Developing a new 3D dataset with Ordnance Survey

Monday 15th May 2017

UCL VEIV Away Day, Bath

Kelvin Wong

EngD Virtual Environments, Imaging & Visualisation

Context

Producers don’t make 3D data as they don’t know what users want…

Ordnance Survey

Data producer

Data user

Users don’t use 3D data as it’s not available…

Three dimensional applications in Geographical Information Systems

Edited by

Jonathan Raper

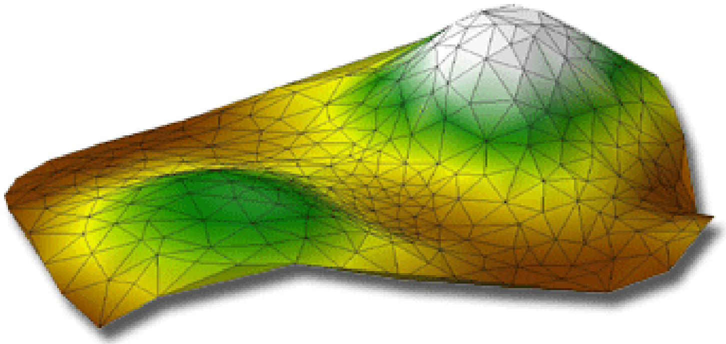
Department of Geography
Birkbeck College
University of London

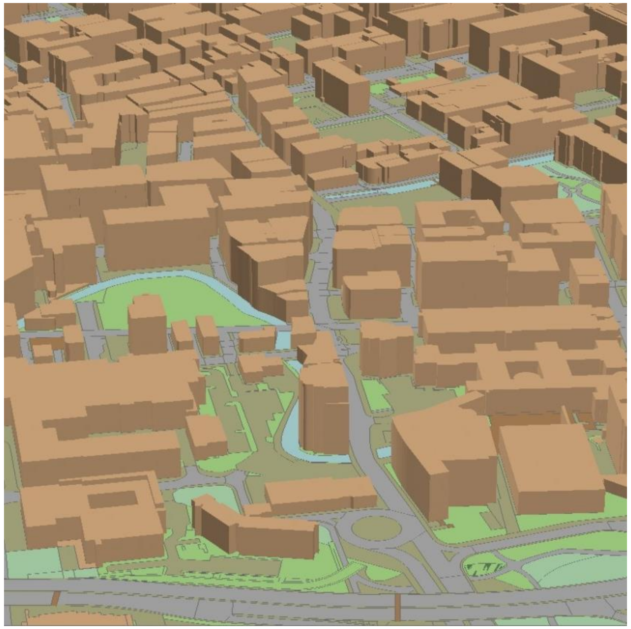
Taylor & Francis
London New York Philadelphia
1989

“3D is a solution looking for a problem”

2D, 3D and 2.5D?

- What is 3D?
- What is 2D?
- What is 2.5D?





My definition of 3D

- Multiple z values for any point
- Volumetric
- Fully describe geometry and attributes

Overview of research

What are the **applications of GIS** which will benefit most from the use of three-dimensional geographic information?

Of these applications, which particularly **justify the use of, and investment in, 3D**?

Applications of 3D

User requirements gathering

Developing a 3D specification

Review of existing 3D datasets

Communicating data quality and fitness-for-purpose of 3D

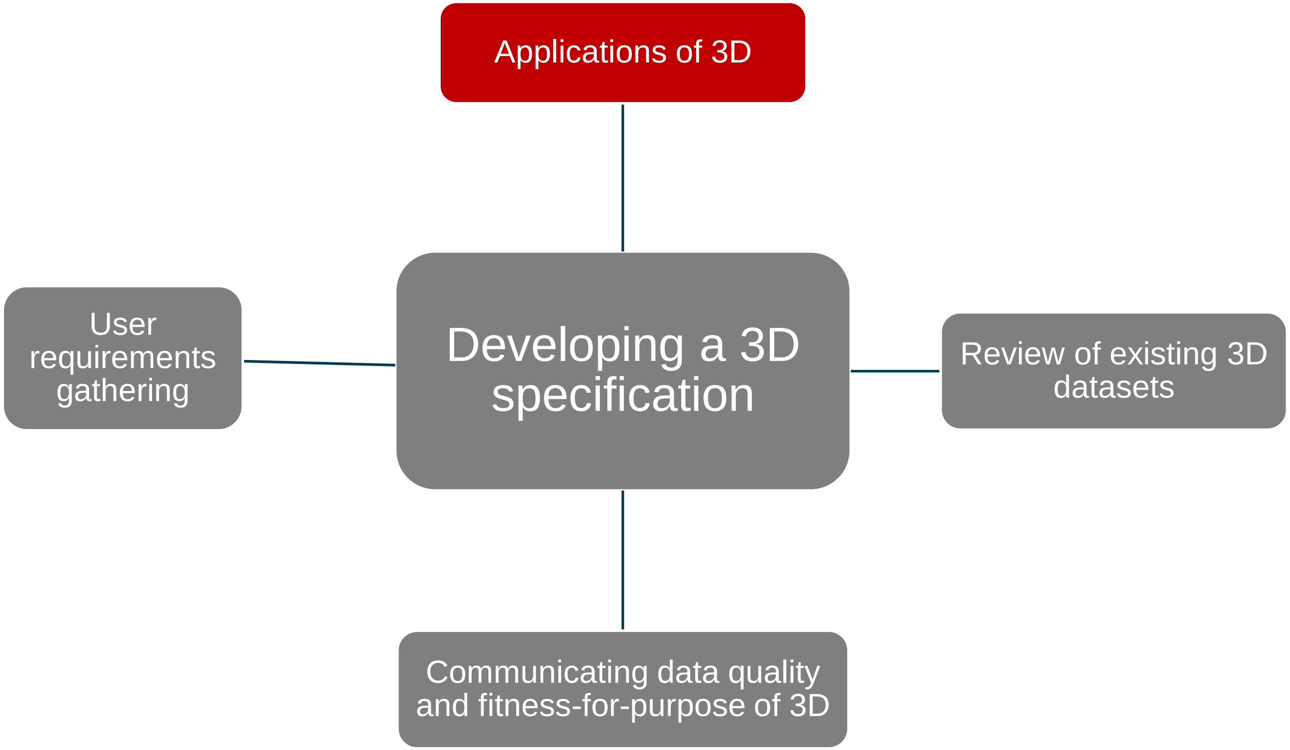
What are the **geometric and semantic requirements** for 3D GI of these particular applications?

