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A Linked Data Platform for Trans-disciplinary Research on the Transformation of Traditional Architecture in Indonesia

Abstract
Traditional Indonesian architecture provides rich opportunities for trans-disciplinary research, integrating the heterogeneous perspectives, terminology, theoretical frameworks, and research methodologies of various disciplines. The trans-disciplinary research projects envisioned in the Tra2in initiative necessitate technical means for sharing data in a meaningful manner, adequate data management practices, new collaborative models, and a change in research culture. This position paper proposes a Linked Open Data approach towards building a data infrastructure that supports trans-disciplinary research. In particular, we outline the high-level vision for a Linked Data infrastructure that will lay the foundations for innovative models of collaborative research in the domain of traditional Indonesian architecture and beyond.

Keywords: Linked Open Data, Trans-disciplinary research, Research Data Management, Digital humanities, Open Science

INTRODUCTION

Traditional Indonesian architecture has developed a range of unique methods and techniques deeply embedded in a rich cultural context and adapted to the subtropical climate and the unstable geological conditions. This body of ingrained architectural knowledge could be usefully transferred to modern architecture, but as building practices increasingly fall into disuse and geological activity threatens the remaining buildings that embody them, the rich cultural and architectural heritage are at risk of being lost. Comprehensive trans-disciplinary research to document, preserve, and understand traditional Indonesian architecture and its cultural and historic context has been limited which is unfortunate, given the potential to transfer its unique solutions to tackle pressing architectural, environmental, and social issues.

Tra2in is an initiative that aims to develop a comprehensive trans-disciplinary research program to investigate traditional Indonesian architecture, document it's rich cultural history and context, and seek opportunities to transfer traditional methods and techniques to modern architecture in order to foster sustainable, energy efficient and socio-economically innovative design and planning concepts. To this end, it will develop a research agenda to analyse traditional architectural typologies integrating perspectives of the social, cultural, and technical sciences. This trans-disciplinary approach will cover a broad range of research questions, methods, and perspectives and result in multi-faceted data collections created and leveraged jointly by a network of researchers with varied backgrounds, including spatial planning, local planning, cartography, history of architecture and building archeology, building physics and building ecology, digital architecture and planning, photogrammetry, three-dimensional design and model making, and social and cultural anthropology. Research collaboration between these disciplines necessitates both technical means to share resources and joint conceptualisations and integrated research methodologies.

In this paper, we propose adopting the Linked Data paradigm to build a research data infrastructure with open interfaces based on standard technologies and query mechanisms to facilitates trans-disciplinary research in this setting. The process to develop such an infrastructure will not only tackle technical challenges, but will inherently be grounded in a mediating process to develop conceptual and methodological coherence around joint research questions. This will result in joint conceptualisations and research workflows that will be implemented in the developed data infrastructure.

Beyond facilitating efficient sharing and effective utilisation of research data within the Tra2in initiative, the proposed infrastructure should also create an environment that cultivates open data sharing practices in a domain that has traditionally not been at the forefront of open science. This will increase the visibility, transparency, and reproducibility of research results through meaningful interlinking of published results with the data, processes, and software used to obtain them. Furthermore, it will also foster access and facilitate data reuse by other researchers and the general public (e.g., provide access to cultural heritage, facilitate citizen science etc.). Finally, an open data platform will also lower the barrier for research collaborations and make it possible to leverage already existing Linked Data (e.g., DBPedia, Wikidata, GeoNames etc.) within Tra2in research. This paper will provide an overview of the key concepts involved in building this trans-disciplinary research infrastructure and highlight key goals and benefits. It is structured as follows: Section 2 provides background information on Linked Data; Section 3 introduces the proposed infrastructure and outlines its architecture; Section 4 covers related work, and Section 5 concludes the paper with an outlook on the future research agenda.

BACKGROUND

The term Linked Data was introduced by Tim Berners-Lee to describe a set of best practices for publishing and connecting structured data on the web. It is based on the idea of extending the concept of the world wide web – which has already created a globally interlinked web of documents primarily intended for human consumption – and create a global web of machine-readable data (Bizer, Heath & Berners-Lee 2009).

From a technical perspective, Linked Data at its core is based on a stack of well-established web standards including (i) RDF (resource description framework), a graph-based data model based on subject-predicate-object triples, (ii) URIs as globally unique identifiers that allow anyone to reference and make statements about resources, and (iii) http to allow clients to retrieve different representations of these uniquely identifiable resources. Like the web of documents, the web of Linked Data is decentralised and spans a massive global graph. A key benefit of the flexible graph-based data model is that it is inherently extensible and requires no ex-ante commitment to a particular schema, but allows modellers to expand and link data in a bottom-up manner.

