GViz - An Interactive WebApp to Support GeoSPARQL over Integrated Building Information

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ABSTRACT

Linked data (LD) is a technology to support publishing structured data on the web so that it may be interlinked. Building Information Modelling (BIM) is a key enabler to support integration of building data within the buildings life cycle (BLC). LD can therefore provide better access and more semantically useful querying of BIM data. The integration of BIM into the geospatial domain provides much needed contextual information about the building and its surroundings, and can support geospatial querying over BIM data. Creating GeoSPARQL queries for users who are non experts in semantic web technologies can be a challenge. In this paper we present a visualization tool built upon HTML5 and WebGL technologies that supports queries over linked data without the need to understand the resulting SPARQL queries. The interactive web interface can be quickly extended to support new use cases, for example, related to 3D geometries. The paper discusses the underlying data management, the methodology for uplifting several open data sources into Resource Description Framework (RDF), and the front-end implementation tested over a sample use case. Finally some discussion and future work is given, with a focus on how this tool can potentially support BIM integration.

CCS CONCEPTS

• **Information systems → Resource Description Framework (RDF)**; **Geographic information systems**; *RESTful web services*; • **Theory of computation → Data integration**; • **Human-centered computing →** Usability testing.

KEYWORDS

Linked Data, Building Information Modelling, GeoSPARQL, WebApp, Usability

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1 INTRODUCTION

Access to reliable structured data plays a central role in supporting existing and future services for managing smart and sustainable buildings and cities [7]. Building Information Modelling (BIM) has been identified as a key enabler to support integration of building data across its life-cycle [8] and with other data sources, such as those related to the buildings geolocation and external environment [29]. The combination of BIM and Linked Data (LD) [16] has the potential to meet the requirements for storing, sharing and interlinking BIM with other data sources, that is, once the data is represented or tagged using Resource Description Framework (RDF) and then published on the web.

Due to a lack of access to detailed BIM models used during the design and construction of buildings, e.g. models stored in the BIM standard Industry Foundation Classes, existing research is looking at methods to iteratively build BIM models using available open data, for example, the authoritative data made available by the Ordnance Survey Ireland (OSi, Ireland's national mapping agency) [24]. OSi data includes over 3.5 million buildings, consisting of GIS data (polygon foot print, geodetic coordinate), and also additional building data such as form, function and status. This data meets some basic requirements for BIM. Combined with other open data such as that provided by the Irish government on data.gov.ie, already a rich set of data sources are available for integration.

The challenge remains how to demonstrate the benefits of this LD approach. Several different clients are available for querying RDF triplestores [31], some having a visual component [30]. These types of tools that support users to do queries over several data sources can provide a gateway into LD based integrated BIM, and visualization can often make the results easier to digest for users not familiar with SPARQL. In this paper we present a WebApp for searching over multiple LD data sets describing different building data sources taken from data.gov.ie and the OSi's data. The WebApp makes use of GeoSPARQL, an Open Geospatial Consortium (OGC) standard that defines a vocabulary for representing geospatial data on the Semantic Web, as well as specifying an extension to the SPARQL query language for processing that geospatial data. Using this underlying technology to manage the data, the WebApp makes use of HTML5, WebGL and Google Maps to provide a means to run polygon based geospatial queries over a map of Ireland, selecting distinct areas and querying buildings in those areas for available data, presented back to the user as a map overlay.

The data used is uplifted into RDF using a tried and tested approach based on R2RML [35] applied to both the data.gov.ie data sets (converting from the available CSV) and also the conversion of the OSi Prime2 data base [14]. The paper presents a web based usability evaluation of the tool that explores users doing several tasks using the key feature of the tools, the geospatial querying. The paper concludes with a discussion of the results of this evaluation, and possible extensions of the tool and methods to support further integration of BIM through the use of geolocation.

2 STATE OF THE ART

Building Information Modelling

Building Information Modelling (BIM) describes an integrated data model for storing all information relevant to the buildings life cycle. This can include a 3D model of an architectural design, electrical installations, fire protection, occupancy, energy consumption, costs, etc [8]. BIM goes further than just providing consistent representation of objects; it also defines object parameters and relations to other objects. Open BIM has the potential to support new and innovative services to support intelligent automation, navigation, energy efficiency and sustainability, but faces several challenges, related to; standardization, data interdependence, data access, security [1] and also the willingness of BIM developers and owners to share their BIM data [24].

For the true potential of BIM to be realized, it is important that developers of new services are given access to available, open and authoritative BIM. Due to the limited availability of BIM data in traditional formats, such as Industry Foundation Classes [24], GIS and other data sources can be used to construct rudimentary BIM models based on a buildings geolocation, and other attributes such as: address, form, function and other openly available properties. Nonetheless, these open data sources remain scattered between different services including the aforementioned data.gov.ie, as well as DBpedia [12]. Linking these data sources with the authoritative OSi dataset, provides an important step toward making BIM available to a wider range of users [24].

