Hey, look up! The benefits of satellite technologies to monitor and manage megaprojects

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Abstract: “Over time, over budget, over and over again.” Despite megaprojects are increasingly being chosen and used as a preferred delivery mode for goods and services in a wide range of industries (infrastructures, banking, air and space exploration, urban and rural areas regeneration), performance data shows that we are still far from knowing how to manage and control them properly. Given the long duration and the complexity of these projects, an effective progress monitoring system can ensure a better outcome in terms of meeting schedule, cost, and project quality. However, this is particularly difficult when adopting the progress monitoring techniques traditionally used in project management. The advent of emerging technologies (e.g., data analytics, ML, IoT, satellites) led researchers to develop and experiment with a plethora of techniques to monitor and assess the working progress of megaprojects. Among them, satellites technologies (i.e. Earth Observation) offer novel opportunities to monitor and assess the impacts of a wide range of projects (e.g., infrastructure and environment restoration megaprojects), however they are loosely deployed for industrial applications and studied in literature. The aim of this paper is to investigate what are (i) the emerging technologies that are more suitable to be used to track megaproject progress (ii) the benefits and challenges of adopting satellite technologies compared to traditional ones and (iii) the potential for concrete application of these technologies in megaprojects in progress or to be launched. Our analysis demonstrates that the benefits of adopting satellite technologies to evaluate project progress are relevant; consequently, other studies can be done to evaluate the application of the same technologies for data collection regarding megaprojects impacts and value creation after its completion.

Keywords: Megaprojects, Satellite technologies, Controlling

I. INTRODUCTION

The management and development of megaprojects, usually defined as projects with a budget of more than US$1 billion, a lifecycle of decades and major social, political and economic impacts, has had considerable difficulty over the past century in reaching the desired outcomes [1], [2]. On one side, the trend to go "Over Budget, Over Time, Over and Over Again" is in most cases an issue, showing difficulties in meeting the initial plan and managing the execution phase of the delivery [1], [3]; on the other side also the achievement of the originally set objectives is extremely risky and notoriously difficult to be managed [4]. The management of megaprojects is usually done by establishing a temporary standalone organization that may be led by a client team, the main contractor, or a joint venture that works for a limited period to achieve shared project objectives in a highly uncertain, non-repetitive environment [5]. From an organizational and managerial standpoint, megaprojects are often divided into subprojects that form at the governance level interrelated project programmes sharing the same objectives and a common pool of resources [6], [5]. Thus, possible failures in the management of megaprojects may arise from (i) the management of the individual subprojects included in the main portfolio; (ii) problems associated with a lack of integration management, shared monitoring, and control systems cross cutting the entire megaproject. The objective of this paper is to propose the use of satellite technologies as a tool for monitoring, integration and control of a megaproject. The paper is organised as follows: the background section highlights the problems of managing and monitoring megaprojects, the limitations of currently available technologies and the characteristics of satellite technologies. The next part presents a hypothesis of the application of satellite monitoring technologies to a Po River renaturation project, presenting the main benefits and challenges.

