Spatial Digital Twin - Special Interest Group
2022 SDT Standards Survey Results

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SSSI Spatial Digital Twin Special Interest Group (SDT-SIG) conducted an industry survey on geospatial standards for Spatial Digital Twin (SDT). The survey clearly shows that the understanding and using if standards is still insufficient. The general benefit of employing standards seems to be understood well. However, a specific knowledge is lacking.

Background

In the period 5th of May to 11th of July 2022, SSSI Spatial Digital Twin Special Interest Group (SDT-SIG) conducted an industry survey on geospatial standards for Spatial Digital Twin (SDT). The survey was intended to understand how the Australian spatial community utilises spatial standards in the development and delivery of Digital Twin products and services. The survey was announced via SSSI channel, mailing lists and social media. The information gathered in this survey is intended to help SSSI to deliver to its members the support needed to further promote and deliver world class geospatial DT products, both nationally and internationally.

The survey focused on the standards produced by three of the top international standard development bodies, those of the Open Geospatial Consortium (OGC), International Standards Organisation Technical Committee 211 for Geographic information/Geomatics (ISO/TC211) and buildingSMART International. The list contains a selection of 73 standards from OGC, 38 from ISO/TC211 and 12 from buildingSMART International. This selection was based around the potential to support and facilitate spatial data products and services, or to support the broader governance of spatial data production and management. In addition to the listed standards, the survey sought to collect any information on software, applications and practices that are not covered by the 73 listed standards.

Survey Results

42 responses were collected between May 2022 and July 2022. Respondents were asked to identify their role within their organisation and whether the organisation contributes to a SDT product. The respondents were allowed to select different options. The classification is as follows: data decision maker (13), data creator (10), data creator, user and decision maker (10), data user (5) data decision maker and user (1) data creator and user (1). The responders were further grouped

according to the type of the institution into: companies (COM), education (EDU), government (GOV) according to the provided e-mails. The results of these questions are listed below **Error! Reference source not found.**.The survey attracted respondents from across private companies, government bodies and academia. Whilst 23 respondents indicated they do contribute to SDT, their activities may vary regarding aims and outcomes. Academia may investigate platforms, analyse options for integration of spatial objects and visualisation or experiment with standards; private companies and governments may work towards developing implementation and deliverable solutions and products for the public good or for revenue. 19 of the 42 respondents indicated they did not contribute to SDT, but they find it valuable to participate in the survey. This might be indicating that there is interest in the spatial community to understand more about this emerging concept and technologies. Supplied email addresses were used to segment responses for industry sector analysis.

	Yes	**No**	**No resp.**
COM	43%	14%	43%
EDU	57%	0%	43%
GOV	27%	27%	45%
GOV/COM	43%	29%	29%
Personal email	20%	40%	40%
No email provided	26%	42%	32%
TOTAL	**23%**	**19%**	

Table 1 Contribution to SDT Products - Breakdown of Sectors of Respondents

Respondents were asked to describe the SDT product or products that they, or their organisation contributed to. The results suggest that there is still much diversity and potential confusion around what is meant by the concept of SDT in the spatial industry (Figure 1). Interestingly, within the responses there are various water related responses, *water pumps, port capacity, great barrier reef hydrodynamic, pump station, asset for aquatic centre.* This may be a hint that SDT are of particular value to the Australian spatial community in the fields of water and marine management.

Figure 1: Word cloud of key phrases from all responses.

ISO/TC 211 Standards

The first group of standards was from the ISO/TC 211 19100 series of standards for geographic information. The respondents were asked to indicate if their organisation is using the standards from this series by providing a Yes/No answer (**Error! Reference source not found.**).

List of ISO/TC211 standards ranked according to their use		
Count	**Title**	**Code**
12	Geographic information - Metadata, Part 1: Fundamentals	AS/NZS ISO 19115.1:2015
6	Geographic information - Geography Markup Language (GML)	AS/NZS ISO 19136.1:2020
6	Geographic information - XML schema implementation, Part 1: Encoding rules	SA/SNZ TS ISO 19139.1:2019
5	Geographic information - Metadata, Part 2: Extensions for acquisition and processing	AS/NZS ISO 19115.2:2019
<=4	Other	

Table 2: Most used ISO/TC211 standards.

Surprisingly, a large group, specifically companies and governments, replied negatively. This might be because of several reasons. It might be that a standard is so embedded in the organisation or software that is used by the organisation that all operations and processes around it have been baked-in and it becomes difficult to see which standards are in use. It might be that no one knows that a specific protocol or way of data exchange is a standard, i.e. there are no checks, balances and reporting that specifically name standards. It could also be that indeed standards are not used, because many organisations see the SDT process as a job that requires learning of specific software packages and the interfaces, data structuring and data exchange formats provided by these packages. This contradicts the response from academia, who are generally focused on investigating and testing the data schemas or data dictionaries being used and the standards and protocols to exchange and transform data.

The respondents were asked to tick all relevant standards from the listed 38 ISO/TC211 standards that had been provided (Appendix A: ISO TC/211). The standard that received the most responses was *AS/NZS ISO 19115.1:2015 - Geographic information - Metadata, Part 1: Fundamentals.* It is clear that it is a very important standard, because every data provider has its own way of structuring the data (features, attributes, relationships, quality) and this needs to be communicated when data is exchanged. Metadata is the only way to convey what information is provided and in what form. Still out of the 42 respondents, only 12 indicated they are using *AS/NZS ISO 19115.1:2015* which is the national adoption of the international ISO 19115-1 standard. This may be due to 29 respondents indicating a role of decision maker, although the common understanding is that exactly decision makers must be aware of the importance of metadata.

It may be recommended that as a minimum requirement the national standard on metadata be applied to ensure ease of comprehension both internally and externally when aggregating, storing or sharing spatial datasets. It is noted that the dominant geographical information system (GIS) tools such as those of ESRI and QGIS do provide plugins and built in options for applying and conforming to *ISO 19115- 1:2014 - Geographic information - Metadata, Part 1: Fundamentals* and *ISO/TS 19139- 1:2018 - Geographic information - XML schema implementation, Part 1: Encoding rules* standards. This might indicate that these standards are being applied (at least partially) within the production of spatial data products and services.

Overall, the indicated use of each individual standard appears to be quite low (Table 3). Further investigation is needed to link the use of standards to the companies. It is also key to remember that 29 respondents indicated they were *decision makers* and not data creators or users. These respondents may not be aware of the granular data production standards that are being applied by data custodians. It could be that some companies/governments do investigate standards and some not.

	Yes	No	No resp.
COM	14%	43%	43%
EDU	43%	14%	43%
GOV	27%	27%	45%
GOV/COM	0%	71%	29%
Personal email	20%	40%	40%
No email provided	16%	53%	32%
TOTAL	**13%**	**29%**	

Table 3: Use of ISO standards

Another aspect that needs to be considered is that many of the standards mentioned in use are on a quite high conceptual level, e.g. *Conceptual spatial schema language*, and others a on a very technical/implementation level such as *GML*, *XML*. The technical standards might have been implemented in interfaces of export file formats and therefore become ‘invisible’. At the same time, the technical standards that provide guidance on how to structure information such as those on *Coverage implementation schema* and *Calibration and validation of remote sensing imagery sensors and data* are not used. The conceptual standards provide a guidance but not a specific implementation, but they are mentioned as used. This might indicate that the conceptual standards are accepted as notions, but the technical implementations continue to be different. These are first observations and therefore it needs to be clarified as to exact use of different types of standards.

When asked to further specify which software supports the standards, 69% of the responders did not provide an answer. This again may be due to a significant proportion of respondents being decision makers not data users and not aware of the specific software.