Like the original, highly ambitious vision for a semantic web as an extension of the current web (Berners-Lee et al. 2001), Linked Data aims to explicitly capture the semantics of published data so that it can be discovered and interpreted by machines. To this end, shared vocabularies with well-defined meaning are used and combined as necessary to make statements about a domain of interest. Whereas the original Semantic web put a stronger emphasis on ontologies and reasoning and envisioned that software agents would autonomously perform inference tasks for their users, however, Linked Data focuses mainly on publishing structured data in RDF using URIs (Hausenblas 2009). This results in a lightweight, bottom-up approach for sharing structured data with associated semantics, which facilitates data sharing and fusion.

The growing web of Linked Data consists of thousands of interlinked data sets that contain billions of triples, a significant portion of which represents scientific and geospatial data (Abele et al. 2017) and some of which will be attractive linking targets for data on traditional architecture in Indonesia.

To date, however, Linked Data adoption within the scientific community has been somewhat mixed. Even though scientific data makes up a signifiant portion of the Linked Open Data Cloud (Abele et al. 2017), it is highly concentrated in certain fields and around particular initiatives. The ambitious vision of Linked Open Science, which would not only make the end results of scientific processes (i.e., publications and their metadata) openly available, but more broadly aims to create a machine-readable infrastructure that connects all scientific assets, referring to each other through shared vocabularies (Kauppinen et al. 2013), remains largely unfulfilled. This is unfortunate, because Linked Open Science can provide a platform for more collaborative and trans-disciplinary research. Limited adoption may partly be explained by the fact that (Linked) Open Science is not only a matter of replacing or adopting particular research tools, and not even primarily a technical issue, but requires fundamental changes in research culture and the organisation of scientific processes. Such methodological, organisational and (research) cultural aspects will be a critical success factor in the development of the proposed platform.

A LINKED DATA APPROACH FOR TRANS-DISCIPLINARY RESEARCH DATA

A key goal of the proposed Linked Data infrastructure is to facilitate trans-disciplinary research, i.e., research that (i) uses a conceptual model that links or integrates theoretical frameworks from multiple disciplines, and (ii) uses study designs and methodology that is not limited to any one field, and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process (Aboelela et al. 2007).

A practical consequence of this trans-disciplinary approach is that research phases (hypothesis development, data collection, analysis etc.) will typically overlap and involve a multitude of heterogeneous stakeholders. In truly trans-disciplinary projects, it is therefore not sufficient to exchange data at given stages of the research process. Rather than infrequently exchanging independently created research results, researchers must engage in continuous collaboration throughout the research projects to collectively construct research assets. This requirement must be reflected in a technical infrastructure that supports concurrent research processes and provides the necessary means for collaboration on the conceptual level to overcome the terminological and conceptual disparities across the disciplines.

Creating shared vocabularies and developing common practices for describing research artefacts will be an important first step towards a trans-disciplinary research data platform. Using these vocabularies, researchers will then be able to describe heterogeneous research artefacts on the metadata level along a number of key dimensions.

First, we will organise architectural research objects along levels of architectural granularity, i.e., building elements, individual buildings, building groups, settlement structures, and regional and supra-regional levels. Research artefacts will be described in terms of this architectural dimension. Second, given that most data in Tra2in will refer to some physical location, the geospatial dimension will be key for organising research data. Additionally, the temporal, cultural, technological, social, and ecological dimensions will also be instrumental in creating a rich description of the context of collected research data, which is critical because it establishes a framework for the interpretation of research data gathered in different settings.

Combined with adequate data management practices and mechanisms to access the actual research artefacts, these uniform metadata descriptions will result in a research data repository that allows researchers to semantically query, locate, navigate, and access relevant data pertaining to a particular research question.

For instance, one of the projects within the Tra2in initiative will investigate the transformation of vernacular building traditions on Flores.
Research questions will particularly revolve around gender and iconology aspects.
To investigate these questions, it will be necessary to review and link historical sources, document and analyse oral history, and survey both historic and contemporary building types and settlement structures. Researchers will collaboratively construct a rich joint data collection by interlinking archival resources, architectural models, photographs, maps, interview protocols, and other research documents.

Compared to manual ad-hoc data exchange, linking disparate research artefacts and embedding them in a joint metadata model will significantly increase the efficiency of data sharing and promote open research practices.
In the given example, links will be established on the metadata level through shared time, location, and architectural dimensions and by applying architectural and cultural concept tags.