II. BACKGROUND AND OPEN ISSUES

A. Problems in managing megaprojects

The extant literature about megaprojects has focused on identifying the main causes and main dimensions determining their very frequent failure [1], [4] (Table A). Most of the issues are identified in the project planning phase, determining an ongoing interest by the literature in defining possible “cures” [1] for a better management of megaprojects in this field. So, for example some authors have attempted to provide solutions to the problem of "optimism bias" (known as a cognitive bias leading to overestimate profit and underestimate cost and schedule baselines of a megaproject [7] by (i) conducting strong benchmarking activities looking extensively to previous projects or data [8], [9]; (ii) developing plans for preventing major risks and uncertainties [1]; (iii) defining from the outset possible front-end tools for avoiding overly optimistic estimates in the planning phase [10]. At the same way, others have concentrated on scope definition issues, arguing that possible strategies for coping with them includes (i) trying to remove ambiguity about the objectives of the work since the initiating phase (possibly using a shared WBS of each single programme) [11], [12]; (ii) establish from the outset the responsibility of scope validation and verification, defining clearly the roles of the sponsor, the client, the owner and operator organization [13]. As far as governance issues are concerned, all the possible cures suggested have the common objective of improving the integration between different programmes and make decision-making procedures smoother; thus some of the solutions proposed in the extant literature include (i) to design a system based governance structure (including all the actors involved in the supply chain) [11], [14]; to aid the formal governance rules with informal mechanism to foster the coordination among different actors involved [15]. All these corrective actions can be effectively deployed during the "shaping" phase of the megaproject. In fact, during this phase the modeling of the megaproject, in which the leading stakeholders promote the work and through multiple iterations try to accommodate or overwhelm the social, economic, and environmental desires of the other stakeholders involved, occurs [16]. However, the “cures” identified in extant literature, while very effective in the strategic phase of project shaping and planning, have reduced effectiveness during the management and execution phase. There are no significant efforts in the literature to identify megaproject control tools during the execution phase, except from some contributions [11], [17] and this is a significant gap.

B. *Megaproject currently adopted control techniques*

The identification of control methods and tools to be used by leading stakeholders could lead to a more effective tracking of progress, enabling corrective actions to be put in place. The corrective actions can, in fact, have a positive effect on both the overall management of the mega-project undergoing and on the achievement of the objectives originally planned. When managing the control of a megaproject, it is necessary to consider that, since it is in most cases divided into programmes, control is usually carried out at this level. Most of the extant literature focuses on single project control and management techniques, while the multi-project context is not explored in depth [18]. Given the complexity of a megaprojects, it seems convenient to structure a stringent control mechanism, setting processes and rules that form an inter-programmes specific bureaucracy of control. However, [19] suggest that in a multi-project context, it is necessary to take into account (i) the number of processes and rules that are used for control and (ii) the level of detail used to control the programme. In fact, several research have shown that the tendency to structure bureaucratic control mechanisms that are too stringent leads to inflexibility and bureaucratic overhead that are counterproductive for multi-project management [19], [11]. Consequently, it is necessary to identify a level of control detail that is effective but at the same time does not make the programme manager lose sight of what issues on the megaproject are significantly relevant. Generally, the focus of megaprojects and programme management contexts should be on the interfaces between projects, being the most critical areas for the overall coordination and accountability [20], [21]. Also, the literature focuses on investigating the so called “one size fits all” approach that suggests that a single method of monitoring should be adopted for all projects included in the program [22]. The benefits encompass decreased complexity associated with the ability to compare the progress of different projects using the same method, guaranteeing the possibility of implementing infra-project corrective actions. However, better results are obtained when the control method is tailored to each project composing the programme depending on its own features [23]. Thus, if the “different project – different method” [11] rule is adopted in a programme, both the control method (eg. milestone) and the relative measurement technique (eg. level of effort, standard time lag, standard cost lag), should be tailored to each project peculiarities to avoid misleading measurements [23]. However, in some megaprojects the nature of the contracts or the presence of peculiar constraints, makes project control difficult through as a measure time and cost lag in the milestone’s achievement. Thus, a “downgrade” of the level of reporting to a direct physical progress tracking is necessary [11]. In these cases, many authors highlight significant problems in tracking the physical progress of ongoing projects with traditional approaches (including manual data collection). In particular, the literature reports:

- Low frequency of monitoring, since the manual data gathering is done on a daily basis or less frequently and anyway not in real time. Thus, it is frequent that this traditional approach does not allow the implementation of corrective actions, because workers may complete their activities before the progress report arrives to the decision makers [24] [25]
- Consequent inefficiency of the reporting method, since the manual data gathering does not allow to present and visualize information in a way that enable a clear and common understanding by the project team. Some authors [26] also presented alternative 4D and time lapsed photographs model with the aim of providing the decision makers with more complete and immediate reports on project’s progresses.

