Open Science for Architecture: A Collaborative Innovation

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ABSTRACT

In an era of rapid technological and social change, open science is emerging as a new process with specific opportunities for scientific innovation and collaboration across disciplines. Among the various application areas suggested by global institutions, the concept of open science from the perspective of design processes and research practices in architecture is still an open topic that might change how we study and build our future cities. Some case studies are explored based on a practical overview of how open science principles can influence the scientific and professional process. Future thinking, generative AI, collaborative platforms, and open research methods have been used to develop innovative solutions for urban, environmental, and social transformations.

Design processes can improve their forms of collaboration and open access to knowledge to overcome traditional design barriers. The text is an invitation to rethink the role of architectural research through the adoption of the opportunities given by the open science movement in enhancing practices and enriching skills, as well as more equitable, innovative, and collaborative design.

Keywords: Open Science, generative design, citizen science, open data visualization, visual-analytic, repository for designing

INTRODUCTION

Since the 17th century, with the beginning of scientific journals, there has been a will to open and share knowledge among researchers and start a dialogue on science topics as never before. With the increased use of technology and the enlargement of available data, the Open Science (OS) movement aims to integrate research, educational, and professional practices, reducing the technological and knowledge divide between and within countries. Also, the Letta report discusses the power of the so-called fifth dimension of freedom, which is the capacity of European research to be transmittable.

UNESCO has provided an important guidance [1] with 2021 recommendations on Open Science, which identifies four key areas of insight:

- open scientific knowledge (setting the standards to make knowledge accessible/transparent/reusable to everyone)
- open science infrastructure (developing and maintaining phygital platforms for sharing/creating knowledge)
- open engagement of societal actors (implement practices as citizen science / crowdsourcing)
- open dialogue with other knowledge systems (supporting communication of scientific knowledge and education towards communities)

Figure 1. Four UNESCO key areas of OS development (open knowledge-infrastructure-engagement-dialogue – source adapted from [1]).

These insights came from the interplay of different stakeholders' opinions (universities and research institutes, education institutes, citizen science experts, National Academies of Science, foundations, librarians, publishers, private sector science services, and intergovernmental organizations) that constitute a complex ecosystem of actors.

Moreover, in 2024, the UNESCO working group of experts explored the intersection of Open Science and AI, highlighting the potential of large language models (LLM) in accelerating scientific discovery, particularly using large datasets made accessible by open science. It was recognized that AI e machine learning tools have a range of possible benefits and risks across all the possible applications of open science, and there is a need for standardized approaches.

Are OS development equally influenced by scientific (research, education) and professional fields (architect, doctor, researcher, manager….)? Indeed, it is essential to investigate the differences to handle this revolution without being overwhelmed. Moreover, these insights require (see Figure above) developing specific tools, evaluation methods, and processes that are different or similarly different in each field, role (private-public), and objective (commercial-educational purpose). This paper will try to find some specificity within the OS insights regarding new infrastructure, type of engagement process, and degree of openness for the actors involved in the architecture field and the growth of new technological opportunities (AI).

THE ROLE OF DATA IN CONNECTING OS PRINCIPLES

OS's initial and overall purpose was to make scientific/technical data more available to all. The organization of data features and potential has become increasingly strategic, requiring new attention to properly developing or aligning OS principles. The crucial role of data was already defined in the Berlin Declaration in 2003, one of the first open science initiatives aiming at sharing scientific information in various formats. In 2016, in the journal Science Data, a consortium of scientists and organizations published the FAIR Guiding Principles (findability, accessibility, interoperability, and reusability), which are the main rules for making information open to future perspective and impacts in terms of formatting, tools, and dissemination. Also, in 2007, the OECD (Organization for Economic Co-operation and Development) set the importance of accessing research

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data from publicly funded projects. With the European Data Act [2] (January 2024), the Commission aims to make more data available via new rules on who can use and access data and for which purposes across all economic sectors in the EU.