As a next step beyond metadata description of research artefacts, the Linked Data approach also makes it possible to establish more granular links between individual elements contained within disparate data sets. This allows researchers to collaborate more closely and jointly construct research assets, but it requires a fundamental shift in research practices from perceiving data as an internal product that is created, managed by, and closely tied to specialised tools, towards conceiving research data as a shared and open resource that a variety of tools can leverage for various purposes.

This paradigm shift from data as a byproduct of research towards data as an infrastructure would result in a more tightly interwoven web of research data. To this end, trans-disciplinary research must develop joint conceptualisations on the content level to not only describe the (e.g., spatiotemporal) context that individual items of interest are embedded in, but the items themselves. To this end, it will be necessary to mediate a process to develop and formalise shared conceptualisations that integrate the respective domain knowledge of the involved disciplines and results in common taxonomies, vocabularies, and ontologies that will be used to establish granular links.

Key benefits of such fine-granular linkage between scientific assets include the possibility to jointly construct these assets in trans-disciplinary research settings. In a fully developed Linked Research Data infrastructure, researchers – as well as other stakeholders and the general public – can use a multitude of tools and perspectives on the data (e.g., interactive maps, 3D visualisations etc.) and choose the most appropriate specialised tool for each task.

Furthermore, this approach has important advantages in terms of transparency, long-term availability and preservation, research reproducibility, web-scale interoperability, and potential for sharing and reuse. Finally, the Linked Data infrastructure makes it possible to apply data fusion and link discovery techniques to automatically identify new links between resources. This can be used for enrichment with both internal and external data and allows others to easily integrate the published data.

Overall, adoption of Linked Data principles should result in sets of tightly interwoven research data based on a conceptual model that links theoretical frameworks and leverages multiple perspectives and skills of the involved disciplines throughout multiple phases of the research process, i.e., meeting the definition of truly trans-disciplinary research (Abolele et al. 2007).

ARCHITECTURE

Figure 1 shows an overview of the proposed Linked research data platform. This platform allows researchers to work independently using their specialised tools and data formats within their respective disciplines, while agreeing on a set of shared vocabularies (illustrated in Figure 2) as a guideline for storing and linking their data in the platform.

The Linked research data platform consists of several layers:

Data Portal

The proposed approach is grounded in a Data Portal, which will host data sets in their original raw formats, resulting in a syntactically and semantically heterogeneous collection of data from various disciplines. We will use existing open source data platforms (e.g., CKAN) and leverage the access mechanisms and metadata annotations they facilitate. Furthermore, the data portal will be used for the open publishing of raw and processed data sets. It will, however, also provide means for access control and allow researchers to select which data sets should be disseminated to the public.

Extraction and Linking

In this layer, we will develop new and use existing tools to extract metadata from the various types of raw data in the data portal. This will include simple techniques like requesting metadata via APIs provided by the data portal, but also more advanced information extraction techniques for particular data types (e.g., named entity recognition in text, such as interview protocols).
The metadata will be aligned to a set of shared vocabularies.
Where appropriate, we will also selectively facilitate transformation of complete data sets into RDF to facilitate fine-granular linkage. To manage all these processes, the extraction and linking layer will rely