How can we **understand and communicate** how well 3D GI meets these geometric and semantic requirements?

3D geographic information vs. 3D visualisation

Applications of 3D

What are the existing and potential applications of 3D geographic information?



Reviewing existing and potential 3D applications

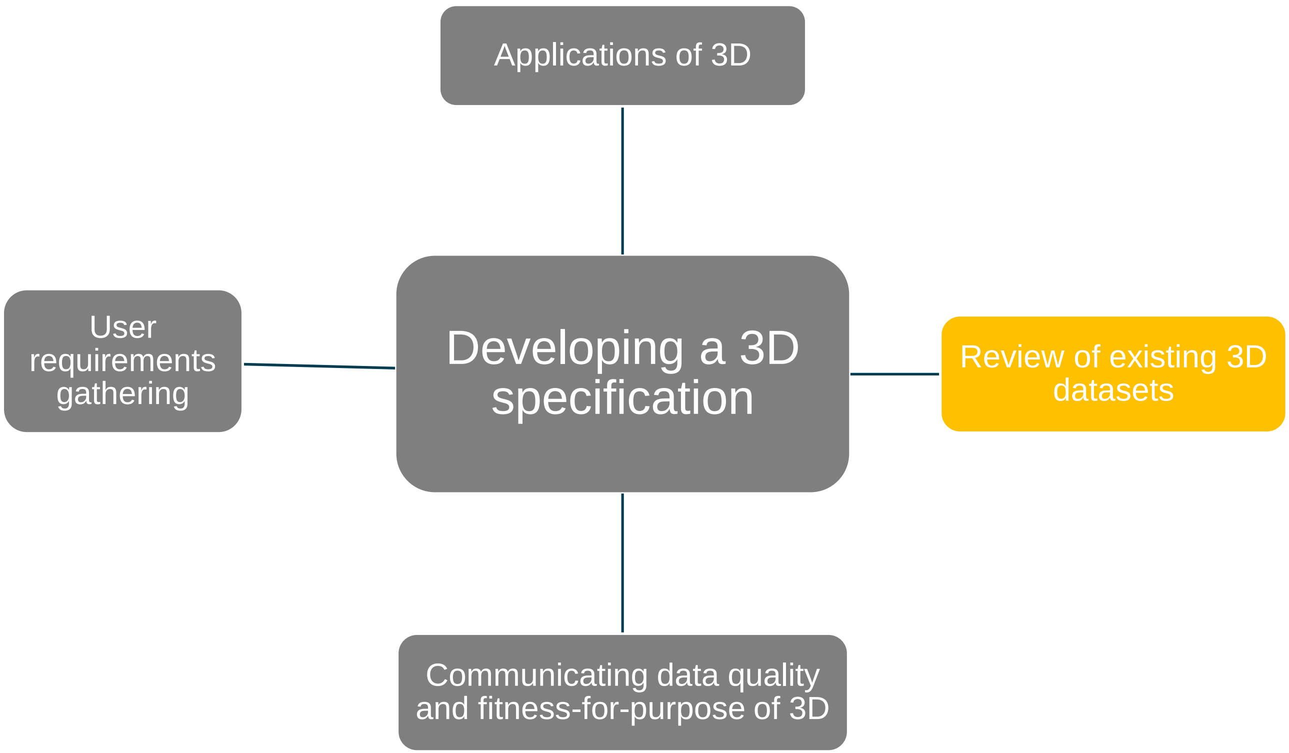
- Archaeology
- Arts & entertainment
- Cadastre & land management
- Facilities Management
- Forestry
- Health and emergency services
- History and heritage
- Infrastructure
- Natural disasters and severe weather
- Navigation and routing
- Noise and air quality
- Solar
- Subsurface applications
- Transport & aviation
- Urban planning
- Virtual reality & gaming

Summary of applications and datasets review

- Applications **which utilise 3D analysis** beyond visualisation (such as cadastre & land management, navigation and solar) **benefit most** from the use of 3D GI.
- Applications which **focus solely on the visualisation** aspects of 3D do not currently maximise the potential of 3D GI.
- Whether there are **further unidentified potential** within the applications for 3D is yet to be fully recognised.