Among all listed software ArcGIS was the most dominant (Figure 2). There is often the notion that ArcGIS is considered GIS, when it is just one of many tools that facilitates the production of geospatial products and services. Results did indicate the substantial use of custom and open-source products, including QGIS and PostgreSQL. GeoNetwork is another application that has been well recognised in the results. It is a software enabling data producers setting up their metadata catalogues in compliance with ISO 19115-1:2014 - which confirms the responses on the most popular ISO/TC211 standards presented earlier. Again, it is an indication that open source, web-based technical tools are appreciated and adopted within the spatial community. However, the use of open-source tools often require certain GIS expertise. In contrast, packages such as ArcGIS can be operated by non-GIS employees (after a basic training), this can potentially lead to the fundamental concepts and quality management of geospatial data not being understood; leading to bad products being produced and maintained by non-spatial GIS people.

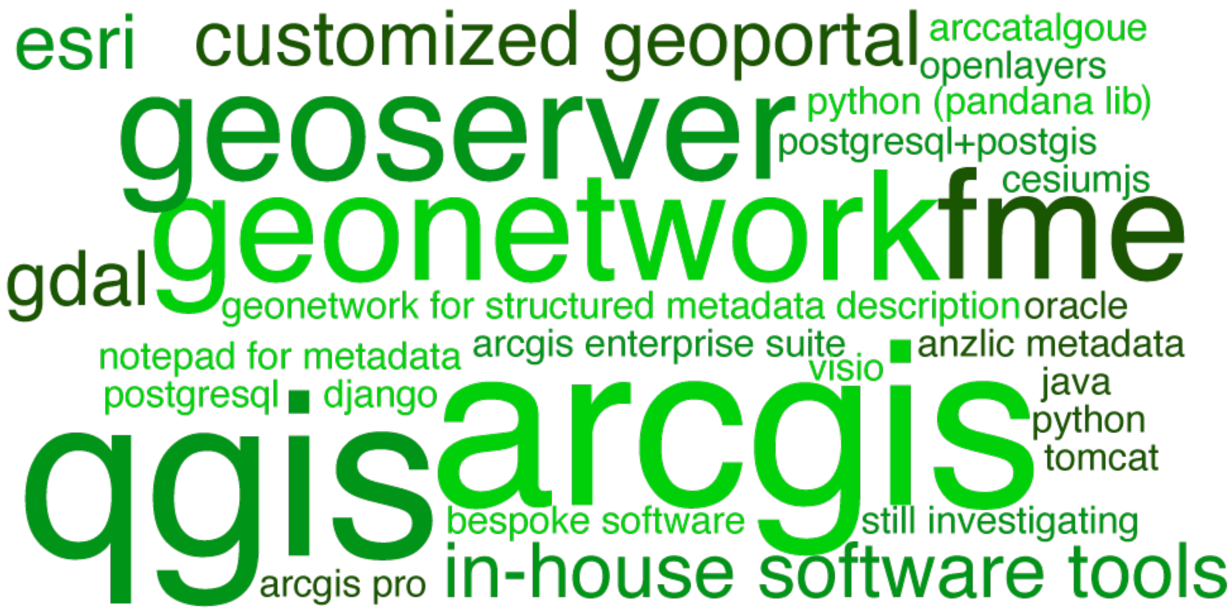

Figure 2: Wordcloud on type of software that supports mentioned standards.

Open Geospatial Consortium (OGC) Standards

Open Geospatial Consortium (OGC) is a standardisation organisation that facilitates the use of geospatial data and services via the FAIR principles: i.e., make data and services *Findable, Accessible, Interoperable and Reusable.* OGC standards are open and every company can become a member of OGC and participate in standards creation, modification and development and currently, OGC consists of more than 500 members with different levels of participation.

OGC standards may not be considered officially adopted by many organisations within Australia, however many of them are used unknowingly because they are embedded as data formats or encoding associated with specific software packages (e.g. in PostGIS or QGIS).

The results may indicate that the knowledge of what OGC does, standards development and innovation programs, is mostly known within academia (Table 4). These results may be an indication that there needs to be some further awareness raising within Australia on the role that OGC may play in spatial technologies.

	Yes	No	No resp.
COM	14%	43%	43%
EDU	43%	14%	43%
GOV	27%	27%	45%
GOV/COM	0%	71%	29%
Personal email	20%	40%	40%
No email provided	16%	53%	32%
TOTAL	**13%**	**29%**	

Table 4: Use of OGC standards

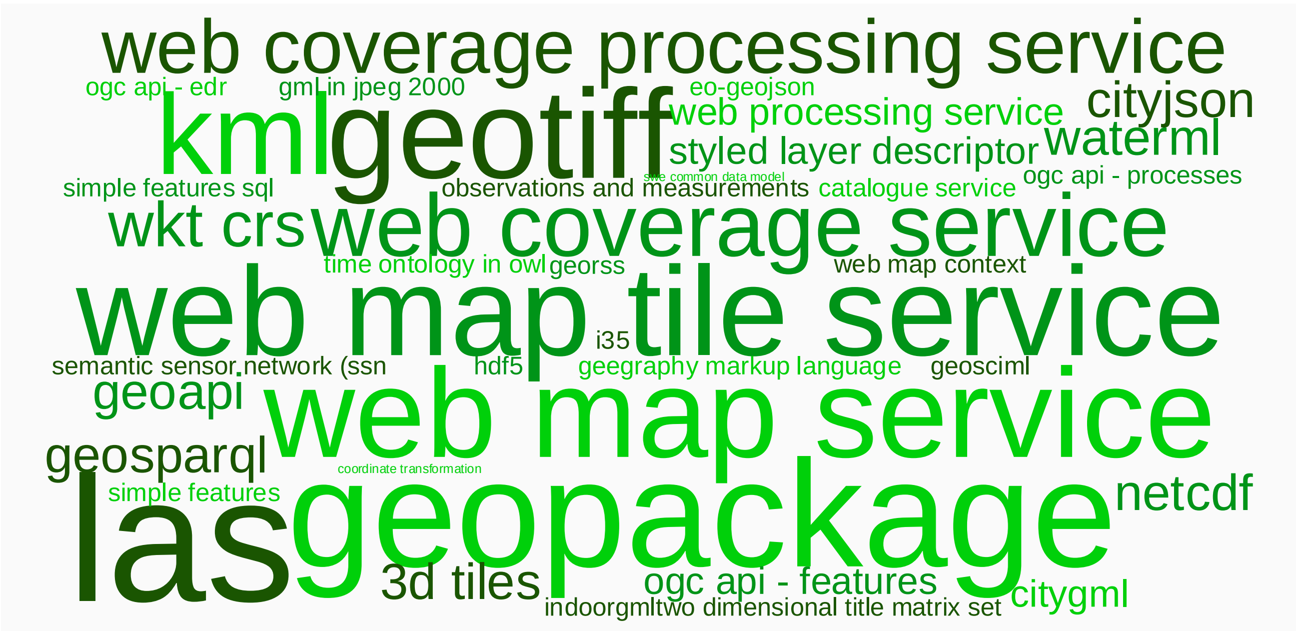

Figure 3: Word cloud of most used OGC standards.

As Figure 3 illustrates, the most widely used OGC standards are the service standards, which are implemented in most of the GIS software. KML is a de facto standard, used mostly by Google, but import and export is provided by almost all GIS software packages. It is worth noting compared to ISO/TC211 standards, more OGC technical standards are used or recognised in these results, i.e., standards that describe file formats and services.

Figure 4 and Figure 5 provide further insight as to which standards are mostly used by academia and government. Figure 4 shows that CityGML is very popular within academia; one of the most investigated data structuring and encoding standards to support different applications.