Linked Data, BIM and Graphical Information Systems

Linked Data (LD) is an approach to expose, share, and connect related data, not previously linked, on the Web [16]. In modern Architecture, Engineering and Construction, data related to different domains such as building geometry and topology data, sensor data, behaviour data, are generated and consumed across BLC stages. The combination of BIM and LD has the potential to meet the requirements for storing and sharing this data. However, the data must be represented as or at least tagged using RDF. GIS systems are information systems with an additional geo-reference [20], a requirement for spatial analysis. Spatial information includes coordinates and relationships between features, as well as additional non-spatial attributes. GeoSPARQL is an Open Geospatial Consortium (OGC) standard that defines a vocabulary for representing geospatial data on the Semantic Web, but also specifies an extension to the SPARQL query language for processing that geospatial data. Research efforts around GeoSPARQL are still ongoing, for example, to explore the conversion of non-RDF data into GeoSPARQL [4], or support for enabling on-the-fly GeoSPARQL-relational database translation [9]. As discussed previously, the OSi's authoritative geospatial data for boundaries has been converted into GeoSPARQL and made available through the GeoHive (data.geohive.ie) domain.

Linking BIM with geospatial data is also an active area of research. In [18] the integration of the BIM standard Industry Foundation Classes (IFC) is explored to support site planning, in terms of localization of materials and services appropriate for optimized productivity of a construction project. IFC is a complex schema originally developed for use by the Architecture, Engineering and Constructions domain for buildings, and making it more accessible for querying can potentially open up new markets and novel tools [24]. Other research has investigated the conversion of standards like IFC directly into CityGML, a standard for describing data related to cities and districts and includes capabilities for describing buildings also [15].

LD-based GIS Visualisation Tools

Several triplestores have been developed to support GeoSPARQL, for example: Parliament, Strabon, Stardog and Fuseki [2, 19, 32, 34]. Each of these have web clients used to access and query the RDF data. Other clients are developed specifically to support editing [11], [10] or querying and visualizing results of triplestores [17, 33, 37]. Collectively, these tools provide a wide range of different functions related to autocomplete, multiple endpoints, query retention, file upload, results download etc. [31].

A popular tool for testing geospatial queries is Yasgui, which has seen features it supports being integrated with a wide range of other related tools [31]. One interesting aspect and a potential contributor to its popularity may be its additional rendering capabilities for visualization of geosparql geometries on a world map [30], allowing users to quickly see the results of their geospatial queries. What none of these tools offer is the creation of geospatial queries based on interaction with the map and the results. Also, the integration of 3D geometries has not yet been considered, and the potential to extend into 3D, so that both 3D and 2D can be queried side by side, could provide new capabilities and support for a wider range of use cases.

The remainder of this paper presents the GViz WebApp that supports GeoSPARQL and the visualization of well-known text (WKT) geospatial geometries, configuration of geospatial queries through an interactive interface, and is built on extensible technologies such as HTML5, JS and WebGL. These features together mean GViz has the potential to support a wide range of existing and future use cases for querying and displaying geospatial geometries.

3 DESIGN

The GViz tool has three main requirements, that it:

(1) supports platform independent configurable geospatial functions to query and visualise integrated data with a geospatial component on the web
(2) be flexible and extensible so as to support existing and future requirements
(3) be usable: i.e. users can efficiently and effectively achieve the tasks it supports whilst also finding the tool to be satisfying to use

To meet 1) the tool design must enable the integration of an RDF triplestore with GeoSPARQL support. The web client itself must enable a user to select a region on a map, and run a query over that region returning any geospatial results within. Additionally it must support the user to access and display data through the interactive map, based on properties of the data, for example, in the case of a building to display data properties about the building. The triplestore must therefore support GeoSPARQL functions. To meet 2) the tool is designed to make use of modern web technologies, such as HTML5 and WebGL, that can support existing and future requirements through highly modular and configurable JS libraries. To meet 3) the tool must be developed with usability in mind, making the completion of actions intuitive and user friendly. Towards that end, this paper presents an initial usability evaluation of the tool set in section 6.