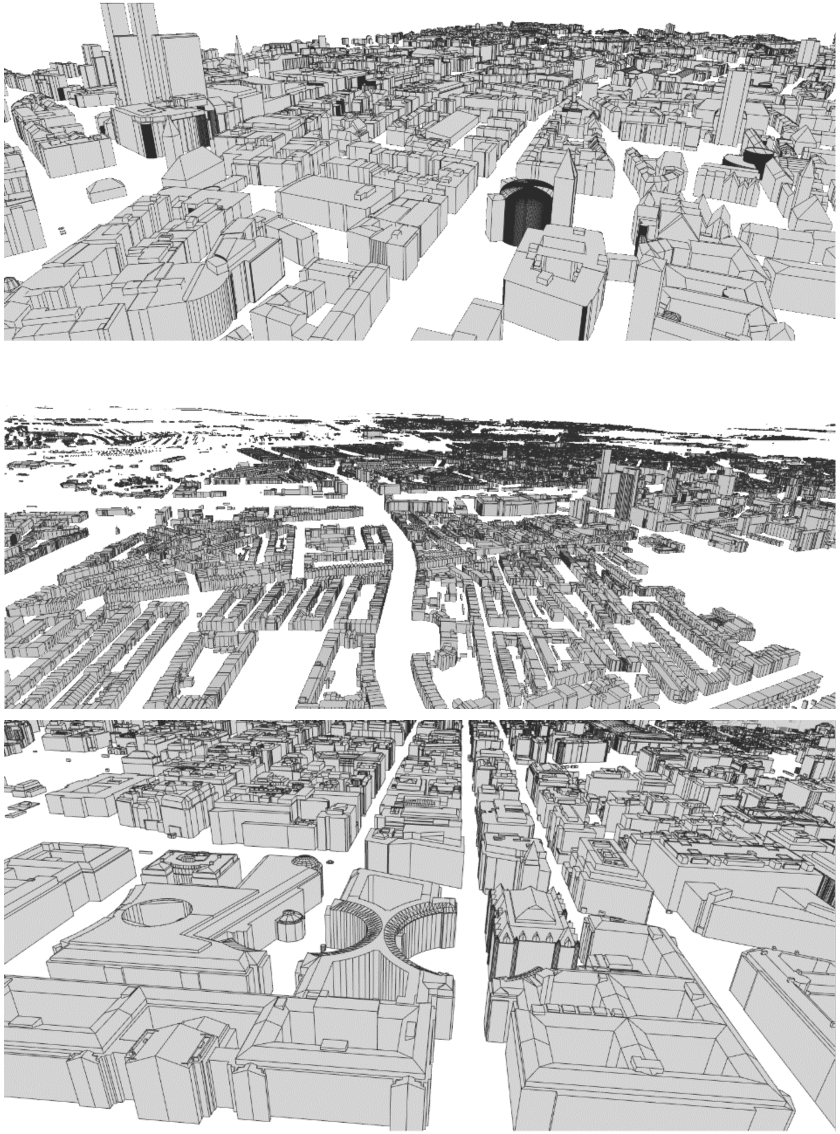
Review of existing 3D datasets

What are the different variations within existing 3D datasets? What can we learn?



Data

1. Berlin, Germany
2. Adelaide, Australia
3. Toronto, Canada
4. Washington D. C., USA
5. Frankfurt, Germany [city centre only]
6. Rotterdam, The Netherland.
7. New York State #1
8. New York State #2
9. Montreal, Canada
10. Sheffield, UK