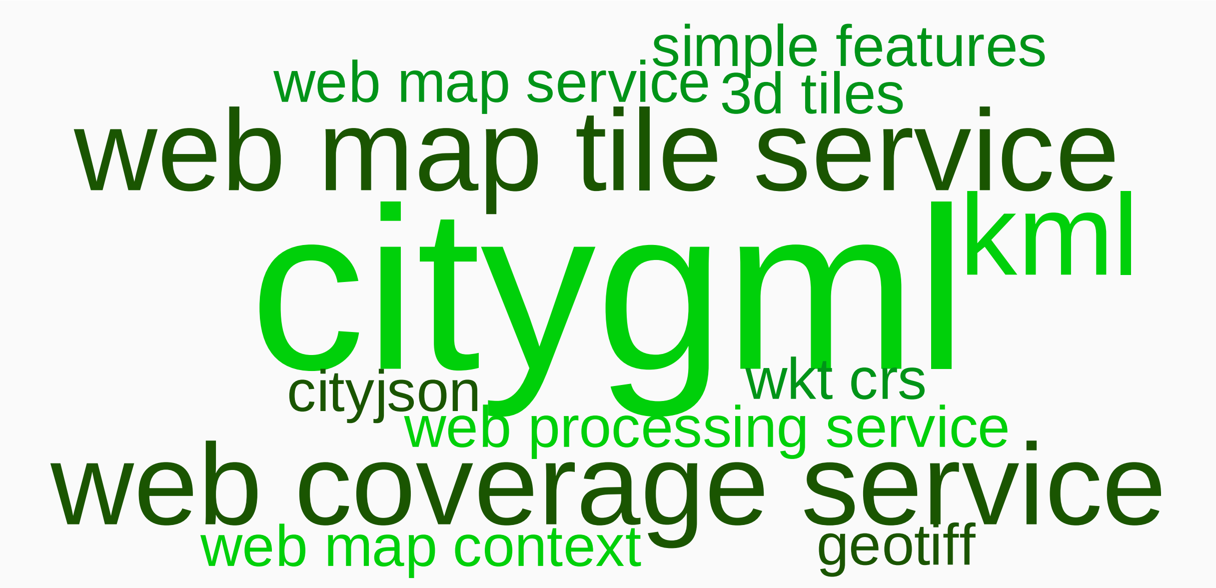

Figure 4: Word cloud of the software used by educational institutions.

In contrast Figure 5 reveals that governments use of OGC standards is dominated by web services, it is largely because since its establishment in 1994, OGC's primary focus has been on developing standards for enabling interoperable geographic web-based formats. Results of our survey confirm that OGC's mission has been accomplished.

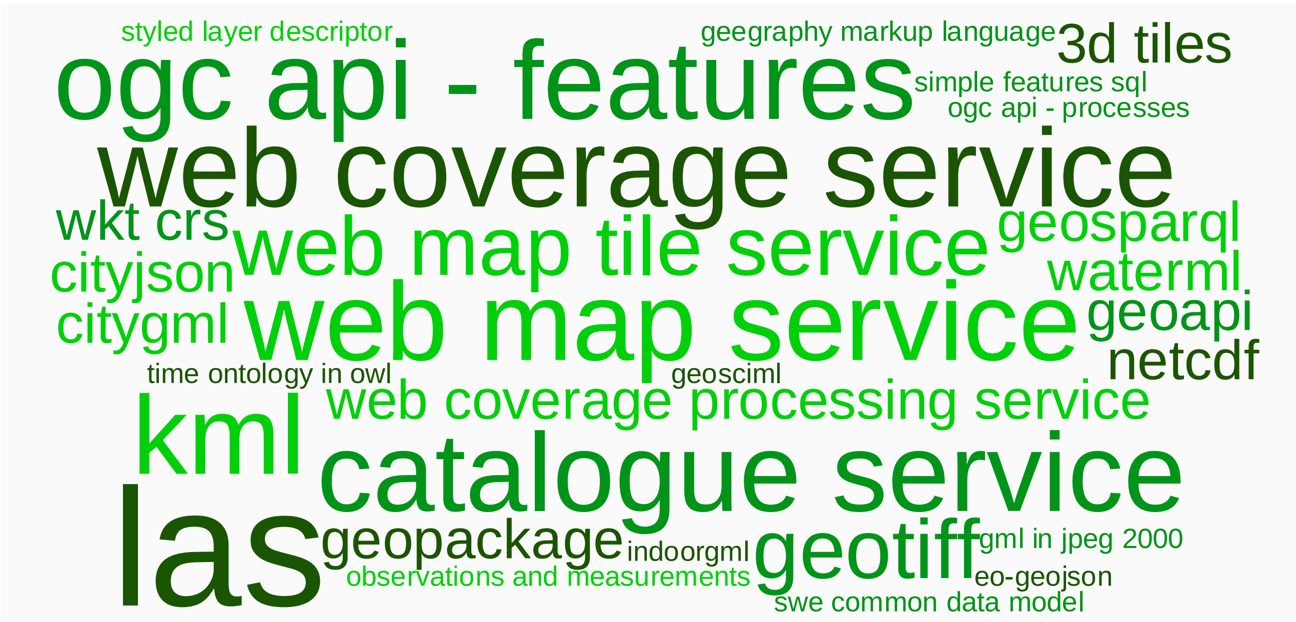

Figure 5: Word count of software used by governments.

Table 5 provides an overview of all OGC standards included in the survey and the number of responses per standard. Notably some of the OGC standards are also ISO/TC211 standards, but they have not been indicated in the OGC section of the survey. For example, GML is marked by 2 responders in the OGC section, while *AS/NZS ISO 19136.1:2020 - Geographic information - Geography Markup Language (GML)* is marked by 6 responders. This might be an indication that the responders are not familiar with the fact that there a OGC and ISO/TC211 spatial standards on the same topic (i.e. with the same title) are identical - this is due to a liaison between the two organisations developing geospatial standards that ensures that there is no duplicity in standards development at ISO/TC211 and OGC.

As with the ISO/TC211 standards, after respondents listed their use of OGC standards they were asked to specify which software, according to their knowledge, uses the indicated standards. 62% of the responders did not answer this question. Figure 6 illustrates that the software used is very similar to Figure 5 results relating to ISO/TC211 standards. Surprisingly, Global Mapper seems very popular, although it does not appear often within conversations in Australia.

List of OGC standards, ranked according to their use					
#	OGC Standard	#	OGC Standard	#	OGC Standard
13	Web Map Service	2	Catalogue Service	1	Coordinate Transformation
13	Web Map Tile Service	2	CityJSON	1	GeoSciML
11	GeoTIFF	2	EO-GeoJSON	1	GeoRSS
9	KML	2	GML in JPEG 2000	1	HDF5
7	LAS	2	GeoAPI	1	I35
7	Web Coverage Service	2	GeoSPARQL	1	IndoorGML
6	GeoPackage	2	Geography Markup Language (GML)	1	OGC API - EDR
5	WKT CRS	2	NetCDF	1	OGC API - Processes
4	3D Tiles	2	Observations and Measurements	1	SWE Common Data Model
3	CityGML	2	Time Ontology in OWL	1	Semantic Sensor Network (SSN)
3	OGC API - Features	2	WaterML	1	Simple Features
3	Styled Layer Descriptor	2	Web Map Context	1	Simple Features SQL
3	Web Coverage Processing Service			1	Two-Dimensional Title Matrix Set
3	Web Processing Service				

Table 5: List of OGC standards, ranked according to their use.

As with the ISO/TC211 standards, after respondents listed their use of OGC standards they were asked to specify which software, according to their knowledge, uses the indicated standards. 62% of the responders did not answer this question. Figure 6 illustrates that the software used is very similar to Figure 5 results relating to ISO/TC211 standards. Surprisingly, Global Mapper seems very popular, although it does not appear often within conversations in Australia.