Data Uplift Methodology

As the GViz tool requires data to be represented as RDF, this section briefly discusses the process currently employed to convert structured non-RDF data into RDF. This process, called uplift [14] has been successfully employed in the conversion of several different data sets most notably the conversion of the Ordnance Survey Ireland (OSi) Prime2 data base boundary data sets, but also OSi data related to Ireland's buildings alongside DBpedia data [24], Irish Central Statistics Office data, and BIM data extracted from IFC [23]. More recently OSi building data sets (containing over 3.5 million building representations) are being converted. To date about 80 thousand buildings are now represented as RDF, with the remainder due to be converted within the next 3-6 months. The properties being converted into RDF include the buildings name (Irish and English), geolocation, and form and function. In future releases these will include more information (e.g. addresses, status, etc.), including provenance information, i.e. historical values and information about who and when changes were made.

The uplift methodology [14] makes use of the R2RML mapping language, and supports conversion of any tabular data source (e.g. CSV, SQL, etc.). The process of conversion consists of 4 main steps. The first an analysis to understand the data source(s), to define mappings to existing vocabulary, and where no mapping exist, to propose extension to these or develop new ontologies. Second, the development of the R2RML mappings to convert the data to RDF and the running of the R2RML process to do this conversion. And finally, the deployment of the data on a triplestore with an exposed endpoint for querying of the data. In step three, testing of the data is also conducted to ensure that the R2RML mappings have generated the data correctly. This includes testing through known tools, such as Yasgui or GViz (for quick visualize confirmation), or more in depth analysis using tools such as luzzu [13].

4 IMPLEMENTATION

The GViz tool has two main components; the back end triplestore and the front end web client. There is also a component to manage secure authentication, discussed here only briefly.

Back-end

To support the type of polygon selections that the GViz tool is to enable, the underling triplestore must support GeoSPARQLs sf:Within. Stardog, Strabon and Parliament all support this functionality. Fuseki currently does not support sf:Within, and is also quite poorly documented making it difficult to set up [3], although it is believed an update to the Fuseki server will mean that future versions will be both easier to deploy, and also support the full range of

GeoSPARQL's functionality. Stardog requires a commercial licence to use, and Strabon, like Fuseki, has a complex set of instructions to set up with poor documentation. Parliament is by far the easiest of the non-commercial GeoSPARQL supporting triplestores to run and enable indexing of geospatial data. This can be done through its web-client with relative ease, making Parliament a good test triplestore. Parliament appears to have ceased active development as of 2016, and so, if the extension to Fuseki materialize, Fuseki may well become a better option. Once you run the triplestore, data is accessed through its endpoint.

Front-end

The GViz front-end supports querying of triplestores through hardcoded endpoints in JS, although this can be easily extended to support user configurable endpoint through an interface, similar to that supported by Yasgui. Access by the client to the underlying triplestore is handled using AJAX. Calls to the triplestore are managed through interaction with the front-end web client, running on the client browser, and built upon JS, HTML5, Google Maps API and WebGL.

Google Maps API was chosen as it provides access to googles maps, as well as providing additional functionality, such as capabilities to add markers to geospatial points, and a drawing manager to support drawing polygons (used for selection). WebGL supports drawing points and 2D polygons, as well as polygon meshes if required. HTML5 and JS further support select boxes and pop up information windows, for example, to filter data or to provide feedback from point and click selections of results. Fig. 1 shows the front-end as an area is selected (black lines), and the resulting geospatial coordinates returned by the select and query (red dots). In the next section we describe a test case for the tool in which four data sources were chosen, uplifted, and then made available for query using GViz. It should be noted that the current implementation of GViz is being run on a web server using node.js. This was to enable authentication, so that different data sets can be made available depending on the log-in. This is implemented using express and mongodb. No support for https can be given though, as Parliament does not support https.

5 GVIZ TEST CASE

To validate the approach four data sets were chosen for integration with the visualization app. The data sets adhere to two criteria; 1) are available in a structured format (e.g. CSV, XML) and 2) have an explicit spatial component. Three data sets from data.gov.ie were chosen that relate to building data. These are:

- https://data.gov.ie/dataset/churches-and-convents1
  - Properties: ID, Name, Address, Organisation, GeoSpatial Point (Longitude and Latitude)
- https://data.gov.ie/dataset/schools1
  - Properties: ID, Address, Phone, School Level, Mixed Status, Fee Paying, GeoSpatial Point
- https://data.gov.ie/dataset/roscommon-thatch-building-survey
  - Properties: ID, Address, Image URI, GeoSpatial Point

Figure 1: GViz - Polygon area based selection

An additional data set was also used, provided directly by OSi (all Garda station buildings in Ireland) and includes the OSi buildings URI and additional data for form and function, information that is maintained by OSi. The OSi data set is generated based on a comprehensive analysis of the data sources [24], resulting in an ontology [22]. For the data.gov.ie data sets, the analysis was superficial, and no mappings were explored to existing vocabulary.