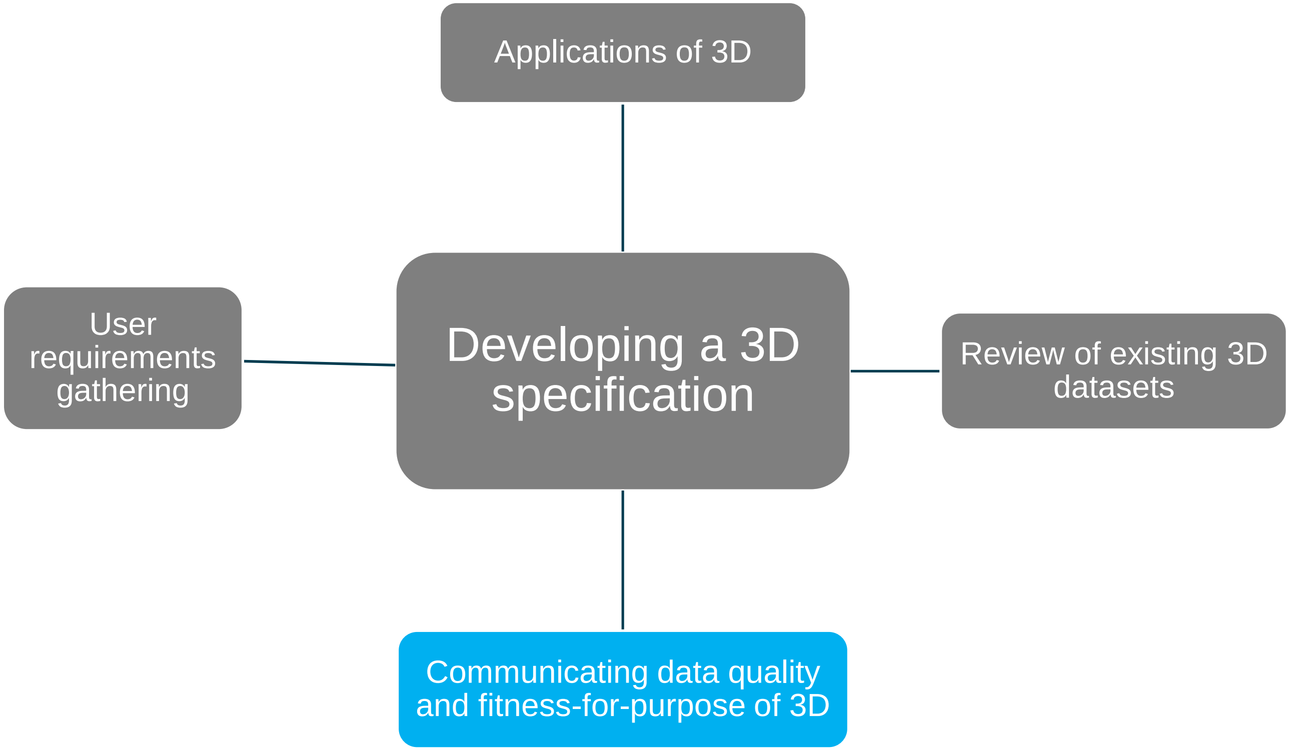


From top to bottom: Frankfurt, Rotterdam & Washington D.C.

City name	Adelaide	Frankfurt (city centre)	Washington D.C.	Rotterdam	Toronto	Berlin
Year created	2015	2009	2015	2011	2015	2009
Formats available	Autodesk 3DS	CityGML	Spreadsheet, Google Earth KMZ/KML, ESRI 3D Shapefile, API	CityGML	Shapefile, ESRI File Geodatabase, MicroStation files, AutoCAD	ESRI PolygonZ, Google Earth KML/KMZ, CityGML, Autodesk DXF, Autodesk 3DS
Total disk size (format)	158MB without textures; 2.3GB with textures (3DS)	123 MB (CityGML)	559 MB (ESRI Shapefile)	2.58 GB without textures; 5.79 GB with textures (CityGML)	289 MB (ESRI File Geodatabase)	15.2 GB (CityGML)
Geographic area covered	15.18 km²	3.3 km²	177 km²	330 km²	709 km²	890 km²
Method of reconstruction	Imported from Autodesk 3ds max models. Additional buildings are included from development application submissions (Adelaide City Council, 2009b)	Reconstruction with parametric shapes from LiDAR based on cell decomposition (Haala and Kada, 2010)	CyberCity 3D using Visual Star, CC-Modeller and CCEdit (CAD system for 3D city models) (Gruen and Wang, 1999)	Automatically using the BAC (Basic Addresses and Buildings) and the height Rotterdam file that was created with the FliMAP system (Maas and Vosselman, 1999)	CADD software using building permits and air photography (Toronto City Planning Division, personal communication, 9th September 2015)	Reconstruction with parametric shapes from LiDAR based on cell decomposition (Kada, 2009; Kada and McKinley, 2009)

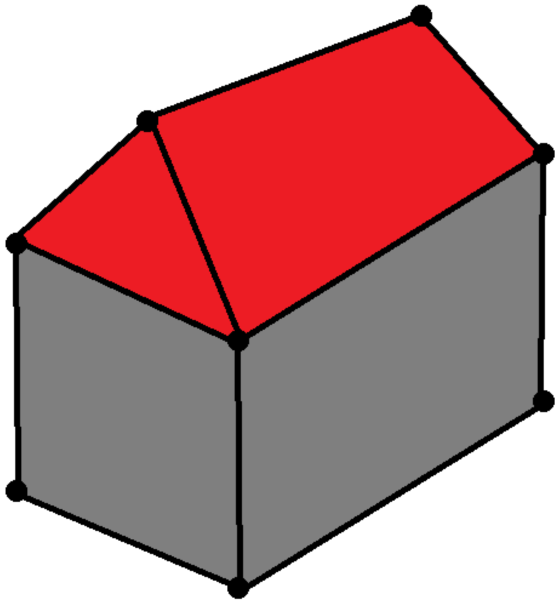
Communicating data quality and fitness-for-purpose of 3D

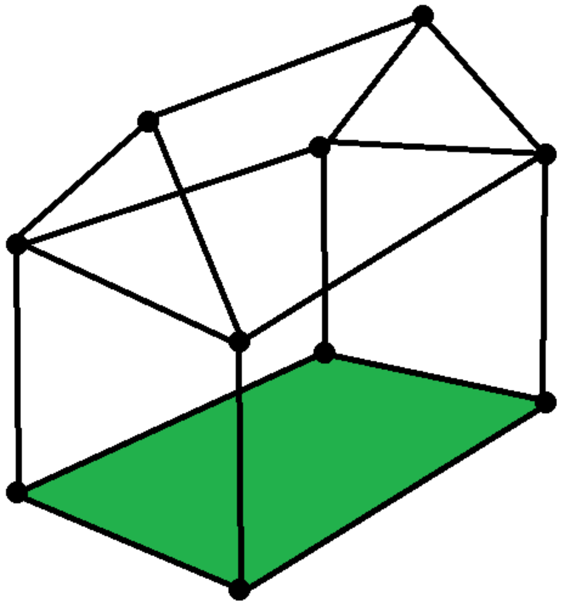
How can we communicate to users what a 3D data is like?