The new rules about data availability are expected to create €270 billion additional GDP for EU Member States by 2028 by addressing the legal, economic, and technical issues that lead to data being underused. Despite the past, the OS principles promote embracing a logic of connecting the existing and inaccessible information to concentrate on continuous improvement. In this regard, all organizations must reflect on the data they own or the information they need to build and manage a proper information network/system. This implies thinking about the quality and management of data with 2 sets of basic common principles. First, it is essential to:

- give value to data (e.g., relevancy, accuracy, completeness, consistency…)
- define the domain and logic of data (e.g, content-realm, coverage-scale-detail, readiness-propensity to change)
- understand the modes of visualization/communication of data (eg., intelligibility, flexibility-portability of data, open format)

Secondly, it is necessary to choose methods for improving the quality of your data [3]. In OS, it is required to set the process of gathering or producing data to make information "Fair by design", which means there are internal control criteria to ensure the quality. Also, it is possible to have a dataset inspection process that allows one to interrogate or assess actual data compared to others and discard the errors. Finally, a data tracking process that reveals or anticipates potential errors must be set up.

An Open information system can then be developed according to its areas of possible activities:

- acquisition and cataloging (e.g, raw data, bibliography, standardized data, metadata, normalized…)
- assessment methods (e.g., statistics, data mining-AI, neural logic…)
- publication, communication or dissemination (e.g., virtual, physical infrastructures)

In general terms, the crucial role of data is mainly about the capacity to "connect" present knowledge with its future development; in particular it is relevant the method we chose to gather, assess, and share; in short, it is a common opinion that "the medium (the pipe of information) is more important than the content it carries." How we organize and select information becomes a generator of learning and the ability to bring order to the abundance and diversity of information available. Technology is seen as an integral part of our learning capabilities to construct new meaning and create/facilitate/speed up connections between specialized knowledge. It is rather arguable that very sophisticated tools and great computing power lead to better results and learning; on the contrary, complex data investigation and analysis technique could lead to false and misleading results that can be trickier to detect errors. Moreover, it is possible to trust the dataset if the quality is reliable. In this regard, data selection and maintenance can change according to the type of dataset: open data, available data, or big data. The latter are, among others, the main types having the most relevance within different scientific fields and professional practices of private and public organizations.

The above attention to data management required new professional roles (data manager, data Stewart), strategically essential to OS and implementation practices in all organizations.

OPEN SCIENCE LEARNING APPROACHES DRIVEN BY AI TECHNIQUES (OS-AID)

Different taxonomic lists of activities can be related to the 8 principles of Open Science defined by the European Commission. The implementation actions can be described according to different variables, for example, the actors engaged, the objectives, or the field of interest. All actors involved (from public to private) must implement:

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1. FAIR Data (e.g., a public research Entity must pay attention to set standards for making research products open to all)
2. Research Integrity (e.g., producing transparent research products)
3. Next Generation Metrics (define new values for assessing research products)
4. The Future of Scholarly Communication (e.g., promotes new forms of sharing content in all phases of development)
5. Citizen Science (e.g., engagement process of public and private actors in research processes)
6. Education and Skills (e.g., continuous training on improvement of the previous pillars)
7. Rewards and Incentives (e.g., recognition of the efforts and qualities of research groups)
8. European Open Science Cloud (EOSC) (which promotes collaboration between researchers in different fields)

Among the potential activities related to OS development, this paper focuses mainly on those dealing with data (open, available, big) and the learning approach that scientific and professional practices can adopt. These activities are driven by automatic learning algorithms (machine learning), so integrating AI (Artificial Intelligence) in the process of turning data into new knowledge. In this context, all analytical experiences and learning practices can get significant support from the AI approach. The lack of a shared definition of AI across the scientific fields makes it challenging to identify its features and potential for OS development practices, but it is possible to start focusing on trends in the adoption of AI techniques and the use of different sources of data for developing learning systems in different scientific fields.

In general terms, we can state that in OS practices, there are two main learning approaches driven by AI:

- top-down learning approach: it runs when the objective is straightforward, and scenario development can be forecasted; these practices require a structured approach where the data has good quality, and the learning algorithm is trained and trustworthy.
- The bottom-up learning approach: it is related to a more hermeneutic process, and the data analyses set the trajectory of the scenario development, having techniques that account for mistakes and uncertainty

These approaches, that we could call OS-AID (Open Science practices Driven by Artificial Intelligence), are specific and require multiple competences to set the targets, organize the data, and run the analytical-learning process. These OS-AID practices can be found across all STEM fields, with a concentration in fields such as medicine, materials science, robotics, agriculture, genetics, and computer science. The most prominent AI techniques [5]cross STEM fields include artificial neural networks, deep learning, natural language processing, and image recognition.

