information and communication technology to bridge the gap between the mass data collections of the technology-driven EO sector and the demand of science, planning, and policy for up-to-date information on the status, properties and dynamics of the urban system. Key components of the Urban Thematic Exploitation Platform (U-TEP) are an open, web-based portal that is connected to distributed high-level computing clusters and clouds and that also provides key functionalities for i) high-performance data access, analysis and visualization, ii) customized development and sharing of algorithms, products and services, and iii) networking, communication and exchange of data and information. The overarching objective here is to enable any interested (non-expert) user to easily generate actionable indicators and information for effective sustainable urban development based on a joint analysis of various data sources such as official survey data, EO mission data, socio-economic statistics, and data collected via social media or citizen science.

So far more than 3.5 PB of data have been processed and analyzed by means of the U-TEP to finally provide a broad spectrum of urban information products and related services for visualization and analytics that have yet successfully been used by more than 240 institutions (science, planning, NGOs, policy) from 41 countries (i.a. World Bank Group, United Nations, Organisation for Economic Cooperation and Development, World Food Programme, Bill and Melinda Gates Foundation, Group on Earth Observation, Global Platform for Sustainable Cities).

2 INTRODUCTION

On the topic of global change, a large-scale transfomation is occurring on Earth where the proportion of people living in urban areas is exceeding that of people living in rural regions. Cities located in Asia and Africa are growing at a staggering pace; megacities are expanding every year and urban sprawls are emerging and spreading across extensive areas of landscapes, that until recently, had been untouched by development or used for agricultural production. This trend towards urbanization shows no sign of abating. Today, approximately 7.2 billion people inhabit Earth and this number is expected to rise up to 9 billion by the year 2050, when 70 percent of the population will be living in cities (UN, 2016).

Even when the urbanization process has regional roots, it also comes with common drivers that can be applied to describe urbanization at the global scale. It is here that Earth Observation (EO) can make a

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valuable contribution. Data from modern EO satellite missions such as US Landsat or the European Space Agency (ESA) Sentinel satellites support sustainable urban planning and management by delivering dedicated information on the spatiotemporal development of the built environment and its key morphological and physical characteristics such as imperviousness, greenness, built-up density, building volume, albedo – from global down to local scale. In other words, satellite-based geo-information delivers an up-to-date and comprehensive image of the built environment, while at the same time documents its changes over time (Seto, 2009; Esch et al., 2010; Gamba and Herold, 2009).

However, to effectively and efficiently access, process, analize and distribute the growing volume of data, the implementation of operational, modular and highly automated processing chains, embedded in powerful hard- and software environments and linked with effective distribution functionalities is of central importance. On this account, the ESA started the "EO Exploitation Platforms (EPs)" initiavite, aiming at the creation of an ecosystem of interconnected "Thematic Exploitation Platforms (TEPs)". Basically, a TEP is a collaborative, virtual work environment with one coherent user interface that provides access to EO data and the tools, processors, and Information and Communication Technology (ICT) resources required to efficiently extract thematic geo-information from mass EO data sources (ESA, 2016). Starting in 2014 and with the first phase ending in 2017, TEPs have been implemented for Coastal, Forestry, Hydrology, Geohazards, Polar, Food Security and Urban applications.

3 THE URBAN-TEP PROJECT

The Urban-TEP project can be considered as an evolving framework platform which brings users and functionalities closer to big data inventories (primarily EO data, but also from other sources.), supports large-scale and complex data exploitation, and facilitates the sharing of data, technology, and knowledge. More information about the U-TEP project can be obtained from the project website via "https://urban-tep.eo.esa.int"

3.1 Consortium, Stakeholders and User Community

The U-TEP platform is developed by a consortium led by the German Aerospace Center (DLR) and integrated by Brockmann Consult GmbH (DE), Gisat s.r.o. (CZ), IT4Innovations (CZ), and Terradue Srl (IT). Terradue Srl contribute with their expertise in developing a web-portal; IT4Innovations, Brockmann Consult GmbH and DLR are responsible for the provision of high performance computing processing infraestructures, services and data storage, and in charged of the data processing and thematic analyses; and finally, Gisat s.r.o. provides with the necessary visualisation and WebGIS components.

The Urban TEP project is designed to serve a broad spectrum of stakeholders operating from global to local scale and including scientific communities, public authorities and governmental organizations, non-governmental and non-institutional communities, and the commercial sector. In the current project phase a dedicated community of "early adopters" is helping the Urban TEP consortium to set-up and optimize the basic system and service functions and therewith to guarantee a high applicability and benefit of the platform. The current main users include i.a. World Bank Group (WBG), United Nations (UN), Organisation for Economic Co-operation and Development (OECD), World Food Programme (WFP), Bill and Melinda Gates Foundation, Group on Earth Observation (GEO), Global Platform for Sustainable Cities (GPSC), WorldPop, Columbia University (CIESIN) - USA, and the Sultan Qaboos University -Oman.