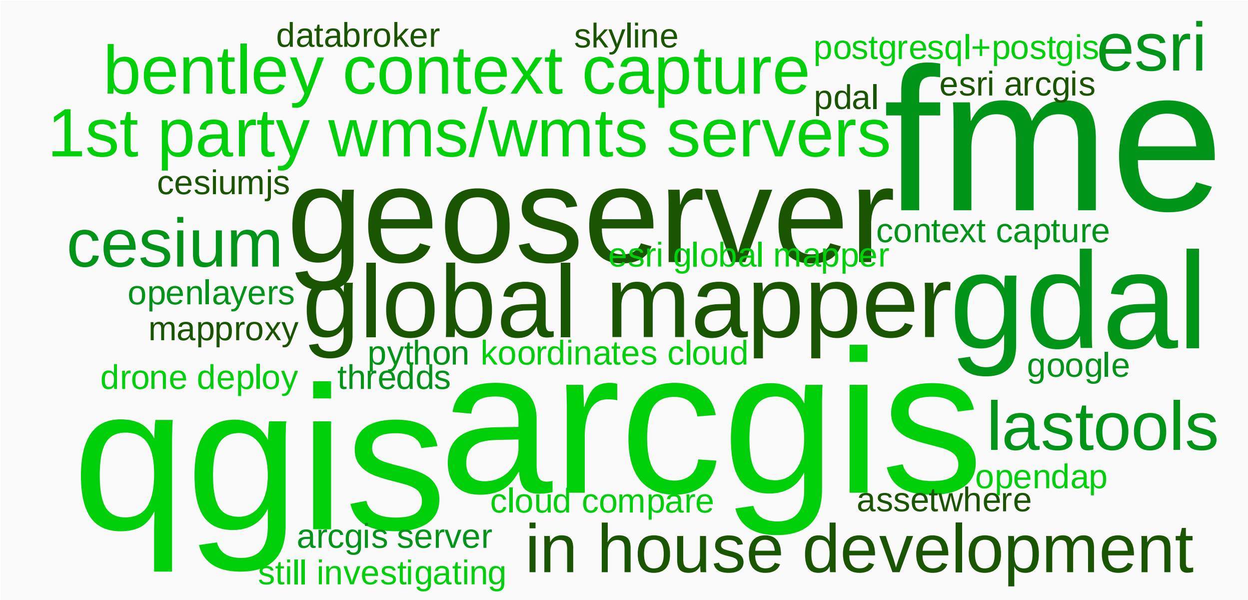

Figure 6: Software packages that employed OGC standards.

buildingSMART International Standards

The last section was devoted to standards maintained by buildingSMART International. The responses to the questions reveal different situation with the use of ISO/TC211 and OGC standards. Government Companies is leading in its focus with 43% of respondents using BIM standards and models.

	Yes	No	No Resp.
COM	21%	36%	43%
EDU	29%	29%	43%
GOV	18%	36%	45%
GOV/COM	43%	29%	29%
Personal email	0%	60%	40%
No email provided	11%	58%	32%
TOTAL	**13%**	**29%**	

Table 6: Use of BIM standards

The most used standard is IFC. IFC is also an ISO standard, but in contrast to other ISO standards, IFC has a very good open documentation on the internet. Note that the list below does not only contain standards but also one technical report: *ISO/TR 23262:2021 - GIS (geospatial) / BIM interoperability.* This is an informative document explaining potential interoperability between GIS and BIM. It is noteworthy that 5 participants indicated the use of this report - this demonstrates keen interest in the community in learning about synergies between informational products and tools. It must be further investigated if this guidance is interpreted and implemented by software developers to ensure IFC-CityGML mapping. Furthermore, there are several standards discussing organisational aspects. It will be valuable to further survey how these are employed for construction processes.

FREQ	STANDARD	FREQ	STANDARD	FREQ	STANDARD
7	AS ISO 16739.1:2021 - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries, Part 1: Data schema	4	AS ISO 23386:2021 - Building information modelling and other digital processes used in construction - Methodology to describe, author and maintain properties in interconnected data dictionaries	3	AS ISO 23387:2021 - Building information modelling (BIM) - Data templates for construction objects used in the life cycle of built assets - Concepts and principles
6	ISO 16739-1:2018 - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema	4	ISO 19650-1:2018 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles	3	AS ISO 29481.2:2018 - Building information models - Information delivery manual - Interaction framework
5	ISO 19650-3:2021 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 3: Operational phase of the assets	4	ISO 19650-2:2019 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 2: Delivery phase of the assets	3	ISO 23387:2020 - Building information modelling (BIM) - Data templates for construction objects used in the life cycle of built assets - Concepts and principles
5	ISO/TR 23262:2021 - GIS (geospatial) / BIM interoperability	4	ISO 19650-5:2021 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 5: Security-minded approach to information management		

Table 7: List of buildingSMART standards

The software that uses the marked BIM standards is mostly software used in Digital engineering (CAD or BIM), but ArcGIS is still present. Notably 71% of responders did not name software tools. It might be that most of the responders were not familiar with BIM software. Again, the use of FME is minimal, although this package provides a powerful workbench to map and convert files and some companies are building dedicated interoperability workbenches. This is also an indication that tools to link GIS and BIM are available, but Digital Engineering may not see the power or usefulness of this approach. Alternatively, the complexity and variety of schemas and terminologies is so large that interoperability issues are discussed only on a project basis between project partners.

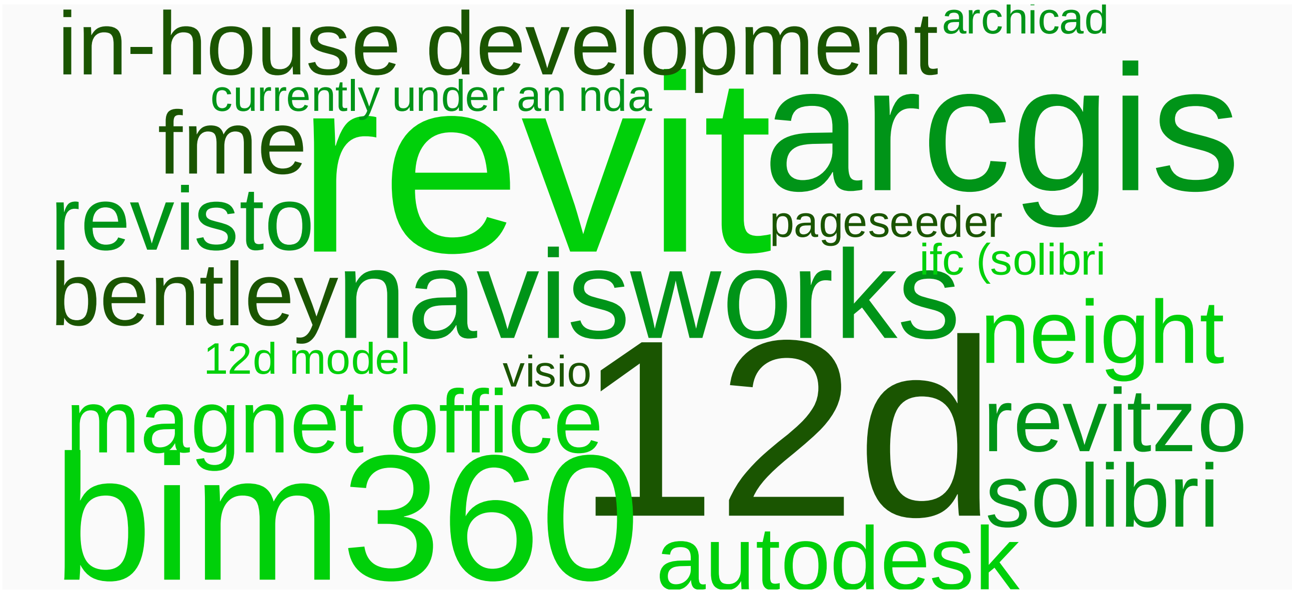

Figure 7: Software packages that employed buildingSmart standards.

Other Standards

Following questions relating to ISO/TC211, OGC and buildingSMART respondents were given the option to indicate if they have used other standards for SDT. Table 8: Use of other standards indicates that governments and companies tend to rely on standards different from ISO/TC211, OGC and buildingSMART, while academia tends to prefer the listed suit of standards. It also revealed that responders had mentioned ISO /TC211 and OGC standards, suggesting that the provided list might have not been complete (e.g., SensorML was not included in the list, but was mentioned by one of the respondents).