In the design practices, AI techniques and learning approaches are still experimental, with few consolidated shared biases among the professional and scientific fields. For example, there are many practices and experiences with a consolidated use of learning approaches as predictive risk analysis (health emergencies, climate changes, potential tax fraud, etc.), but also management analyses for extracting meaning, directions, or controls useful for an organization/system, for understanding service shortages or potential new growth needs. On the other hand, among the various application areas, the concept of open science from the perspective of design processes and research practices in architecture is an open topic that might change how we build our future cities, and within its implementation practices, we could find some logic for further development.

Case Studies

Among the two learning approaches mentioned above, it is important to frame some case studies and recursively trace some insights that might shed light on possible development practices in the specific field of architecture. Experiences and case studies are explored based on how open science principles have been influencing practices. Rather than the specific outcomes or metrics of OS’s practices, the paper tries to understand the general impact on architectural design.

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More than private, within Public Bodies (National or Local Administrations, Public Services Companies, Educational systems) is possible to distinguish specific practices that apply the four UNESCO key areas of OS development (open knowledge-infrastructure-engagement-dialogue). We can mark at least three areas where OS has been influencing practices:

- Public Decision Systems (e.g. simulation design-twin cities; support in co-design or co-assessment processes with a large quantity of data; consistent decisions and coherence to design policy or design recommendations)
- Governance of policy, services, and processes (e.g, control and speed up processes for predictive maintenance or efficiency assessment programs; monitoring systems for anticipation of warning signals in infrastructures…; open e-governance practices in authorization processes of design proposals)
- Management of data and information (e.g., collection/interpretation and systemic view of multilevel large quantities of multilevel data in all phases of design processes, from pre to post design)

If we focus on design practices, we can distinguish some slight differences in the impact that OS practice can have on the activities of researchers and a professional practitioner of architecture.

- Research practices: It is possible to find many research projects focusing on the co-design development of design solutions, with citizen science initiatives for crowd sourcing and for boosting the dialog between different scientific fields. These practices make a deep use of predictive/forecasting approaches which are known in literature within the future thinking discipline, but also open research methods and different tools for gathering and sharing information, and design decisions which are findable in the literature regarding the DDSS (design decision support systems). Here, the four UNESCO key areas of OS development (open knowledge-infrastructure-engagement-dialogue) are all represented, and Academies are ruling their practices to intensify the impact of adopting open policies. These practices are studying innovative solutions for urban, environmental, and social transformations.
- Professional practices: In this context, it is common to find OS principles mostly related to technological development and tools used in all the design and construction phases. Here, there is interest in the development of a new kind of infrastructure for sharing, for co-working, for virtual and simulation services and facilities. In these cases, new kinds of dialogue are established among the practitioners, with often cooperative and competitive focuses. In fact, we can find practices with design led by generative AI and collaborative platforms for sustainable design to overcome design barriers and boost change, or open tools for the innovation of the production of building components, or for monitoring the efficiency of prototypes, parts of buildings, and projects. The impacts of these practices are service-oriented, and stakeholders are running individual purposes often open to restricted targets of experts and practitioners.

Among the most comprehensive OS experiences and case studies related to architectural and design field, it is essential to mention the ecosystem of EU initiatives and policies like the platform for heritage professionals and researchers named European Collaborative Cloud for Cultural Heritage (ECCCH) which is the core of numerous funded EU projects like ECHOES (European Cloud for Heritage Open Science); the common Data Space for Cultural Heritage which have set standards and categories of open information on European cultural heritage managed by different sectorial actors Europeana, Icomos ect …. These platforms will provide access to data, innovative scientific resources, and advanced digital tools. Heterogeneous actors and sectors, with a primary input from the design and architectural field, are working on digitizing existing knowledge about tangible and intangible heritage objects. Among the benefits, these platforms will facilitate a collaborative analysis of CH assets, facts, and phenomena.

More general initiatives, such as the European Open Science Cloud (EOSC), are trying to connect different disciplines and sectors. These platforms, mainly dedicated and populated by the research actors, will perform their best within the process of building a proposal for funding research. There are even projects which are trying to “guide” the transition of researchers to a collaborative funding procurement as for example the project The Open Science Framework (OSF) which is a tool that promotes open, centralized workflows by supporting

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different phases of the research lifecycle, including developing a research idea, designing a study, storing and analyzing collected data, and writing and publishing reports or papers. Even the Italian National Plan on Open Science in Italy has stated that the main target is the monitoring of best practices of multistakeholder dialogues and of knowledge dissemination.