- Low quality of collected data since data gathering is often conducted directly by the site managers. This means that (i) different background and experiences can lead to a different method of tracking progress for certain parameters: thus data can be biased by subjectivity [27]; (ii) the correctness and integrity of the data collected is not guaranteed in any way [25].

For megaprojects where one of the subprojects must be controlled with physical control tracking procedure, the complexity and integration required to control the entire program makes it particularly difficult to adopt a manual data collection system. To overcome this problem, there is a need to establish alternative tracking techniques that can guarantee (i) the collection of high quality and not biased data from the project site; (ii) an effective visualization of information about the project progress, so that the decision makers can take rapid and effective decisions and implement corrective actions; (iii) a real time tracking of the project progress that allow a constant overview of the project site status, ensuring the possibility of a continuous and not sporadic supervision of the site.

III. MONITORING MEGAPROJECTS

C. *Traditional and emerging monitoring technologies*

In the last decade, researchers and practitioners have advanced several technologies and techniques to improve the efficiency and efficacy of megaprojects progress monitoring. Some of these technologies include in-situ 3D laser scanning, compute vision technology, photogrammetry, 4D Building Information Modeling [25], [26]. Among the real-time monitoring techniques, there are critical path methods, visual progress control techniques, virtual reality to monitor the progress of construction from digital images and video [28]–[30].

These technologies and techniques are effective but still poor in (i) collecting high quality and not biased information, (ii) providing effective visualizations, and (iii) supplying real-time information. Satellite technologies (i.e., Earth Observation) are widely adopted in other domains and offer interesting opportunities to overcome the above-mentioned limitationsEarth Observation (EO) refers to satellite remote sensing technologies used to observe the Earth's physical, chemical, and biological systems and to monitor land, water (i.e. seas, rivers, lakes) and the atmosphere [31]. EO relies on the use of satellite-mounted payloads to gather data and images about Earth's characteristics. EO data are often integrated with in situ data to produce information and data intelligence applications (e.g., progress of a construction site) [32]. Two main categories of EO satellite imagery technologies are used to monitor infrastructures: (i) Active imagery (e.g., Synthetic Aperture Radar, Light Detection and Ranging) characterized by active sensors. Active imagery can be used regardless the local light and weather conditions (for example even in case of clouds and in the night). (ii) Passive imagery (e.g., panchromatic, multispectral, characterize by passive sensors, which gather the Earth's own radiated energy, providing real color images. They depend on the local weather or lighting and their use is predominantly daytime [33], [34]. The performances of EO satellites are evaluated according to three key parameters: (i) the spatial resolution, refers to the size of the smallest feature that is detected by the satellite. The spatial resolution ranges from kilometers to centimeters depending on the satellite. The best commercially available imagery has 30 cm spatial resolution. (ii) The spectral resolution refers to the number of spectral bands and the spectral width of each band captured by the satellite. (iii) The temporal resolution indicates the frequency of images acquisitions for the same area. Current active sensors provide high spatial resolution images compared with the passive counterparts. Current passive sensors capture submeter spatial resolution images [35]–[37]

iii.ii. Applications

Satellite-based applications are suitable for monitoring and identifying changes in a range of physical and environmental applications (e.g., environment restoration megaprojects). The integration of active and passive EO satellites imageries offer the following opportunities to monitor the observed area:

- Periodic measurement: EO satellites periodically (within hours, days, weeks depending on the area) gather the image of the area. The past EO imageries can be accessed to investigate phenomena of the past and reconstruct historical series [38].
- Standard and consistent measurement: EO satellites acquire the same imagery of the area over time [32].
- Pervasiveness and comparability of the measurement. EO satellites acquire in the same way imageries from different areas, favoring their comparison [31].
- Precise and multilevel measurement: EO Satellites offer submeter spatial resolution imageries. EO satellites provide information about the underground, the ground surface (e.g., land, water, vegetation, urban settlements, infrastructures) and the atmosphere (e.g., PM2.5 and PM10 concentration) of the area observed [39]–[41].