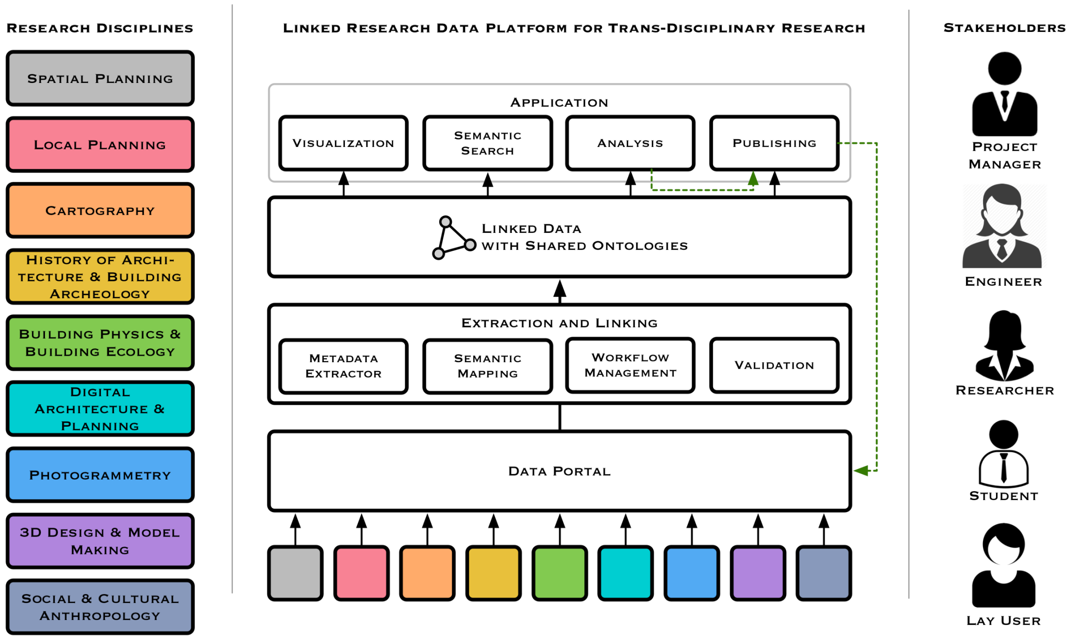

Figure 1: Architecture Overview

on a workflow engine for the definition and enactment of extraction and processing workflows. This engine will also implement adequate data management practices and provide mechanisms for automatic provenance tracking and validation.

Linked Data with Shared Ontologies
This layer provides uniform access to the trans-disciplinary research data and lays a foundation for various applications that will be implemented on top of the integrated data. Rather than conducting data integration manually in an ad-hoc manner or implementing it in the tools used for individual isolated analyses, the resulting integrated Linked Data built around joint conceptualisations can be queried and used by multiple tools and stakeholders.

Application
Applications built on top of the integrated Linked Data include, but are not limited to semantic search (on the metadata and more granular levels), interactive visualisations, complex analyses, and data publishing. Applications can feed data back into the data portal (e.g., the results of analyses on Linked Data can be published on the data portal – cf. dotted arrows in Figure 1; automatic provenance tracking can ensure the reproducibility of results in these scenarios).

The shared vocabularies in Figure 2 consists of two parts: (i) Core ontology and (ii) Discipline-specific ontologies.

The Core Ontology
The core ontology covers main concepts and relations that are relevant in the overall project, e.g., (basic) architectural knowledge, location, and provenance information. To this end, we will reuse existing standard ontologies and vocabularies to foster interoperability with external data sources such as DBPedia[1]. Starting points for the development of the core ontology will include the DC[2] vocabulary for basic metadata terms, VOID[3] for the description of the linked data sets, FOAF[4] for representing humans and agents, PROV-O[5] for provenance information, SKOS[6] for structuring domain knowledge, Geonames[7] for representing geographical information, and Time ontology[8] for time representation.

Discipline-specific Ontologies
These ontologies represent extension modules for concepts and relations that are specific to particular disciplines. For instance, the underlying iconography behind a certain traditional architectural artefact is relevant in various contexts, but can be scoped independently. To follow a modular approach and facilitate a bottom-up construction approach around a compact core of agreed-upon shared concepts and discipline-specific extensions, we will represent this information not in the core, but in separate discipline-specific ontology modules. To this end, we will follow well-established ontology design patterns[9] and reuse specific vocabularies such as STOLE ontology for historical document (Adorni et al. 2015) or the Art and Architecture Thesaurus (AAT) for generic concepts related to art, architecture, conservation and other cultural heritage (Gill and Baca 2015).

RELATED WORK

Scientific collaboration has long been striving for wider reuse and sharing of knowledge and data. Consequently, sharing of resources, resource metadata, and data has become an important need in the scientific community (Keßler et al. 2013). To this end, different disciplines have set up repositories for their research data, but proprietary APIs and domain-specific data models pose interoperability challenges and as a consequence, many such initiatives have fallen short of making research data openly accessible, reusable, increasing the transparency of research, and ensuring reproducibility of scientific settings (Keßler et al. 2013).

The Linked Data paradigm (Bizer et al. 2009) and its application to scientific research has strong potential to overcome these challenges and expand the traditional idea of Open Science (David 2004). Driven by its capabilities towards realising web-scale data sharing and reuse, initiatives for linked open publishing of research results, such as OpenAire[10] and researchobjects.org[11], have seen increasing adoption recently.

Some scientific fields have already made particular progress in the adoption of Linked Data technologies. Examples include computer science (particularly disciplines such as geoinformatics, bioinformatics etc.), the life sciences, which have a long history of using ontologies, and economics, which benefits from strong growth in socio-economic Linked Data published by governmental bodies (Schmachtenberg et al. 2014) and institutions such as the World Bank.