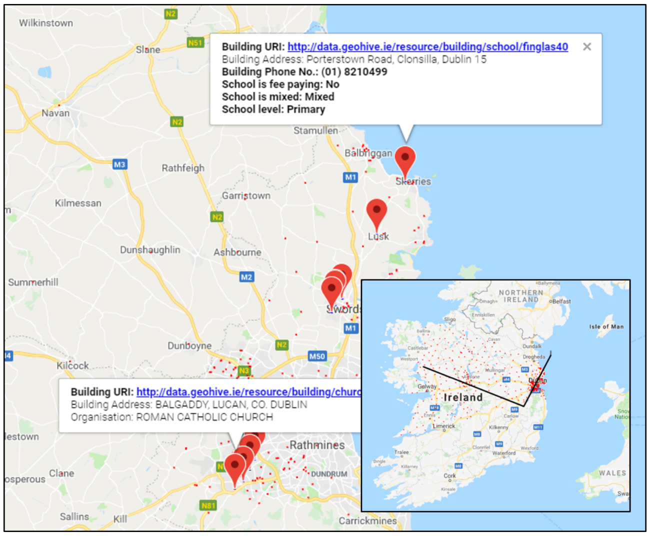

Figure 2: GViz - Polygon area based selection

Instead, a temporary namespace was created as a place holder for the properties, generated based upon the column names. Where columns across data sets shared similar semantics (e.g. Address), the same temp property was used, although in some cases the R2RML mappings need to concatenate columns into one property as Address could cover two or more columns, depending on the data set.

Listing 1: A sample SPARQL query to Parliament

```
PREFIX geo: <http://www.opengis.net/ont/geosparql#>
PREFIX geof: <http://www.opengis.net/def/
                function/geosparql/>
PREFIX osi: <http://ontologies.geohive.ie/osi#>
PREFIX geoff: <http://ontologies.geohive.ie/geoff#>
PREFIX temp: <http://ontologies.geohive.ie/temp#>

SELECT
    ?uri ?form ?function ?name ?address ?iuri
    ?phone ?org ?fee ?mixed ?level ?poly_geom
WHERE {
    ?uri geo:hasGeometry ?geom.
    OPTIONAL{?uri geoff:hasForm ?form.}
    OPTIONAL{?uri geoff:hasFunction> ?function.}
    OPTIONAL{?uri osi:hasName> ?name.}
    OPTIONAL{?uri temp:hasAddress> ?address.}
    OPTIONAL{?uri temp:hasImageURI> ?iuri.}
    OPTIONAL{?uri temp:hasPhone> ?phone.}
    OPTIONAL{?uri temp:hasOrganisation> ?org.}
    OPTIONAL{?uri temp:hasFeePaying> ?fee.}
    OPTIONAL{?uri temp:hasMixedStatus> ?mixed.}
    OPTIONAL{?uri temp:hasSchoolLevel> ?level.}
    ?geom geo:asWKT ?poly_geom
    .FILTER(geof:sfWithin(?poly_geom,
        "POLYGON(( -8.84875046875004 54.09632741172031
        , -9.62877976562504 52.66126550188105,
        -4.9486039843750405 53.32254658410386,
        -8.84875046875004 54.09632741172031))"
        ^^geo:wktLiteral )).
}
```

In Fig. 1 an area query is executed through the interface, returning all geospatial data within the area. Listing 1 shows the resulting SPARQL query generated by the select, and adapted for the RDF generated by the R2RML mappings. Fig. 2 shows a “select" being run after the initial query. The select functionality allows the user to draw a second line (or polygon) to intersect with points of interest. Each point intersected by the line displays a clickable marker. Upon clicking this further information on the building it represents is displayed, based upon the R2RML mappings. Some additional functionality is also possible using radio buttons, allowing further filtering based upon the form and function of the building. To see the full set of current functionality of the tool, there is an online video available here [21].

6 USABILITY EVALUATION

As usability is one of the key requirements of the GViz tool, we conducted a preliminary evaluation to determine usability of the key feature of the tool, i.e. the capability to do configurable GeoSPARQL queries over the data. The methodology for the evaluation has been applied in previous usability assessments [25–27]. Full evaluations consist of both a formative and summative evaluation. Summative evaluations are conducted when a tool is fully developed. As this is a prototype tool, here we present an initial formative evaluation. These are conducted during the development to mould or improve a product and therefore, results are expected to reflect the early development stage. Outputs of formative evaluations may include participant comments (attitude’s, sources of confusion, and reasons for actions) and other usability problems and suggested fixes determined through observation and feedback.