Metrics

1. Mean number of vertices;
2. Mean number of edges;
3. Mean number of face;
4. Minimum 2D footprint area and;
5. Minimum feature length.
6. Euler characteristic ($V - E + F$)





Results – Simple geometry metrics (1)

City name	Adelaide	Frankfurt (city centre)	Washington D.C.	Rotterdam	Toronto	Berlin
Number of buildings	4,569	10,588	51,886	181,686	397,602	537,208
Total no. of vertices	932,142	245,455	4,408,678	4,894,975	10,917,879	10,553,991
Total no. of edges	2,445,284	365,862	7,259,299	7,761,599	21,787,065	15,811,582
Total no. of faces	1,505,950	143,284	2,762,051	2,548,795	3,546,117	6,411,443
Mean no. of vertices per building (1.d.p.)	204.1	23.2	85.0	26.9	27.5	19.6
Mean no. of edges per building (1.d.p.)	535.2	34.6	139.9	42.7	54.8	29.4
Mean no. of faces per building (1.d.p.)	329.6	13.5	53.2	14.0	8.9	11.9

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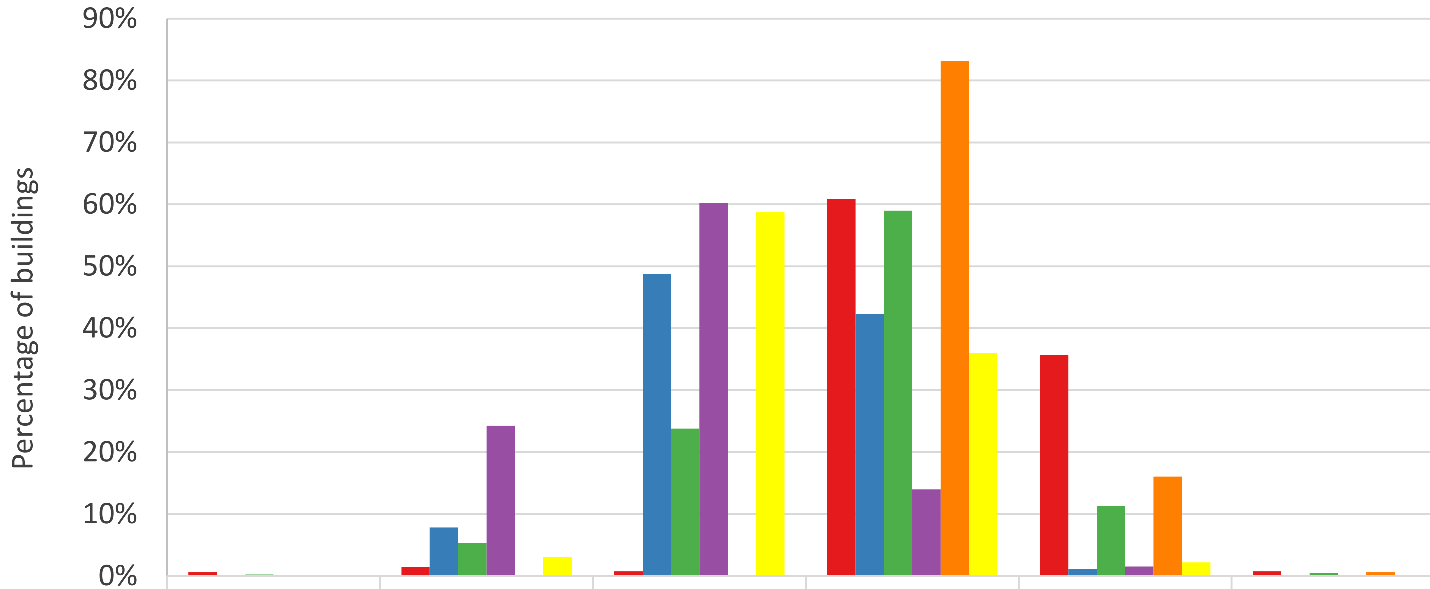
Results – Minimum footprint area



	0 to 1 sqm	1 to 10 sqm	10 to 100 sqm	100 to 1,000 sqm	1,000 to 10,000 sqm	10,000+ sqm
Adelaide	0.59%	1.44%	0.74%	60.82%	35.65%	0.74%
Frankfurt	0.03%	7.84%	48.74%	42.26%	1.11%	0.02%
Washington	0.21%	5.31%	23.79%	58.98%	11.28%	0.42%
Rotterdam	0.02%	24.24%	60.20%	13.96%	1.51%	0.07%
Toronto	0.00%	0.02%	0.16%	83.16%	16.05%	0.60%
Berlin	0.00%	3.09%	58.70%	35.96%	2.19%	0.05%