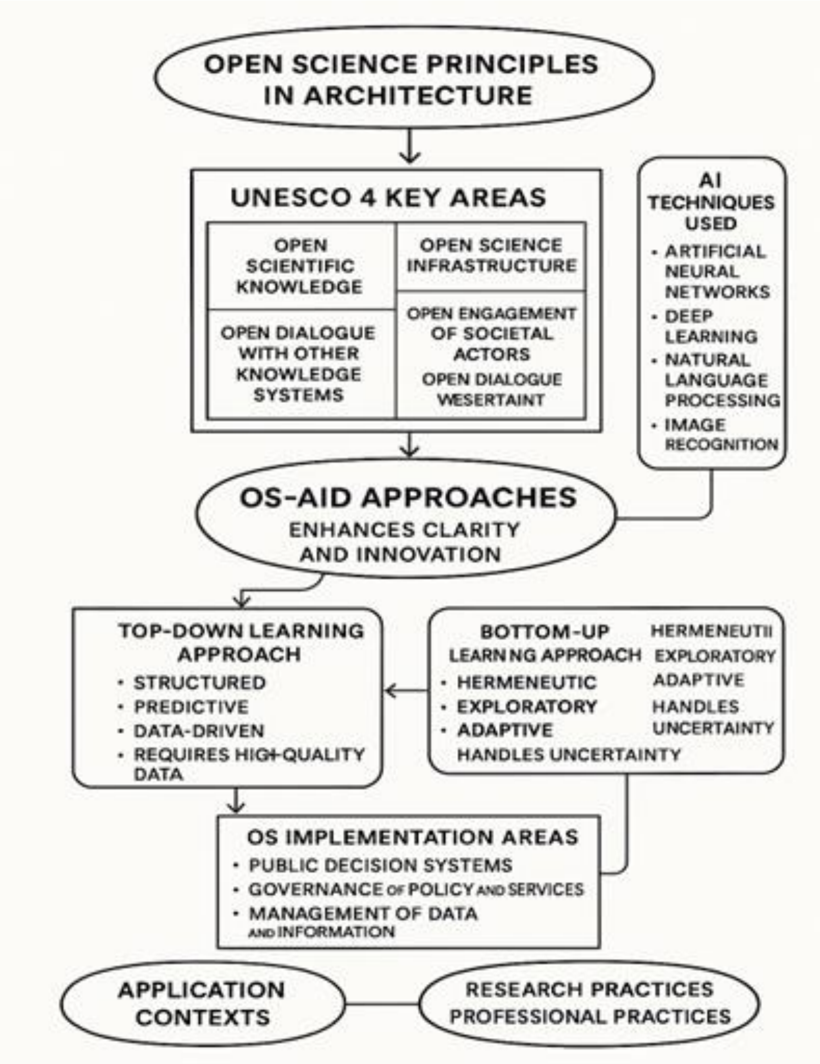

Fig. 2 Diagram that visually organizes how OS-AID approaches, underpinned by open science principles and AI, enhance clarity and innovation in architectural research and practice (source own, assisted by AI software for visualization)

Other examples of OS applied to projects of architecture and design are those related to Open Design-Open-Source Architecture, which are exemplary models for participatory design, based on digital platforms/tools, shared tools, and open-source software. In these examples, both practitioners, users, decision makers, researchers, and communities interact within the design process, overcoming the top-down model, providing inclusivity, more transparent decisions, and making design more innovative. Some recent initiatives analysed in academic studies show how online platforms and communities enable the development of open architectural projects, where the project source, the community of participants, and the digital platform are key elements. For example, using open data and open-source software for studying and defining spatial criteria of urban quality (e.g. sustainable mobility, just energy consumption, mapping recycling of building/demolition products) for achieving healthy and sustainable cities [4]. There are lots of open-libraries of architectural history (e.g MIC Censimento delle Archietture italiane dopo il 1945) or inventory of buildings features (European building stock characteristics-Eubucco) which are silos of potential knowledge for setting comparative studies and collaborative actions for gaining a better learning model of current status of architectures.