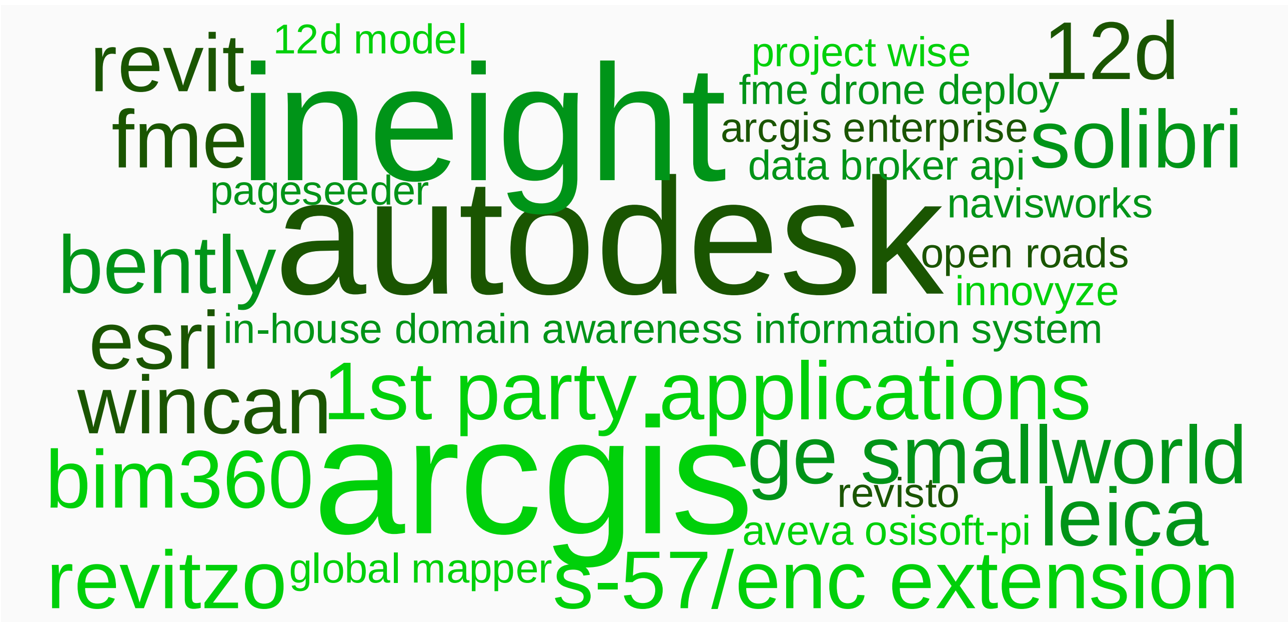

Figure 8: Software packages that employed 'other' standards.

TfNSW DE Framework may be a good example that was mentioned within the responses. A framework that cannot be seen as one standard, but a selection of important concepts from many international standards and national standards. This may be a good example of Australia adapting notions from a variety of standards for their more relevant application within the Australian context. However, it can make it difficult to understand the actual number on the utilisation of international standards when they may be embedded within these aggregated or derived standards.

	Yes	No	No resp.
COM	21%	36%	43%
EDU	0%	57%	43%
GOV	36%	18%	46%
GOV/COM	43%	29%	28%
Personal email	20%	40%	40%
No email provided	5%	63%	32%
TOTAL	**13%**	**29%**	

Table 8: Use of other standards

Software mentioned was again mainstream GIS and BIM packages. Notably, Bentley software became more prominently mentioned in this section, which indeed provides a different vision on some of the data integration issues. It is clear that large vendors provide direct access to native formats, which then become de facto standards. Examples of these are all well-known file formats, dwg, dxf, shape, obj, etc. Then more verbose, but open, semantically rich XML-file formats can become obsolete.

Another generic question asking about used software delivered all kind of output: specialised GIS and BIM software packages (ArcGIS, OGIS, Revit, AutoCAD, Bentley, Cesium etc), web services (WMS, WFS, RestAPI, FTP), formats (GeoJSON) and DBMS (PostGIS). In a separate question the management of data was addressed. The responders provided several databases not mentioned previously such as SQLite, Oracle, Oracle Lite and MySQL, but the ESRI database was again leading. Distributed storage on Azure was also mentioned.

General discussion

When respondents were given an opportunity to pose questions and add comments, we uncovered a very diverse range of suggestions and questions surrounding file formats, data quality and accuracy standards for design and as-built models and standardisation for features of interest across local to national government agencies.

The links between standards and file formats is very interesting. As mentioned above, standards vary from conceptual notions to technical descriptions. Some standards can be directly realised as file formats, such as CityGML, LandInfra, IFC, IndoorGML, KML etc. Further, encoding can differ; It can be based on GML or GeoJSON. Some technical implementations can be also implemented as a spatial schema (i.e. the SQL to create the spatial schema). Therefore, it is important to understand what the standard is and at how it can be implemented.

Often stakeholders request shapefiles, unaware that the shapefile is a file encoding that relies on ESRI geometric data types and the source spatial schema. It does not provide a unified representation of spatial information, nor metadata about the specific spatial schema. Furthermore, users may truncate the attribute names, which might lead to unclear natural language interpretations. In contrast, although we've seen the popularity of the metadata standard, its comprehensive use (i.e. providing metadata beyond the bare minimum, which does not include provision of the data dictionary) is still not universally undertaken as best practice. This combination of truncated fields of a product specific data schema and lack of metadata may lead to misinterpretation of datasets and their associated values.

To avoid this, other file formats, such as GeoPackage (OGC standard) or FME (Safe Software), may be utilised for data interchange. This file format maintains full-length attribute names and is contained in one container file (as opposed to three or more files composing a shapefile). It may be speculated that its lack of usage in the geospatial community is due to its being released fairly recently (in 2014 as opposed to the 1990s release of shapefile), yet due to its compactness, the update of GeoPackage is quite rapid. Another disadvantage of using shapefiles is the limit in its size - it can be at most 2GB, which is fairly limiting when it comes to detailed Digital Twins for large areas.

Discussion and Conclusions

As this survey covered both decision makers and those dealing directly with data products, it may give a broad overview of how standards are understood when averaged across those roles and responsibilities. However, going forward a more targeted separation of data creators vs data decision makers and their responses world help give a clearer indication of the role and responsibility of the key standards users, and how within the organisation might require additional exposure to the benefits of standardisation in geospatial product and service delivery.

The survey clearly shows that the understanding and using standards is still insufficient. The general benefit of employing standards seems to be understood well, but specific knowledge is lacking. Only few technical standards, which are adopted by software vendors and applied for data sharing are well known and largely used. Further studies are needed to understand the use of conceptual or guiding spatial standards. The academia shows a slightly better interest in using and working with standards, but it is because many data modelling and sharing aspects are part of the research agendas of university groups. Furthermore, some researchers are directly involved in the design and modification of spatial standards.

The ISO standards are mostly used, followed by BIM and OGC standards. This may not come as a surprise since the ISO brand is a popular indicator of quality for most organisations. However, as the ISO standards need purchasing, in contrast with the equivalent OGC standards, it would be interesting to investigate how an institution decides on the purchasing of a specific standard. Is the decision taken on the basis of a recommendation from Standards Australia, ANZLIC or another governmental body? Are there cases when a standard has been purchased and never used? Furthermore, it is not well known that many OGC standards are ISO standards as well. OGC standards are open and can be freely downloaded from the OGC web site. Such a knowledge can speed up standards implementation and save resources.

Ultimately who is responsible for driving the utilisation of standards within spatial data production and distribution? Conflict points can arise when:

- Top-down decision makers request standards not understanding the implication on databases, automation processes and existing schema relationships.
- Data producers are not given the time and resources required to develop and maintain robust standard-based processes within the organisation, letting ad-hoc patch and deliver solutions that break standardisation rules to react to demands on time and delivery.

An important aspect is the human resource. Who can read, understand and implement concepts, notations and procedures described in the standards? Are there actual graduates with geospatial degrees that have read these documents and could therefore implement them? It would be worth to study which universities in Australia have included spatial standards topics in their curriculum.

Recommendations

This survey aimed to investigate the spatial standards for SDT, i.e. each Digital Twin that makes use of spatial data. The survey clearly illustrated that it would be beneficial to provide a definition of SDT. Does SDT deal with shape and size of real-world objects or only with location, such as sensors measurements? Then the role of the spatial standards in the SDT must be specified. They can be used to harvest data from different state and government repositories, but they can be used as a foundation of the spatial data structure for building a SDT platform. Consequently, organisation and governments can be given further indications where in the production chain of SDT they belong to.