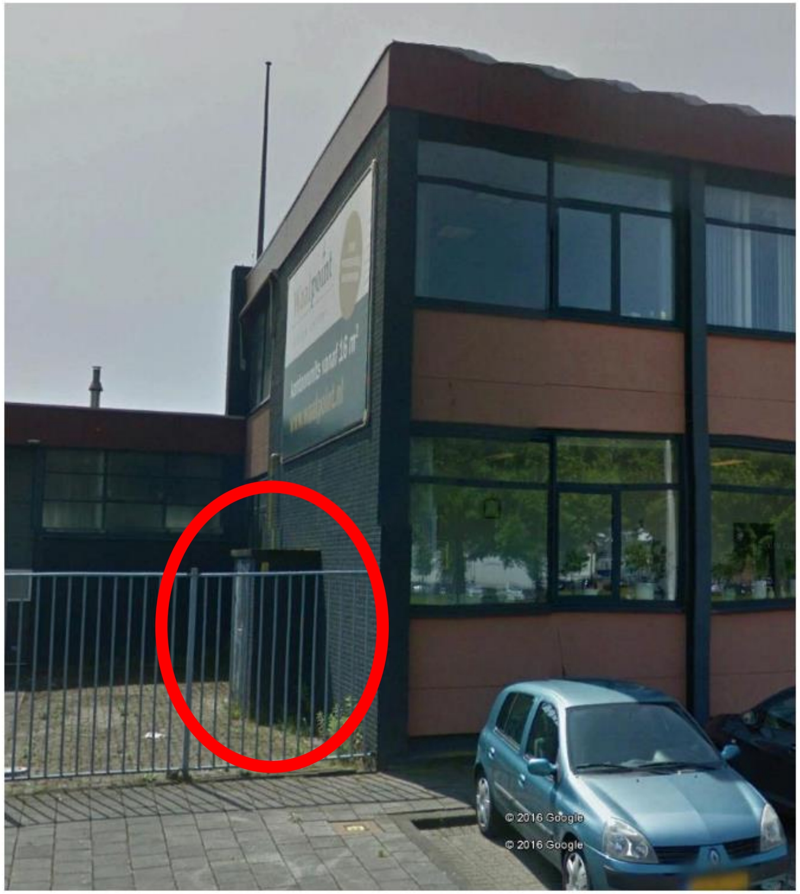
Frequency distribution of 2D footprint area in all six datasets by the extent

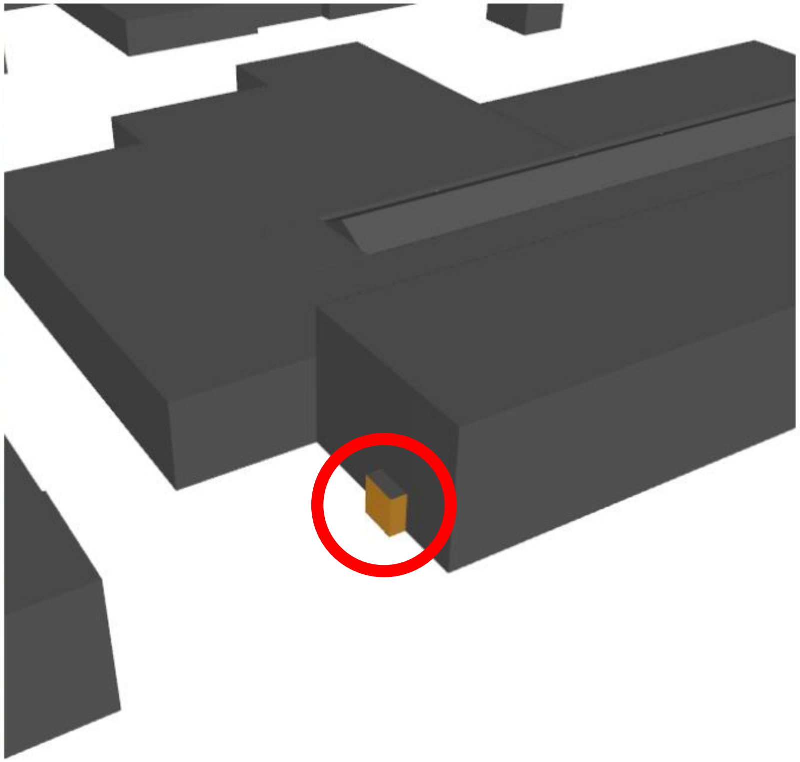
Minimum footprint area – Dispersion

	Q1	Q2	Q3	5th Percentile	1st Percentile	Standard Dev	Mean	Coefficient of variation
Frankfurt	27.24	78.11	163.41	**7.81**	5.46	274.70	135.31	2.03
Rotterdam	10.82	50.94	71.47	**5.46**	3.43	633.36	114.77	5.52
Toronto	465.97	595.42	767.78	**256.41**	151.19	1894.89	936.06	2.02
Berlin	29.57	73.97	153.91	**13.09**	5.80	582.61	178.70	3.26
Adelaide	453.37	745.91	1324.85	**216.22**	2.15	2000.17	1269.12	1.58
Washington	81.05	180.54	429.67	**8.86**	2.61	1612.49	536.16	3.01