Several applications already leverage EO satellites imageries, for example:

- Land use and cover mapping: EO imageries are used to investigate the state and the evolution of the land usage (e.g., urbanization) [35].
- Carbon biomass assessment: EO imageries are used to assess the forest biomass. For example, the carbon sequestrated by a forest is estimated via tree crown area [40].
- Disaster and risk management: EO imageries are used to predict natural disasters (e.g., flooding) and to assess the damages after their occurrence (e.g., damages to infrastructures) [39].
- Water resources: EO imageries are used to monitor the quality of the water (e.g., concertation of pollution) and to assess and predict hydrological cycles (e.g., precipitations and droughts) [37], [42].
- Ecosystem and biodiversity: EO imageries are widely used to monitor the state and evolution of the flora and fauna (e.g., crop and vegetation monitoring, migratory flows of animals) [43], [44].
- Infrastructures and construction: EO imageries are used to assess and monitor the subsidence of the terrain around an infrastructure, the static and dynamic condition of infrastructures and buildings (e.g., structural defects of a bridge) [45].

The adoption of EO technologies in infrastructure and environment restoration megaprojects is loosely deployed for industrial applications and poorly studied in project studies literature.

D. Potential of EO technologies to monitor environmental restoration megaprojects

Environmental restoration megaprojects consist in coordinated anthropogenic activities to restore the environment and the natural ecosystem [46]. In river basin areas, these megaprojects are delivered to improve the flood attenuation capacity, the water provision, and the ecosystem health [44]. The aim of these megaprojects is to redesign and restore the catchment promoting a proper flow of water in the river basin [47]. In practice, catchment restoration comprises the construction of gabions, weirs, and dams; the renovation of alluvial fans and the planting of trees in degraded areas [46]. Environment restoration megaprojects last many years, have huge impact on the territory, including flora and fauna, and their construction site extends over wide linear lengths (unlike single site large-scale infrastructure megaprojects projects such as dams, wind farms or nuclear power plants).

EO technologies offer novel opportunities to monitor and track the progress of environment restoration megaprojects. In the initiating phase, EO imageries are used to improve the scope definition. For example, they offer consistent time series imageries and pervasive measurement to assess the water flows and the vegetation health, insightful to identify the primary areas of intervention [46], [48]. EO imageries are also used to identify possible stakeholders, through the analysis of settlements (e.g., residential, agricultural, and industrial) along the river. In planning phase, EO imageries are used to plan the infrastructural intervention along the river basin. The structured time series data offer the base to simulate effect-cause relations of the intervention [49], [50]. In the execution and monitoring phase EO imageries are used to monitor the advancement of the construction and planting activities, to assess the vegetation and the changes of the basin area. EO imageries offer information regarding the restoration site, depending on the quality and the availability of the data, on daily or weekly basis [51]. They offer a structured, periodic, and quasi-real time information acquisition strategy that allow an efficient monitoring of the schedule reducing operational delays and costs. In the monitoring phase, EO imageries offer the opportunity to compare information and measurement over time [37], [52], showing possible misalignment with the scope and the objectives of the megaprojects. Information is also used to predict the evolution of the restoration of the river basin area. By looking at the environment characteristics (e.g., quality of water, vegetation, and air), EO imageries can also be used to pervasively monitor the state of the vegetation and pollutants in the river basin area. In controlling phase [38], [53]–[55], EO imageries offer high quality, not biased information and quasi real-time with effective visualization of the restoration program status and progress, favoring an efficient and effective control.