The main evaluation metric we evaluate is user satisfaction, measured by using the System Usability Scale (SUS). SUS is a simple ten-item scale giving a global view of subjective assessment of usability. The statements in SUS are chosen to identify extreme expressions or attitudes. SUS also provides a point structure to assign to the answers of a particular test rating overall satisfaction between 0 and 100. Bangor et al. [5] suggest that a score in the seventies should be deemed acceptable for a finished product, and those below still have usability issues of concern. With respect to the number of participants required to find all potential problems, this may vary according to the users, the tasks, and the system under test. At least a range between five and fifteen is required to evaluate sensitive parameters as depicted in [28, 36].

The evaluation is structured upon Common Industry Format (CIF). A CIF usability report must include; a description of the product/model, the goals of the test, the test participants, their background and the tasks they are to perform, the method for conducting the test, the experimental design

Questions	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)	Total
I think that I would like to use this system frequently	0%	19%	44%	31%	6%	100%
I thought the system was easy to use	0%	38%	31%	31%	0%	100%
I found the various functions in this system were well integrated	0%	38%	38%	25%	0%	100%
I would imagine that most people would learn to use this system very quickly	13%	69%	6%	13%	0%	100%
I felt very confident using the system	6%	44%	25%	25%	0%	100%
Total	4%	41%	29%	25%	1%	100%
I found the system unnecessarily complex	6%	31%	25%	38%	0%	100%
I think that I would need the support of a technical person to be able to use this system	6%	6%	13%	38%	38%	100%
I thought there was too much inconsistency in this system	0%	6%	19%	75%	0%	100%
I found the system very cumbersome to use	0%	31%	31%	31%	6%	100%
I needed to learn a lot of things before I could get going with this system	0%	6%	19%	56%	19%	100%
Total	3%	16%	21%	48%	13%	100%

Figure 3: SUS Scores

of the test, the usability measures and the numeric results and analysis [6].

Goal, participants and backgrounds

The goal of this experiment is to assess the level of usability of the GViz tool for users with technical backgrounds when conducting a typical task related to the geospatial queries. 16 participants took part in this experiment. For an initial evaluation, this number was considered sufficient. These were taken from members of the ADAPT-TCD research centre and the OSi Ireland. A pre-questionnaire asked for some background on their roles in their organization. This broke down as follows, from ADAPT: 4 postdocs/research fellows, 4 Ph.D students, 2 project managers/coordinators, 1 research assistant, 1 academic and 1 software engineer. Of these, 9 are computer scientists, 2 project managers, and 2 linguists. From OSi 2 GIS IT professionals, 1 Industry representative all working in the domain of GIS.

Experimental description, tasks description, and technologies

The evaluation explored the participants completion of four tasks (below). These relate to the main feature of interest in the GViz interface:

(1) Select an area of the map to run a GeoSPARQL query to return buildings within
(2) Select returned buildings for further examination
(3) Click on the marker to see data about the building
(4) Filter the data

More on these tasks can be found here [21]. The technologies used have been presented in the implementation section.

Findings

The SUS scored 60 out of 100. Fig. 3 gives a breakdown of the SUS questionnaire scores as percentages. The participants were also asked 'What features of the tool, if any, did you like/dislike?', "What additional features would you like to see, if any?" and to provide any 'Further comments'. Positive comments about the features included "Once using the app, it is intuitive", "Display of red dots (geolocation) on map is clear", "Interesting way to select a region", "the ability to select regions" and two related to the "Filtering" of results. Negative comments included "The shown geo locations (red dots) from the area selection are too small if you zoom in", "Having to use a keyboard: right click is preferred if you're not a power user; having to draw polygons: good if you want to be very specific but most people aren't -> use a simpler selection. Marker dots are indiscernible to the visually challenged.", "Having to use a keyboard: right click is preferred if you're not a power user; having to draw polygons: good if you want to be very specific but most people aren't -> use a simpler selection. Marker dots are indiscernible to the visually challenged.", "Coloured markers - very hard to distinguish colours when you are colourblind", "The select tools are basic for a web mapping tool".

For extra features participants commented: "Button options as opposed to "s" or "d". Maybe a "drawing" option as opposed to clicking to draw a polygon? (free form as opposed to straight lines)", "Maybe some kind of "dragging" feature that could allow you to draw say a square around the city, rather than having to define the boundaries yourself." and "different markers (shape?) for different types", and "the ability to download the selection (URI,X,Y,form,Function) as CSV or similar". For further comments: "Second attempt when selecting all filters did not reveal any buildings", "Its hard to see what the exact application of the tool is. If it is to select features and read data from pop-ups from a users point of view it compares poorly with propriety (Arc) and open source alternatives (mapbox, leaflet). The fact that it is using linked open data may be of interest from a research point of view." and "This has potential". In the next section we address these findings and comments.