The survey indicates that there is a need to provide further guidance on the use of standards. What is the role of a standards? How a specific standard come to implementation and what kind of implementation. Some standards are related only to sharing data. The original data structures that are managed by an organisation stays unchanged and only the format of the delivered product is according to a standard (e.g. metadata, CityGML, IFC). There are standards that prescribe what kind of vocabulary and attributes have to be used as well as how to model specific component (e.g. wall in IFC). Other standards help to perform transformations between two data structures (or data schemas) (e.g. CityGML to IFC) and a set of specialised algorithms must be developed, which however are not included in the standard. Third standards are related to the client-server interfaces (WMS, WFS). It would be useful to categorise the spatial standards according to their place in the production line: data collection/modelling, storage, exchange and/or visualisation. These categories can be further matched with the needs of the organisation.

The help in using standards can be in different directions: provide a classification of standards about their nature (conceptual or technical), prepare MoSCoW (must, should, could, won't) prioritisation, prepare explanations how to use standards, develop implementation specifications or guidelines, i.e. how to develop products and services according to standards.

This survey attempted to investigate tools and services that support standards, but the results only indicated that more elaborated study is needed. Usually the software is used as 'it is', without deep understanding whether the tools and services are standard-compliant nor if the standards are missing information, which is vital for the Australia market. In this respect, it would be useful to make the users aware of the fact the standards can be amended, or alternatively international standards can be adapted for domestic use.

Further understanding and knowledge about the OGC standards has to be developed.

- OGC standards are free documents and for some standards general public (not only OGC members) can participate in providing feedback and developing standards.
- ISO standards are paid but hold greater official status which can be utilised to promote products and services as being compliant to official and recognised best practices as supported by a standards development body.

- OGC can have a corresponding ISO standard. This can allow users to test their implementation through OGC and then, if required by their organizational rules, obtain ISO documentation to ensure official compliance.

Interesting aspect, that have been raised by some of the participants is the interchangeable use of terms standards and file formats. Almost each vendor has its own native format to export data, but not all of the file formats are necessarily a recognised standard. A typical example is the shapefile. Any spatial schema can be exported as a shapefile. The shapefile can also carry information (geometry types, semantics, attributes) that is structured strictly according to a specific standard. The issue is becoming even more complicated when 3D visualisation is needed. Depending on the type of the file format, information (semantics, attributes, even some geometry types) can be easily lost. This is especially true when 3D game engines (such as Unreal and Unity) are employed. The visualisation file formats take care only of properties that are needed for the rendering on the screen (geometry, colour/material). Furthermore, the rendering engines maintain a more elaborate geometry data than GIS software. Note, this survey did not cover visualisation standards. The link between specific file formats and standards needs to be clarified. In some cases, it may indeed appear that no standard is available and a practical ad-hoc solution is employed.

Finally, it is clear that the standards to be adopted (as spatial data descriptions, data exchange, data management and visualisation) need to be fit for purpose and independent of state and local authority requirements. Only in this way it will be possible to ensure quick developments of appropriate services, easy access to data (e.g. through APIs), transparent information about quality of data, clear usage restriction and license obligations, as well as security and authentication. It should be also noted that SDTs should be integrated with many other non-spatial data, which means that the spatial communities need to interact with the broader standards to deliver an efficient Digital Twin.

Appendix A

List of survey questions

1. What role do you hold in your organisation, or what activities best represent your role in regard to geographic or spatial data products and services? Tick all that apply.
2. Do you or your organisation contribute to a spatial Digital Twin product?
3. Please describe the the spatial Digital Twin product or products that you or your organisation contribute to.
4. Do you use Geographic Information standards from the ISO TC 211 19100 series? https://www.iso.org/committee/54904/x/catalogue/p/1/u/0/w/0/d/0
5. From the subset we identified as relevant for Digital Twin, please check all that apply.
6. Please list the software applications used to create, process or share data services or products that use these standards.
7. Do you use Open Geospatial Consortium (OGC) standards? https://www.ogc.org/docs/is
8. From the subset we identified as relevant for Digital Twins, please check all that apply.
9. Please list the software applications used to create, process or share data services or products that use these standards.
10. Do you use buildingSMART or BIM standards? https://www.iso.org/committee/49180/x/catalogue/p/1/u/0/w/0/d/0
11. From the subset we identified as relevant for Digital Twins, please check all that apply.
12. Please list the software applications used to create, process or share data services or products that use these standards.
13. Do you use any standards that were not included above?
14. Please list all other standards that you use. Examples include standards such as BSI, AS/NZS, ISO, IEC, ITU, Web3D, IoT, W3C, NSW LandXML Recipe, ADAC XML (as Designed as Constructed), TfNSW Digital Engineering (DE) Framework.
15. If you have included additional standards, please list the software applications used to create, process or share data services or products.
16. Which technologies or software are used when accessing, receiving or sharing data and information for Digital Twin applications? Example: FTP, RestAPI, File Geodatabase, Geojson, WFS, Bentley, AutoCAD, ArcMap, QGIS etc.
17. Which software or systems are used when storing and maintaining data and information for Digital Twin applications? Example: Oracle, file GDB, SQLite, Postgres, AWS GeoServer etc.
18. Please provide comments on anything not covered above that you believe will contribute to the knowledge building and development of spatial Digital Twin standardisation practices within Australia.
19. Please provide contact details if you wish to contribute to a follow-up technical survey related to spatial Digital Twins. Please provide your name and best contact email.

Appendix B

ISO TC/211

List of ISO TC211 standards, ranked according to their use	
12	AS/NZS ISO 19115.1:2015 - Geographic information - Metadata, Part 1: Fundamentals
6	AS/NZS ISO 19136.1:2020 - Geographic information - Geography Markup Language (GML)
6	SA/SNZ TS ISO 19139.1:2019 - Geographic information - XML schema implementation, Part 1: Encoding rules
5	AS/NZS ISO 19115.2:2019 - Geographic information - Metadata, Part 2: Extensions for acquisition and processing
4	AS/NZS ISO 19107:2020 - Geographic information - Spatial schema
4	AS/NZS ISO 19111:2019 - Geographic information - Referencing by coordinates
4	AS/NZS ISO 19134-2008 - Geographic information - Location-based services - Multimodal routing and navigation
4	AS/NZS ISO 19160.1:2018 - Addressing, Part 1: Conceptual model
4	AS/NZS ISO 19162:2018 - Geographic information - Well-known text representation of coordinate reference systems
4	SA TS ISO 19115.3:2018 - Geographic information - Metadata, Part 3: XML schema implementation for fundamental concepts
3	AS/NZS ISO 19101.2:2019 - Geographic information - Reference model, Part 2: Imagery
3	AS/NZS ISO 19103:2018 - Geographic information - Conceptual schema language
3	AS/NZS ISO 19112:2019 - Geographic information - Spatial referencing by geographic identifiers
3	AS/NZS ISO 19150.2:2018 - Geographic information - Ontology, Part 2: Rules for developing ontologies in the Web Ontology Language (OWL)
3	AS/NZS ISO 19150.4:2020 - Geographic information - Ontology, Part 4: Service ontology
3	AS/NZS ISO 19157:2015 - Geographic information - Data quality
3	AS/NZS ISO 19161.1:2020 - Geographic information - Geodetic references, Part 1: International terrestrial reference system (ITRS)
3	AS/NZS ISO 19162:2020 - Geographic information - Well-known text representation of coordinate reference systems
3	AS/NZS ISO 19168.1:2021 - Geographic information - Geospatial API for features, Part 1: Core
3	ISO/TS 19166:2021 - Geographic information - BIM to GIS conceptual mapping (B2GM)
3	SA TS ISO 19157.2:2018 - Geographic information - Data quality, Part 2: XML schema implementation
2	AS/NZS ISO 19109:2018 - Geographic information - Rules for application schema.
2	AS/NZS ISO 19116:2020 - Geographic information - Positioning services
2	AS/NZS ISO 19123.2:2019 - Geographic information - Schema for coverage geometry and functions, Part 2: Coverage implementation schema
2	AS/NZS ISO 19130.1:2020 - Geographic information - Imagery sensor models for geopositioning, Part 1: Fundamentals
2	AS/NZS ISO 19131-2008 - Geographic information - Data product specifications
2	AS/NZS ISO 19137-2008 - Geographic information - Core profile of the spatial schema
2	AS/NZS ISO 19146:2019 - Geographic information - Cross-domain vocabularies
2	AS/NZS ISO 19160.3:2020 - Addressing, Part 3: Address data quality
2	AS/NZS ISO 19160.4:2020 - Addressing, Part 4: International postal address components and template language
2	AS/NZS ISO 19165.1:2019 - Geographic information - Preservation of digital data and metadata, Part 1: Fundamentals
2	SA TS ISO 19163.1:2018 - Geographic information - Content components and encoding rules for imagery and gridded data, Part 1: Content model
2	SA/SNZ TS ISO 19159.3:2019 - Geographic information - Calibration and validation of remote sensing imagery sensors and data, Part 3: SAR/InSAR
1	AS ISO 19155.2:2018 - Geographic information - Place Identifier (PI) architecture, Part 2: Place Identifier (PI) linking
1	AS/NZS ISO 19165.2:2020 - Geographic information - Preservation of digital data and metadata, Part 2: Content specifications for Earth observation data and derived digital products
1	SA TS ISO 19159.2:2018 - Geographic information - Calibration and validation of remote sensing imagery sensors and data, Part 2: Lidar
1	SA/SNZ TR ISO 19167:2021 - Application of ubiquitous public access-to-geographic information to an air quality information service