E. Po River restoration: A business case for EO technologies?

This section sets the basis for integrating emergent technologies for monitoring the progress of environmental restoration megaprojects, using the Po River basin (Northern Italy) as a main case study. Like other environmental restoration megaprojects, the project of renaturation and restoration of the Po River basin expands over a large natural area located across 4 regions in north Italy (Piedmont, Lombardy, Emilia-Romagna, and Veneto), 13 provinces, a total of 183 municipalities. As a result, the area is subject to a number of different jurisdictions and directives (from the regional to the local level), supervised by the Interregional Agency for the Po River (Agenzia Interregionale per il fiume Po, AIPo). Furthermore, its strategic location and geographic characteristics pose several challenges to harmonized and comprehensive monitoring using traditional techniques, with consequent fragmentation of information and reporting that make timely data acquisition a hard-to-reach perspective.

To overcome these issues, EO technologies offer an attractive solution to monitoring the progress of renaturation and restoration interventions along the Po River basin. Theoretically, this research contributes to the rapidly evolving stream of literature on megaprojects, revealing the role, pertinence, and relevance of satellite technologies in monitoring environmental restoration projects.

During the preliminary stage of the project, EO imagery can be employed to monitor and report on catchment restoration and water quality along the Po River before (first semester of 2022 and historical/archive data), during (second semester of 2022-2026), and after (2026-2030) the project implementation. EO imagery offers several advantages over traditional monitoring technologies to assess water quality:

- It allows to cover a wide, cross-regional area, without incurring in the constraints of different jurisdictions and reporting systems within the area of interest.
- It provides real-time or nearly real-time data for cross-period comparisons to assess water conditions at each development stage and across multiple segments of the rivers.
- It provides accurate information regarding pollution hotspots along the river basin, allowing for mapping a multitude of sources and pathways of pollution across different compartments (e.g., residential and urban areas, agricultural areas, industrial sites, construction sites, natural areas, etc.).
- Finally, it allows to map the impacts of pollution on the local ecosystems, socio-economic systems, and the project advancement overall in real-time or nearly real-time, thereby providing insights on and decisional support to strategic project management interventions.

During the project implementation, EO imagery serves to better define the scope of the project via harmonized and consistent measurements of water flows in the river’s basin, as well as to timely identify aquatic ecosystems and vulnerable areas that could be affected (directly or indirectly) by the project implementation. Secondly, in the planning phase, we will use EO imagery to assess cascading effects of the project on the vulnerable areas previously identified and consequently propose project’s modifications, ranging from prevention and preparedness measures to urgent responses and interventions when the ecological requirements are not met. Thirdly, benefits associated with the use of EO in the execution and monitoring phases pertain to nearly real-time monitoring and reporting on the advancement and evolution of the project’s activities and related impacts on water quality overall and over a specific time period (including repeated measurements over several consecutive days). Finally, in the closing phase, EO imagery enables a comprehensive and consistent assessment of the project’s objectives, deadlines, and ecological impacts throughout all phases to ensure that the requirements set during the project design and implementation are met.

IV. CONCLUSION AND FURTHER STEPS

The preliminary results of our research show that the use of EO technologies for monitoring megaproject progress offers promising benefits. In project contexts where the assessment of progress through physical monitoring is necessary, the use of EO technologies enables to significantly reduce the biases of traditional methodologies. It also provides up-to-date project information, allowing for more immediate decisions regarding possible corrective actions in case of deviations from baselines. This makes the decision-making process smoother, thereby facilitating the role of portfolio managers. Consequently, EO technologies can address the gap of identifying possible 'cures' to the failure of mega-projects in the execution phase. The field research on the use of EO technologies in the Po River basin renaturation project is still at an early stage. Up to now, the research has focused on water quality monitoring, but in future project steps it is expected that EO technologies will also be used to (i) assess the status of reforestation achieved; (ii) assess the changes in the watercourse as a result of the displacement of existing containment systems; (iii) control the expansion of perifluvial wetlands. It is also expected that the use of EO technologies will be used not only in the monitoring phase of project progress but also in the evaluation and assessment of the project benefit.

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