7 DISCUSSION, CONCLUSION AND FUTURE WORK

This work presented a prototype WebApp called GViz for providing configurable geospatial functions using GeoSPARQL on an interactive map. The tool has been demonstrated using a test case of four sample open data sets taken from both the OSi building data and data.gov.ie data. A usability evaluation was also conducted to gather early feedback on the usability of the tool when selecting and querying this data. Overall satisfaction (SUS 60) is close to a 'C' passing grade, but still below what would be needed for a release version. Considering the early nature of this prototype, we nonetheless consider this a promising start from a usability perspective, and part of an iterative process of development and evaluation.

There were many comments on how the tool could be improved in future implementations. Some of these comments are related to implementation choices, for example, the display of geolocations as red dots or the interaction using keys on a keyboard, that can be easily addressed in newer versions. Other comments, such as those related to how geospatial queries are created, for example, using preset shapes (circles for example around a point) are design choices that have already been considered, and again can be implemented in future versions. Ideally, the generated queries should be available for display alongside the interactive map and polygon drawing, similar to the SPARQL query editing box in a tool such as Yasgui. Other comments from GIS professionals were related to alternative tools such as leflet and mapbox, with one not having a full understanding of the unique ability to select from multiple integrated data sets based on a single query. Nor that the tools given work with their own internal proprietary models and APIs, and as such, cannot be said to be open. Negative comments like these may have also influenced the final SUS score, and could be ameliorated with a better explanation in the instructions.

The tool has been shown to provide functionality to enable a user to select an area of interest and run geospatial queries over the data set. This goes beyond the functionality of existing SPARQL web clients, such as Yasgui, with respect to interactive queries and visualisation of data. The GViz tool can therefore potentially form part of a suite of tools to support non-expert users generating queries over geospatial data, providing visual feedback. This research opens to doors to several possible extensions of the tool, here we discuss in short some of the potential extensions to GViz and future research exploration.

Integration of BIM data based upon Geolocation

In previous work the potential for using geolocation as an identifier for buildings was explored [24]. This work showed that it is possible to determine, based upon some criteria (i.e. distance between points) that two buildings with a location that is very close can be considered to be the same building, thereby opening up the possibility of integrating the data from two sources. Future work will examine the GViz tool

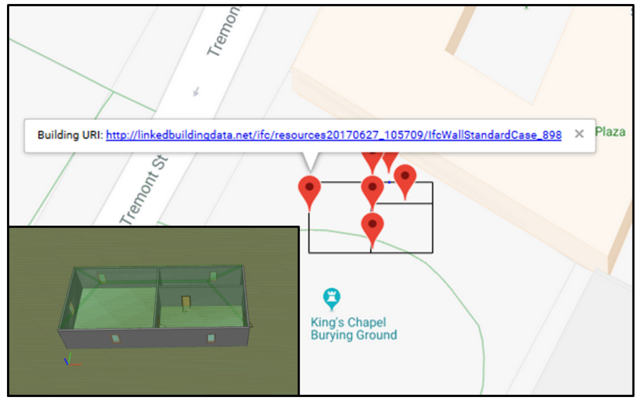

Figure 4: GViz - Visualisation of smallhouse.ifcowl walls after conversion to GeoSPARQL (selected using GViz)

as a potential for selecting an area, querying over several datasets, and then running an algorithm to determine if two points can be considered belonging to the same building. This will require consideration of the distances between buildings and the buildings geolocation, as it is possible if two buildings use a different method for generating its geolocation (for example, a centroid or the building entrance) the algorithm may determine that adjacent buildings are the same. Other properties will also be explored to improve the accuracy of the selection process, for example building name, address, building number, floor area etc.

Here GViz becomes a useful tool to do selects over areas, as the alternative would require all buildings across data sets to be compared, and in the case of OSis > 3.5 million buildings, such a process would require significant processing. In particular, it will give capabilities for users to align their models with authoritative OSi building URIs.

Integration of IFC models

In [23] it was shown that IFC can be uplifted and geospatial data extracted, thereby supporting geospatial functions over IFC data. This process can provide yet another data stream for integrate BIM and once again, the potential for building owners of BIM models to align and share aspects of their IFC models publicly, could potentially attract developers to develop new tools to support those owners managing and maintaining their buildings. This work is currently being extended to support the conversion of building elements, such as walls, into WKT, allowing a buildings floorplan to be converted in geospatial.

Fig. 4 shows an initial conversion of smallhouse.ifc to ifcowl with additional GeoSPARQL describing the buildings walls in 2D and displayed in GViz. The walls have then been selected, and the URI of the wall entity displayed. It should be noted, smallhouse.ifc is a test model, and as such, its geospatial coordinates do not actually align with any existing physical site. We include it here because it is a popular test IFC model. The possibility therefore exists to move seamlessly from the geospatial domain into the building domain, aligning 3D BIM models with 2D geospatial data, and visualising this data through interactive WebApps like GViz.