Appendix C

Additional Standards

	List of additional standards, provided by the responders
1.	IHO S-57 and S-100
2.	TfNSW Digital Engineering (DE) Framework
3.	TfNSW Digital Engineering (DE) Framework
4.	ADAC XML
5.	ICSM Lidar Standard: https://www.icsm.gov.au/sites/default/files/2017-03/LiDAR_Specifications_and_Tender_Template.pdf
6.	SensorML, Various ""standard"" vocabularies based off things like O&M, SOS, QUDT <http://qudt.org/>, PUV <https://github.com/CSIRO-enviro-informatics/PUV-ont>
7.	Emerging netcdf-ld standard <https://www.ogc.org/pressroom/pressreleases/4704>, netCDF-CF (Climate and Forecast) standards
8.	NATSPEC
9.	ISO-OGC
10.	Will develop WA specific standards where required - will take an adopt, adapt or develop approach.
11.	A large number of construction-related standards including BSI, AS/NZS, ISO, IEC, ANSI, etc.
12.	Organisation defined Asset Spatial Data Standard
13.	AS 2885.3, AS 2430.1, ISO 19115-1
14.	We have our own set of standards that we require anyone to submit spatial data around for any design and construct project. This is more a practical set of standards ensuring accuracy and attributes are provided to ensure data can be seamlessly ingested in our spatial systems

	Use of software that uses the standards not listed in the survey
1.	ArcGIS S-57 / ENC extension and in-house domain awareness information system
2.	InEight / 12d / Revitzto etc.
3.	Bentley (open roads, project wise), Autodesk, Solibri, ArcGIS. FME. InEight
4.	1st party applications
5.	Mostly use our Data Broker API to provide a common interface to datasets. That provides links to different distributions, and it is up to the client software to be able to handle the distributions it wants to.
6.	Revit, 12D Model, Navisworks, Revisto, BIM360
7.	Nothing more than what you mentioned
8.	Pageseeder
9.	Wincan, Aveva OSIsoft PI, Leica, Autodesk, ArcGIS enterprise, Innovyze etc
10.	GE Smallworld
11.	ESRI, global mapper, FME Drone Deploy

	List of software, not listed before
1.	ArcMap, GlobalMapper, AutoCAD, 3DR, Revit
2.	Navis
3.	RestAPI, CityGML files, CityJSON files
4.	QGIS
5.	ArcGIS applications including, ArcMap, ArcCatalog, ArcGIS Pro, ArcGIS Online, WMS, WCS
6.	FTP, RestAPI, File Geodatabase, GeoJSON, WFS, WCS, CSW, OGC API, Esri API
7.	Bentley products, Autodesk, 12d, ArcGIS
8.	ESRI web services
9.	RestAPI, ESRI Portal, Bentley, AutoCAD, Pointerra,
10.	Err, not sure, sorry. We do have WFS and ArcMap, so I guess those. And GeoServer, and we're installing GeoNetwork.
11.	AutoCAD, ArcGIS, FTP, IFC
12.	QGIS, ArcGIS, PyQGIS, GeoJSON, metadata, geospatial DataMart from Australian Government databases, GEOSPATIAL DATA SCIENCE
13.	QGIS, Bentley, Cesium
14.	FTP, RestAPI, GeoJSON, GeoTIFF, WFS, WPS, OpenDAP, Thredds, GeoPackage, FlatGeoBuf, Zarr, netCDF, ArcMap, QGIS, Python, JavaScript,

List of software, not listed before	
15.	WFS, WMTS, KART, QGIS, MAP LIBRE
16.	TopoShare, TopoDOT, AutoCAD, Bentley, Esri, Revit, Civil3D, OpenRoads Designer
17.	BIM360, 12D Synergy
18.	Revit, ArcGIS
19.	Dgn-shp-dwg-gdb-wms-wms-csw-wps
20.	FTP, RestAPI, File Geodatabase, WFS, Bentley, AutoCAD, Magnet Office, MapInfo, ArcMap, QGIS, Magnet Field
21.	AutoCAD
22.	PostgreSQL+PostGIS, MQTT, Kafka
23.	Any and all. Will need to cater for all of these types of software and services.
24.	None
25.	Unsure
26.	FTP RestAPI Autodesk Suite Maximo SAP
27.	QGIS, WFS, WMS
28.	ESRI
29.	ArcGIS Enterprise, Site Scan, Revit, Navisworks, Recap, AutoCAD, Cloud Compare
30.	ESRI Products, FME
31.	ArcGIS Online, ArcGIS Pro, FME, tile packages, scene package
32.	QGIS, Mapserver, GeoJSON, WFS
33.	ArcGIS enterprise mainly, and Leica TrueView enterprise
34.	MapInfo
35.	File geodatabase, ArcGIS Pro, KML
36.	AutoCAD, GE Smallworld, QGIS, ArcMap, FME, File geodatabases,
37.	ArcGIS Server, ArcGIS Online, File Geodatabase
38.	Geodatabase, API, ESRI
39.	ArcPro, ESRI Portal, QGIS - base (2) data derived from WFS
40.	ArcGIS platform (Online, SceneViewer), Skyline TerraExplorer, REST API, WFS, Cesium, Unreal Engine
41.	WFS, MapInfo, QGIS
42.	ESRI AutoCAD, Drone Deploy, FME GlobalMapper

Software and technologies for database management	
1.	File GDB
2.	AutoCAD
3.	Postgres
4.	Postgres
5.	Oracle, ArcSDE, Excel .csv files, PowerBI
6.	Not Digital Twins specific geospatial information and data: Oracle, Postgres, File (for big data)
7.	AWS, Pointerra,
8.	ESRI ArcGIS Enterprise
9.	File GDB, Postgres,
10.	AWS, GeoServer, Postgres?
11.	SQLite, Python geopandas, OSMNX, OpenStreetMap, QGIS mapping of shapefiles
12.	Postgres
13.	Any really. Whatever we need to. The usual array of database, file and object formats. SQLite, Postgres, PostGIS, SQL Server, MongoDB, s3, GeoServer, Thredds, file systems, GeoTIFF, COG
14.	POSTGIS, KART, GPKG
15.	Amazon, Azure, FTP
16.	CTERA (Cloud file storage)
17.	Oracle-Postgres-gdb
18.	Oracle, SQLite, Postgres, AWS GeoServer, MS Access
19.	PostgreSQL+PostGIS, MQTT, Kafka
20.	Still investigating, but likely will be cloud services and storage.
21.	None
22.	Unsure

Software and technologies for database management
23. Not defined yet
24. T1
25. ESRI File GDB and published Services
26. MS SQL, file gdb
27. ESRI
28. fileGDB, tile package; scene package
29. SQLite, SQL Server, Postgres/PostGIS
30. EGDB, Leica DB for TrueView, OSIsoft PI for time-series data platform
31. MapInfo
32. File geodatabase, Arc Server/SDE
33. Smallworld Core 430, File geodatabases,
34. Microsoft SQL Server
35. Oracle, AWS
36. AWS s3, GDB
37. ArcGIS Server/Enterprise/Online
38. ESRI Enterprise geodatabase (SQL) FGDB) ESRI Enterprise Rest services
No Response: 4 (10%)

Please provide comments on anything not covered above that you believe will contribute to the knowledge building and development of spatial Digital Twin standardisation practices within Australia.