At the scale of product design, we can find examples of collaboration between designers and final users give rise to an open design process for that allow to the transition from current standard globalized production to "massive personalization of production" where objects are similar and unique with infinite personalization as footprints of their users requires.

New specific technologies and tools are serving these processes like, for example, parametric software (Grasshopper, Revit, Generative components and design), or 3d printing hardware for objects/architectural spaces/buildings, providing the control of costs, the environmental impacts or the societal consequences. Technology gives the chance to explore, modify or interact with a virtual design (from city to object) to test options, solutions, spatial criteria, in a process that is even open to non-expert stakeholders. Tools as BIM (Building Information Modeling), provide access to a "stored knowledge" which can be a repository for design, allowing for the collaboration with different science fields/sectors in alignment with the OS principles. In these cases, knowledge can come from various sensors (Internet of Things) or dataset (open-big data), or crowdsourcing. With the use of these tools, projects become a continuous evolutionary process rather than a method to apply each time as an endless process. In this sense, a project becomes like an open operating system (Linux), an open platform that enables different applications in the different phases (design, construction and use) of the design process. Various actors compete or collaborate delivering their opinion at different scales, like in social media.

DISCUSSION AND CONCLUDING REMARKS

In general terms, this paper shows that the potential of OS movement within the architectural fields is related to three elements: people, data, and infrastructure. The stakeholders, leading or interested in exploiting a new approach in design and architecture have some obligations and some opportunities, especially in the research practices or public services, which might influence the uptake of OS. The lack of incentives or rewards might slow the adoption by private stakeholders. Understanding the role of each actor is crucial as well as setting paths for collaborating among category of stakeholders.

The data that is available, which needs to be structured and open to all, in all phases of project development, has few tools and digital standards able to give access to and reuse information for design purposes. The more cross-disciplinary experiments that "contaminate" the silos of knowledge, the more consistent and innovative services will be available for the OS areas of application. There is a large amount of data (mostly unattended, uncover) and there is a need for special expertise for data mining, data management/stewardship and data analyses. In the design field, we need visual analytic expertise for cross-disciplinary dialogues and engagement processes. In this regard, the augmented help of AI strategic tools (LLM) or AI models are already developed in certain scientific fields (mainly stem, IT, medicine, manufacturing) and stakeholders (mainly public and private services) while design has an established use of software (design information system) and generative AI design/parametric design.

The tools and technologies might manage to overcome silos of knowledge and, mostly, provide new learning approach, or even generating new learning by having the ability to organize the abundance and diversity of available design solutions, restoring intervention, technical equipment, maintenance strategies and so on…

Among the main opportunities given by the adoption of OS principles during the design process, we highlight the enhancement of practices and skills; during the design process, the added support of all available information and sources is essential in decision-making. This often requires gathering lots of information and data to analyze and deliver non-technical communication. In this regard, for example, open tools for communication and their visual support can make a complex message/solution easier for people to understand, to be adopted, or to start advocacy processes. Moreover, people engaged in this process gain new abilities that make their duties faster/more efficient, and better rewarded. Also, the more equitable, inclusive, and collaborative design, especially those related to the public realm, is a complex duty and often requires ensuring proper, inclusive, and collaborative interaction. The "ladder" of engagement [6] requires a lot of work and

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competencies to give equal opportunities to all and take part in the decision; an open process and tools give rights and duties, making the collection and analysis of information easier to assess.

The text of this paper is an invitation to think about the emerging role of OS principles in architectural research and professional practices of design. The ongoing initiative (EU or private), the different actors and sectors involved, and the different focuses and approaches make this topic wide and challenging.

Architectural and city design can be influenced by OS movement as urban areas are increasingly identified as open systems, as the best fields for flourishing resilience and diversity. Instead of a system where all is predicted and controlled, OS principles can become an approach to study and design the future developments that encompass uncertainty and continuous changes as design conditions. At the same time, OS can support the challenge to gather and assess complex amount of data/information both for the decision makers and for the designers, also for allowing proper replication or scaling up of technologies and design solutions.

However, open science also comes with its challenges. Doing open science for research is often limited to increasing open access products while there is an urgent need to assess the value of existing repositories, to set proper data management plan both in research proposals and in academic practices. Again, the role of people involved is crucial and the perimeter of OS development is still variable and wide that requires strategies to build consensus and consistent results. The discussion of this essay remains broad, and it need of further research on architecture-specific challenges like regulatory barriers.

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