3.2 Conceptual Design

The U-TEP is a web-based (Fig.1) and open platform that enables any interested user to exploit EO data easily and with no data download complications. The system allows the generation of thematic information, which combines not only different EO data, but data from other sources such as statistics, surveying and volunteered greographic information. Users involved in urban and environmental science can produce, for example, thematic information on growing cities, the impact of climate change on the built environment, or the erosion of biodiversity due to human disturbance.

In general terms, the main objective of the platform is to facilitate effective and efficient urban management by systematically exploring i) on-demand and up-to-date geo-information about the status and development of urban areas for any region and time of the users interest, ii) the massive processing power provided by modern ICT-infrastructures and technologies, and iii) the capabilities of participation and sharing of knowledge by using new media and ways of communication.

The U-TEP technical concept is based on a generic, modular, multi-purpose systems design, facilitating maximum flexibility with respect to the adaptation to various user requirements and application scenarios as well as to available data processing and analysis technologies and IT infrastructures. The main componets of the U-TEP are:

1) *Web-portal.*
2) *High-level computing clusters,*
3) *Unique portfolio of thematic data,*
4) *State-of-the art pre-processing, analysis, and visualisation techniques,*
5) *Customising functionalities for transfer of algorithms/products into services;*
6) *Functionalities to disseminate data, functionalities, and information, and*
7) *Support of networking and communication activities*

Considering these basic components, the U-TEP can serve to various service models such Platform as a Service (PaaS), Infrastructure as a Serviced (IaaS), Information as a Service (InaaS), and Software as a Service (SaaS). The platform functionalities follow an Open Source strategy, which means, they are based on an Open Source components and models, with an online presence at "https://github.com/U-TEP". Moreover, the interfaces between the integrated software APIs are based on Open Standard specification (e.g., OCCI, OGC). The aim of an open strategy is to assure sustainable developments.

It is important to mention that the U-TEP platform is not designed to access EO data directly, and therefore, does not perform as a classical data distribution tool.

Fig. 1: U-TEP web-portal (https://urban-tep.eo.esa.int) serving as entry point to the system.

3.3 Supported Use-Scenarios

The conceptual design of the U-TEP primarily aims at supporting four general use scenarios.

1. *Explore existing thematic content*

The user can select a broad spectrum of existing thematic content on urban themes provided on the U-TEP platform. Moreover, the user can upload own data and content (e.g., statistics) and jointly analyze and visualize the available thematic layers based on state-of-the-art tools of Geographic Information Systems. Any openly available thematic content or generated result can be exported.

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2. *Task individual on-demand analyses*

The user can conduct on-demand processing and production of thematic content based on multi-mission remote sensing imagery and additional data sources (e.g., cadastral data, statistics, and socio-economic data). The additional data might either be publically available on the platform or individually uploaded by the user.

3. *Develop, deploy and offer your own content or application*

The U-TEP platform allows for the individual development and deployment of analysis techniques, thematic products and application-oriented services. Therefore, the platform offers interfaces to upload and run user-defined algorithms and processes and provides functionalities to develop own methods and products (e.g., by using the Sentinel tool boxes) directly on the platform. Developed applications or products can then be presented and shared at the U-TEP platform application and product store.

4. *Learn more about innovative data sets and methods*

The U-TEP platform provides various opportunities to inform about innovative products, applications and initiatives and the latest state-of-the-art methods and solutions. These approaches and products might even be available for first testing on the platform by the interested user and the user can also contribute a rating of or feedback to the method or solution in order to support further optimization and/or operationalization.

3.4 U-TEP Products Portafolio and Services

Currently the U-TEP platform has successfully been used to process a vast amount of satellite data collections, including global coverages of multispectral Landsat scenes for the years 2015, 2010, 2000 and 1990 (948,894 images), a global dataset of 25,550 Envisat-ASAR radar images collected between 2010-2012, and Sentinel-1 and Sentinel-2 data collections covering several regions in central Europe and Africa. The results of this EO-based processing have been used to support the generation of several new global thematic layers, including the Global Urban Footprint (GUF 2012) binary human settlement mask (Esch et al., 2017) several collections of TimeScan products providing spectrally and temporally harmonized representations of the land surface (Esch et al., 2017) and the experimental GUF-DenS 2012 (Fig. 2) product derived from a combination of the binary GUF 2012 and TimeScan-Landsat 2015 data (Esch et al., 2017). A more detailed specification and visualization of all products and services already available is provided at the Urban TEP website/portal. The currently available on-demand processing services include TimeScan on-demand (Sentinel, Landsat), Functional Area Definition (urban-rural), and Data Visualisation and Analytics (ESA, 2018).