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REFERENCES

[1] Kereshmeh Afsaria, Charles M. Eastmann, and Dennis R. Sheldena. 2016. Cloud-based BIM Data Transmission : Current Status and Challenges.

[2] Apache. 2019. Fuseki: serving RDF data over HTTP. https://jena.apache.org/documentation/serving_data/. Accessed: 22-Jan-2019.

[3] Apache. 2019. Spatial searches with SPARQL. https://jena.apache.org/documentation/query/spatial-query.html. Accessed: 22-Jan-2019.

[4] Sören Auer, Jens Lehmann, and Sebastian Hellmann. 2009. LinkedGeoData: Adding a Spatial Dimension to the Web of Data. In *The Semantic Web - ISWC 2009*, Abraham Bernstein, David R. Karger, Tom Heath, Lee Feigenbaum, Diana Maynard, Enrico Motta, and Krishnaprasad Thirunarayan (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 731–746.

[5] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *J. Usability Studies* 4, 3 (May 2009), 114–123. http://dl.acm.org/citation.cfm?id=2835587.2835589

[6] Nigel Bevan. 1999. Common industry format usability tests. In *Proceedings of UPA'98, Usability Professionals Association.*

[7] Muhammad Bilal, Lukumon O. Oyedele, Junaid Qadir, Kamran Munir, Saheed O. Ajayi, Olugbenga O. Akinade, Hakeem A. Owolabi, Hafiz A. Alaka, and Maruf Pasha. 2016. Big Data in the construction industry: A review of present status, opportunities, and future trends. *Advanced Engineering Informatics* 30, 3 (2016), 500 – 521. https://doi.org/10.1016/j.aei.2016.07.001

[8] Andre Borrmann, Markus Konig, Christian Koch, and Jakob Beetz. 2018. *Building Information Modeling: Technology Foundations and Industry Practice.* Springer International Publishing. ISBN: 978-3-319-92861-6.

[9] Diego Calvanese, Benjamin Cogrel, Sarah Komla-Ebri, Roman Kontchakov, Davide Lanti, Martin Rezk, Mariano Rodriguez-Muro, and Guohui Xiao. 2017. Ontop: Answering SPARQL Queries over Relational Databases. *Semantic Web Journal* 8, 3 (2017), 471–487. https://doi.org/10.3233/SW-160217 Semantic Web Journal outstanding paper award for 2016.

[10] Stephane Campinas. 2014. Gosparqled - SPARQL Auto-Completion. https://github.com/scampi/gosparqled. Accessed: 22-Jan-2019.

[11] S. Campinas, T. E. Perry, D. Ceccarelli, R. Delbru, and G. Tummarello. 2012. Introducing RDF Graph Summary with Application to Assisted SPARQL Formulation. In *2012 23rd International Workshop on Database and Expert Systems Applications.* 261–266. https://doi.org/10.1109/DEXA.2012.38

[12] DBPedia. 2019. Structured content from Wikipedia project. http://wiki.dbpedia.org/. Accessed: 22-Jan-2019.

[13] Jeremy Debattista, Sören Auer, and Christoph Lange. 2016. Luzzu—A Methodology and Framework for Linked Data Quality Assessment. *J. Data and Information Quality* 8, 1, Article 4 (Oct. 2016), 32 pages. https://doi.org/10.1145/2992786

[14] Christophe Debruyne, Eamonn Clinton, Lorraine McNerney, Atul Nautiyal, and Declan O'Sullivan. 2016. Serving Ireland's Geospatial Information as Linked Data. In *Proceedings of the ISWC 2016 Posters & Demonstrations Track co-located with 15th International Semantic Web Conference.*

[15] Yichuan Deng, Jack C.P. Cheng, and Chimay Anumba. 2016. Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison. *Automation in Construction* 67 (2016), 1 – 21. https://doi.org/10.1016/j.autcon.2016.03.006

[16] Tom Heath and Christian Bizer. 2011. Linked Data: Evolving the Web into a Global Data Space. *Synthesis Lectures on the Semantic Web: Theory and Technology* 1, 1 (2011), 1–136. https://doi.org/10.2200/S00334ED1V01Y201102WBE001

[17] F. Hogenboom, V. Milea, F. Frasincar, and U. Kaymak. 2010. *RDF-GL: A SPARQL-Based Graphical Query Language for RDF.* 87. https://doi.org/10.1007/978-1-84996-074-8_4

[18] Ebrahim P. Karan and Javier Irizarry. 2015. Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services. *Automation in Construction* 53 (2015), 1 – 12. https://doi.org/10.1016/j.autcon.2015.02.012

[19] KRR&A. 2019. Strabon - Semantic Web Standards. http://www.strabon.di.uoa.gr/. Accessed: 22-Jan-2019.