- Consulting on DT development and maturity assessment.
- Uniclass for asset data
- Maintain a national, authoritative, openly available unique ID for every feature of interest.
- Need to consider if there is sufficient engagement within government, between different levels of government and also between government and private sector for example utilities.
- **ISO/TS 37172:2022 -** Data exchange and sharing for community infrastructures based on geographic information.
- *This document provides a framework for data exchange and sharing based on geographic information for smart community infrastructures, along with specific application scenarios.*
- ISO 37108:2022
- The application or standards to be adopted need to be fit for purpose and independent of state and local authority requirements.
- Open-source software and AS, ISO and IEC
- -Spatially Enabled Digital Twins of the Built and Natural Environment in Australia.
- -Data cleaning of geospatial datasets using machine learning
- -Machine learning technologies and other advanced analytics to process the geospatial data to deliver insights and model future scenarios.
- -Visualizations of geospatial datasets showing the Digital Twin assets
- Open Standards should be adopted, and software applications created and maintained in open source / vendor neutral manner to produce and consume Digital Twin datasets.
- Cesium
- OGC
- ISO, SA, IEC standards
- Geospatial accuracy
- TC 211 standards
- Cadastral boundary referencing protocols.
- Utilising plane (scale 1:1) models and projected (MGA) information together.
- BIM to GIS interoperability guidance, standards, transformation workflows
- Metadata requirements for Survey Information Models
- Accuracy standard for reverse engineered models
- Needs standards and backing from Private and Public sectors. Accurate 3d Cadastre must be developed to make the material in value.
- I guess 80% of emphasis is on urban Digital Twin. It seems vital to pay attention to rural features to support land-use planning goals.
- For Mining and Underground Utilities
- Geolocation
- Real-time info processing is critical for DT, in particular the streaming data.
- Once development and implementation start, I will have a better idea. However, good governance and data management across government will be key to success.
- Sharing, transformation and value to unit to 'break down the silo'.
- Guidance material for key audience groups: executive/strategic, management and technical
- I am dealing primarily with Asset based Digital Twins. Our GIS system is currently in the process of transitioning to a new system which is currently covered by an NDA, and I cannot currently discuss further.
- None, not really interested in whiz bang marketing snazzy twinnies, we need real GIS solutions on the ground in a simple cost-effective manner.
- Many organisations are in the planning stages of creating a Digital Twin. Please create some questions directed specifically for these organisations.
- none

- The value that standard practices provide when sharing data across government agencies and when assets are bought and sold - the "Digital Twin" in a standard form makes it a ready to go" asset that has true value.
- Every software vendor claims their solution provides a Digital Twin. SSSI needs to come out strong and lead the definition and function and debunk the nonsense.
- Standard datum and model format
- GDA 2020?
- Depends on scale and nature of DT. Can it be local?
- There was not an option in the standards set of questions which says you do not know. I am a data creator, and many workers simply recreate a process already developed by others, which we are not aware of whether they have originally designed these to set standards.
- Don't have good standards/processes for incorporating existing 3D (building) models into a broader 3D ecosystem. All the existing file formats seem to have limitations in terms of transferring model complexity, location and textures. For example - trying to incorporate a Revit BIM into a spatial Digital Twin format.
- The first thing you may want to work on is providing a standard definition of what you are referring to as a spatial Digital Twin. Tricky, but providing some direction will help everyone. Digital Twins can be so many different things to so many different organisations with spatial often providing on a piece of that puzzle, NASA who originally coined the Digital Twin concept for use with the Apollo missions - we are looking to use the following (Digital Twins can be defined as a realistic, functioning digital representations of a physical asset or system which can be visually interacted with and used to enhance the value, resilience, and productivity of the real asset and the wider system in which it operates.) I think the challenge for Digital Twins in the spatial arena is what systems are there and data formats that scale to the size needed to make seamless Digital Twins be able to be visualised in the 3D space. We need to be looking at gaming engines like Unreal Engine and formats like I3S. It would be great if someone like Landgate could lead the way in testing the building of some 3d environments that show organisations what is possible in this space as I think it is a big step from our traditional spatial 2d and 3d environments. Also a Digital Twin can be a place where sensor and time data also interact, what might the standards and systems be for these to be incorporated into a spatial Digital Twin? I would be super keen to be involved in helping to set up a workshop on this to help better define this journey and explore options at a state level, feel free to get in contact if you need any help or input!

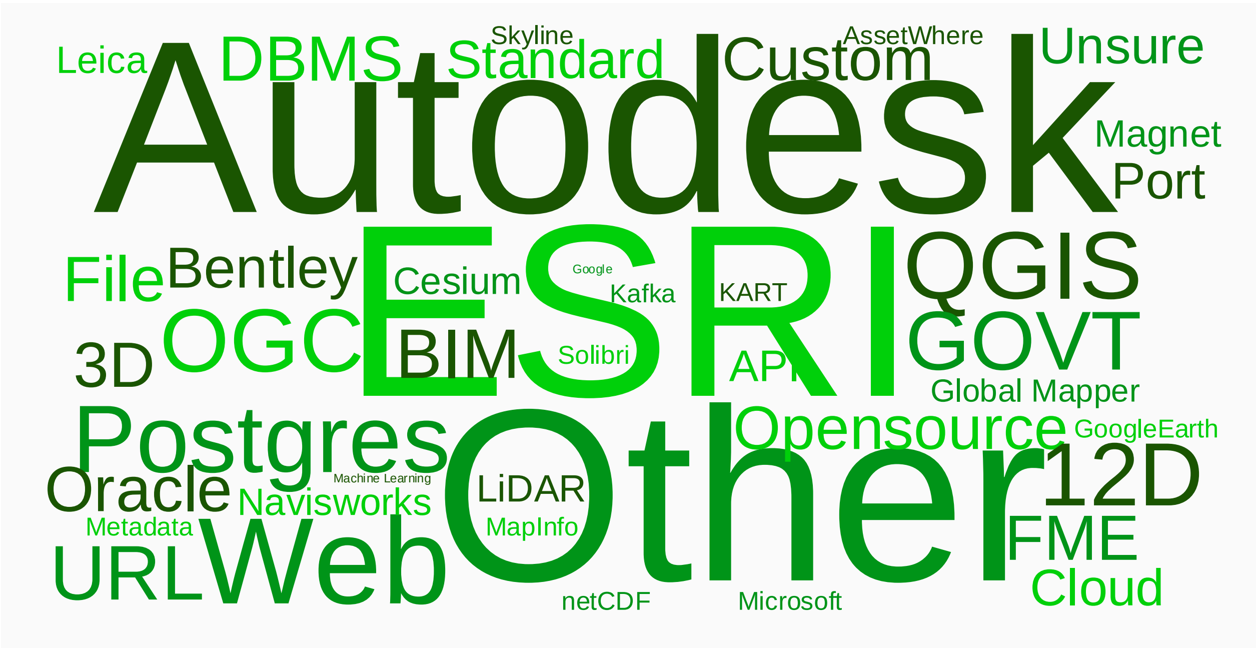

Figure 9: Aggregated list of software and tools mentioned.