Specific initiatives in fields that are more closely related to the research domain of the Tra2in initiative, such as cultural heritage, historic studies, and the digital humanities, have also produced

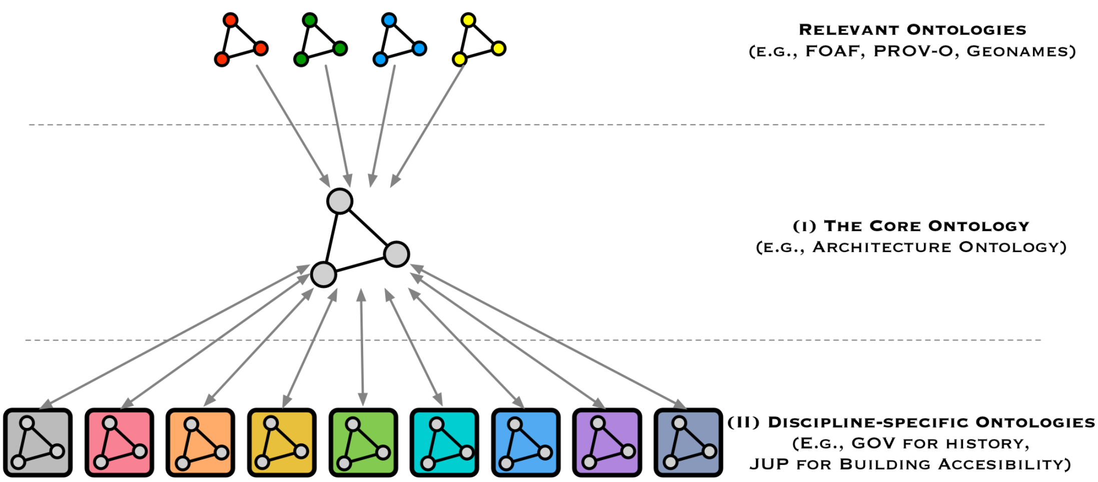

Figure 1: Ontology Design

1 http://dbpedia.org/
2 http://dublincore.org/
3 http://www.w3.org/TR/void/
4 http://xmlns.com/foaf/spec/
5 http://www.w3.org/TR/prov-o/
6 http://www.w3.org/TR/skos-primer/
7 http://www.geonames.org/
8 http://www.w3.org/TR/owl-time/
9 http://ontologydesignpatterns.org
10 http://www.openaire.eu
11 http://researchobjects.org

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12 http://collection.britishmuseum.org/

13 http://www.europeana.eu/portal/en

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vast collections of structured data and bibliographic collections and published them as Linked Data (cf., e.g., the British Museum[12], the Europeana project[13], etc.).

Moreover, a range of more narrowly focused projects that have published Linked Data on a diverse range of subjects illustrate the broad applicability of Linked Data in the digital humanities and cultural heritage informatics. Illustrative examples include, for instance, historic Dutch ships and sailors (de Boer et al. 2014), the First (Hyvönen et al. 2012) and Second World War (Hyvönen et al. 2016), and archeological data on early domesticated animals in Anatolia (Kansa et al. 2014). The latter contribution also covers methodological aspects and provides a model for collaborative research and the associated editorial and data review processes to improve data documentation and quality and create the ontology annotations needed for comparative analyses by domain specialists. Approaches to connect historical text to the Linked Data cloud (de Boer et al. 2013) and to facilitate exploratory search of historical data (Odijk et al. 2015) will also provide interesting starting points.

In the architectural domain, a lot of ontology engineering work focuses on building engineering and building information models, which has resulted in contributions such as the building information model (BIM) ontology (Succar 2009) and the smart appliances reference (SAREF) ontology (Daniele et al. 2015). While these ontologies have primarily been developed to characterise modern buildings, they could serve as a basis and inspiration for building the ontologies in Tra2in.

CONCLUSIONS

Linked Open Data principles can provide a solid foundation for the development of a research infrastructure for trans-disciplinary research on traditional Indonesian architecture at the interface of technical, cultural and social science disciplines. Beyond the development of a largely static research data repository, we envision to also develop new models of collaboration and research data management practices for trans-disciplinary research based on Linked Open Science principles. To this end, it will be necessary to mediate a process to develop and formalise shared conceptualisations among a highly diverse set of researchers.

We expect that the methodological and technological insights gained in the project will be generalisable beyond the Tra2in context and that the resulting platform as well as the trans-disciplinary research processes it enables can serve as a model for Linked Data-driven collaborative research in other domains.

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