[20] Xin Liu, Xiangyu Wang, Graeme Wright, Jack C. P. Cheng, Xiao Li, and Rui Liu. 2017. A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS Int. J. Geo-Information* 6 (2017), 53.

[21] Kris McGlinn. 2019. GVis Video Tutorial. https://www.scss.tcd.ie/~mcglink/video/tutorial/geovis/geovis.html. Accessed: 22-Jan-2019.

[22] Kris McGlinn. 2019. OSi Building Ontology. http://ontologies.geohive.ie/osi/building/. Accessed: 22-Jan-2019.

[23] Kris McGlinn, Christophe Debruyne, Lorraine McNerney, and Declan O'Sullivan. 2017. Integrating Building Information Models with Authoritative Irish Geospatial Information. In *ISWC 2017, the 16th International Semantic Web Conference.* 66–74. ISBN: 978-3-319-68204-4.

[24] Kris McGlinn, Christophe Debruyne, Lorraine McNerney, and Declan O'Sullivan. 2017. Integrating Ireland's Geospatial Information to Provide Authoritative Building Information Models. In *Proceedings of the 13th International Conference on Semantic Systems - Semantics2017*, Vol. 13. ACM Press, 57–64. https://doi.org/10.1145/3132218.3132223

[25] Kris McGlinn, Lucy Hederman, and Dave Lewis. 2014. SimCon: A context simulator for supporting evaluation of smart building applications when faced with uncertainty. *Pervasive and Mobile Computing* 12 (2014), 139 – 159. https://doi.org/10.1016/j.pmcj.2013.02.003

[26] Kris McGlinn, Kelvin Jones, Aitor Cochero, Anton Gerdelan, and Dave Lewis. 2015. Usability evaluation of an activity modelling tool for improving accuracy of predictive energy simulations. In *Proceedings of the 14th Conference of International Building Performance Simulation Association (IBSA).*

[27] Kris McGlinn, Baris Yuce, Hendro Wicaksono, Shaun Howell, and Yacine Rezgui. 2017. Usability evaluation of a web-based tool for supporting holistic building energy management. *Automation in Construction* 84 (2017), 154 – 165. https://doi.org/10.1016/j.autcon.2017.08.033

[28] Jakob Nielsen. 1994. Enhancing the Explanatory Power of Usability Heuristics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '94).* ACM, New York, NY, USA, 152–158. https://doi.org/10.1145/191666.191729

[29] Pieter Pauwels, Sijie Zhang, and Yong-Cheol Lee. 2017. Semantic web technologies in AEC industry: A literature overview. *Automation in Construction* 73 (2017), 145 – 165. https://doi.org/10.1016/j.autcon.2016.10.003
[30] Laurens Rietveld and Rinke Hoekstra. 2013. YASGUI: Not Just Another SPARQL Client. In *The Semantic Web: ESWC 2013 Satellite Events*, Philipp Cimiano, Miriam Fernández, Vanessa Lopez, Stefan Schlobach, and Johanna Völker (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 78–86.
[31] Laurens Rietveld and Rinke Hoekstra. 2015. The YASGUI Family of SPARQL Clients.
[32] SemWebCentral. 2019. Parliament High-Performance Triple Store. http://parliament.semwebcentral.org/. Accessed: 22-Jan-2019.
[33] Paul R. Smart, Alistair Russell, Dave Braines, Yannis Kalfoglou, Jie Bao, and Nigel R. Shadbolt. 2008. A Visual Approach to Semantic Query Design Using a Web-Based Graphical Query Designer. In *Knowledge Engineering: Practice and Patterns*, Aldo Gangemi and Jérôme Euzenat (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 275–291.
[34] Stardog. 2019. Stardog-The Knowledge Graph Platform for the Enterprise. https://www.stardog.com/. Accessed: 22-Jan-2019.
[35] W3C. 2019. R2RML: RDB to RDF Mapping Language. https://www.w3.org/TR/r2rml/. Accessed: 22-Jan-2019.
[36] Alan Woolrych and Informatics Centre. 2001. Why and when five test users aren't enough. In *Proceedings of IHM-HCI 2001 Conference*. 105–108.
[37] Martins Zviedris and Guntis Barzdins. 2011. ViziQuer: A Tool to Explore and Query SPARQL Endpoints. In *The Semanic Web: Research and Applications*, Grigoris Antoniou, Marko Grobelnik, Elena Simperl, Bijan Parsia, Dimitris Plexousakis, Pieter De Leenheer, and Jeff Pan (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 441–445.