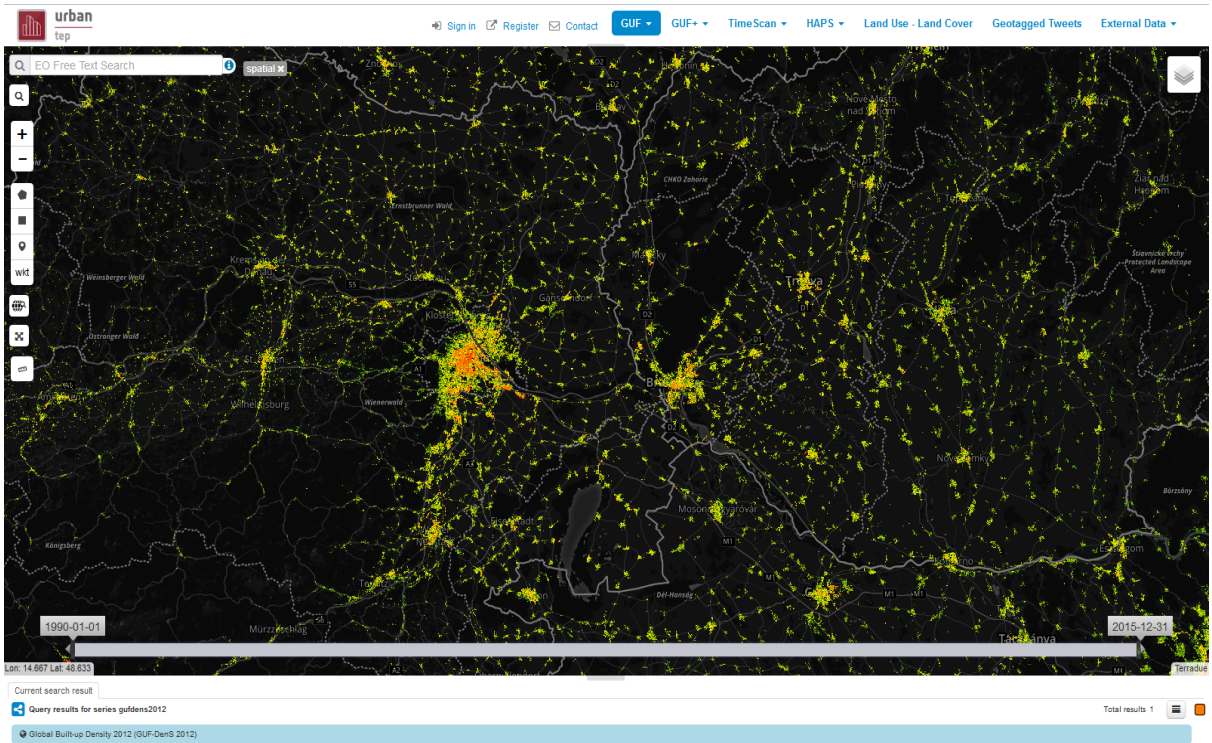

Fig. 2: U-TEP geobrowser showing current product portfolio and exemplary visualization of GUF-Density layer for region of Vienna, Austria.

Moreover, several (global) auxiliary data sets have been integrated in the Urban TEP, including demo data for High Altitude Pseudo Satellites (HAPS), WorldPop, Gridded Population World, Global Administrative Units, VIIRS Nighttime Lights, ESA CCI Land Cover, World Bank statistics, UN statistics or geotagged Tweets (ESA,2018).

4 CONCLUSIONS AND FURTHER DEVELOPMENTS

The main objective of the U-TEP is to initiate step changes regarding remote processing (bringing users-to-the-data), enabling technology (facilitating large-scale exploitation and timeliness of mass data analyses), distribution of expertise by sharing of data and methods (increase of assets, fostering of innovation, supporting benchmarking), and the establishment of open, integrative, participatory, collaborative concepts (community stimulation, increasing outreach). Currently, most services for thematic information can be considered non-generic and often just a short term solution, as they are mainly project funded and with a very specific focus and area of interest. For these reasons, the technological progress that the Urban TEP is expected to initiate in the near future will provide a number of advantages for the users, including, but not limited to:

1. Free and open access to and use of state-of-the art infrastructures (computing, data management, storage), techniques (e.g., multi-source data fusion and analysis) and EO-derived information products.
2. Efficient exploitation of full spectrum of available EO data streams and archives.
3. Validated and benchmarked algorithms and products.
4. Access to network of experts and stakeholders that share experiences and best practice applications.
5. Market place of ideas and driver of innovation
6. Seed point for the animation of new user communities outside EO/geo-sector.
7. Gaining of better knowledge on urban system and increased efficiency, effectiveness and sustainability of functions and services in policy, planning, economy, and science.

In the current project phase, which covers the time span from March 2015 to March 2018, already more than 240 institutions from more than 40 countries have requested access to the U-TEP and products.

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