Dispersion of minimum footprint area

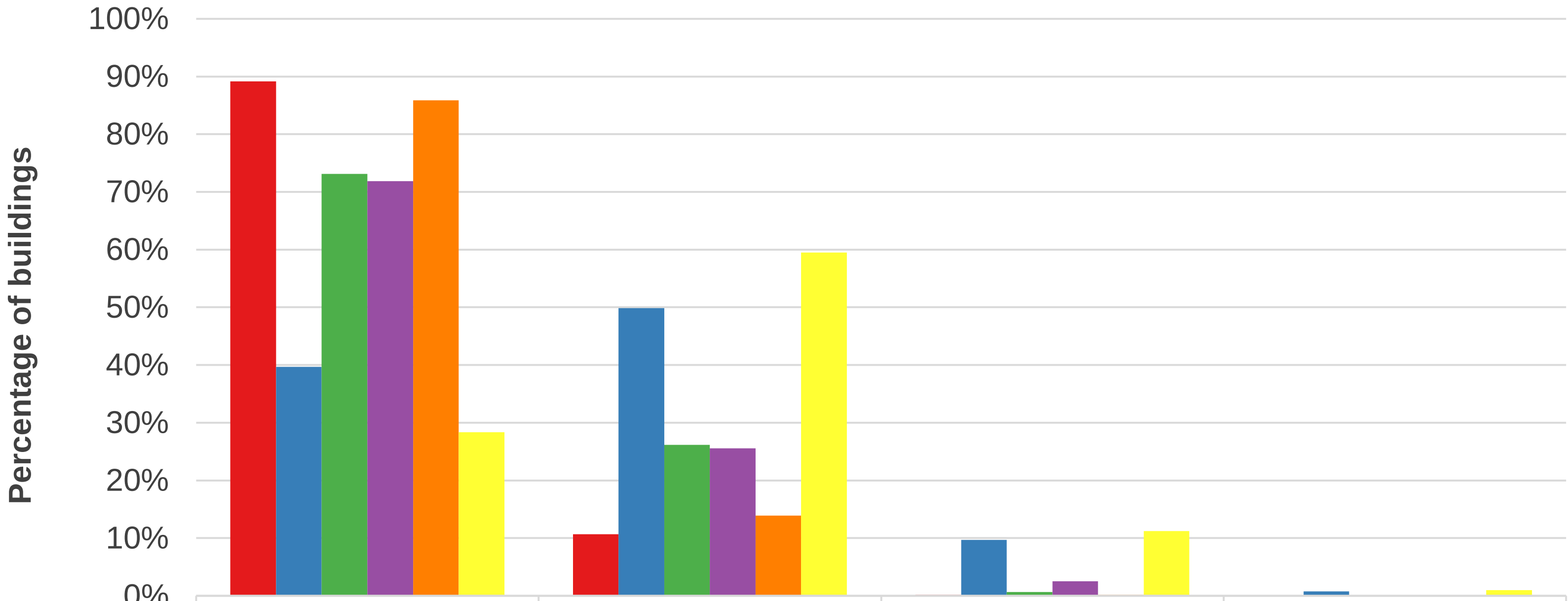
Discussion – Minimum footprint





Shared features such as small sheds found in Rotterdam with its own unique parent identifier

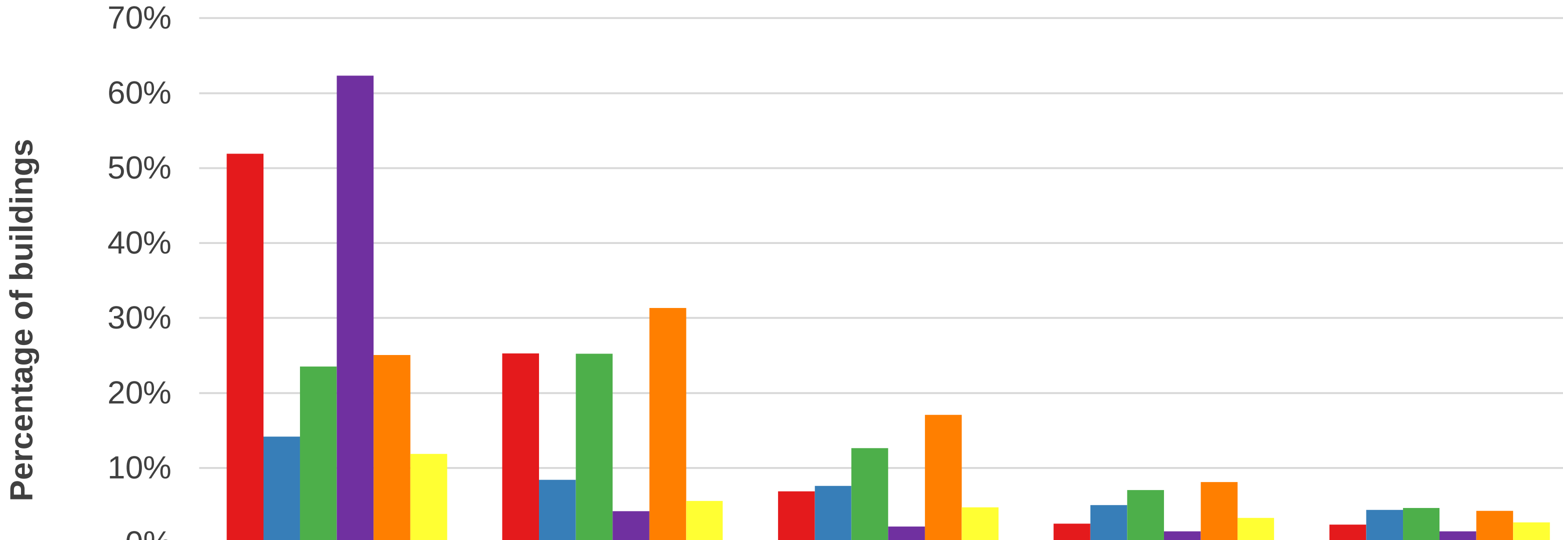
Results – Minimum feature length (1)



	0 to 1m	1 to 5m	5 to 10m	10+ m
Adelaide	89.1%	10.7%	0.2%	0.0%
Frankfurt	39.7%	49.9%	9.7%	0.8%
Washington	73.1%	26.1%	0.7%	0.0%
Rotterdam	71.9%	25.6%	2.5%	0.0%
Toronto	85.9%	13.9%	0.2%	0.0%
Berlin	28.3%	59.5%	11.2%	1.0%

Frequency distribution of minimum feature length by percentage of buildings

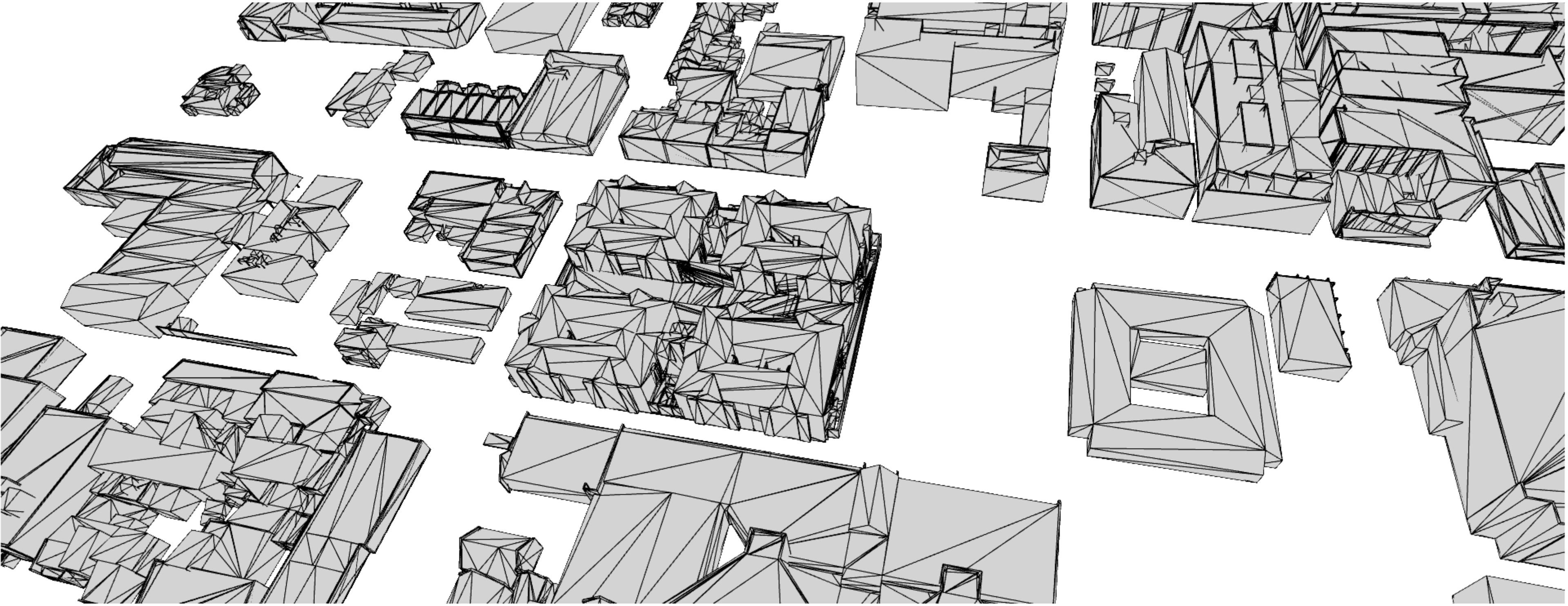
Results – Minimum feature length (2)



	0 to 0.2m	0.2 to 0.4m	0.4 to 0.6m	0.6 to 0.8m	0.8 to 1m
Adelaide	51.9%	25.3%	6.9%	2.6%	2.5%
Frankfurt	14.2%	8.4%	7.6%	5.1%	4.4%
Washington	23.5%	25.2%	12.6%	7.1%	4.7%
Rotterdam	62.4%	4.2%	2.2%	1.5%	1.6%
Toronto	25.1%	31.3%	17.1%	8.1%	4.3%
Berlin	11.9%	5.6%	4.7%	3.4%	2.7%

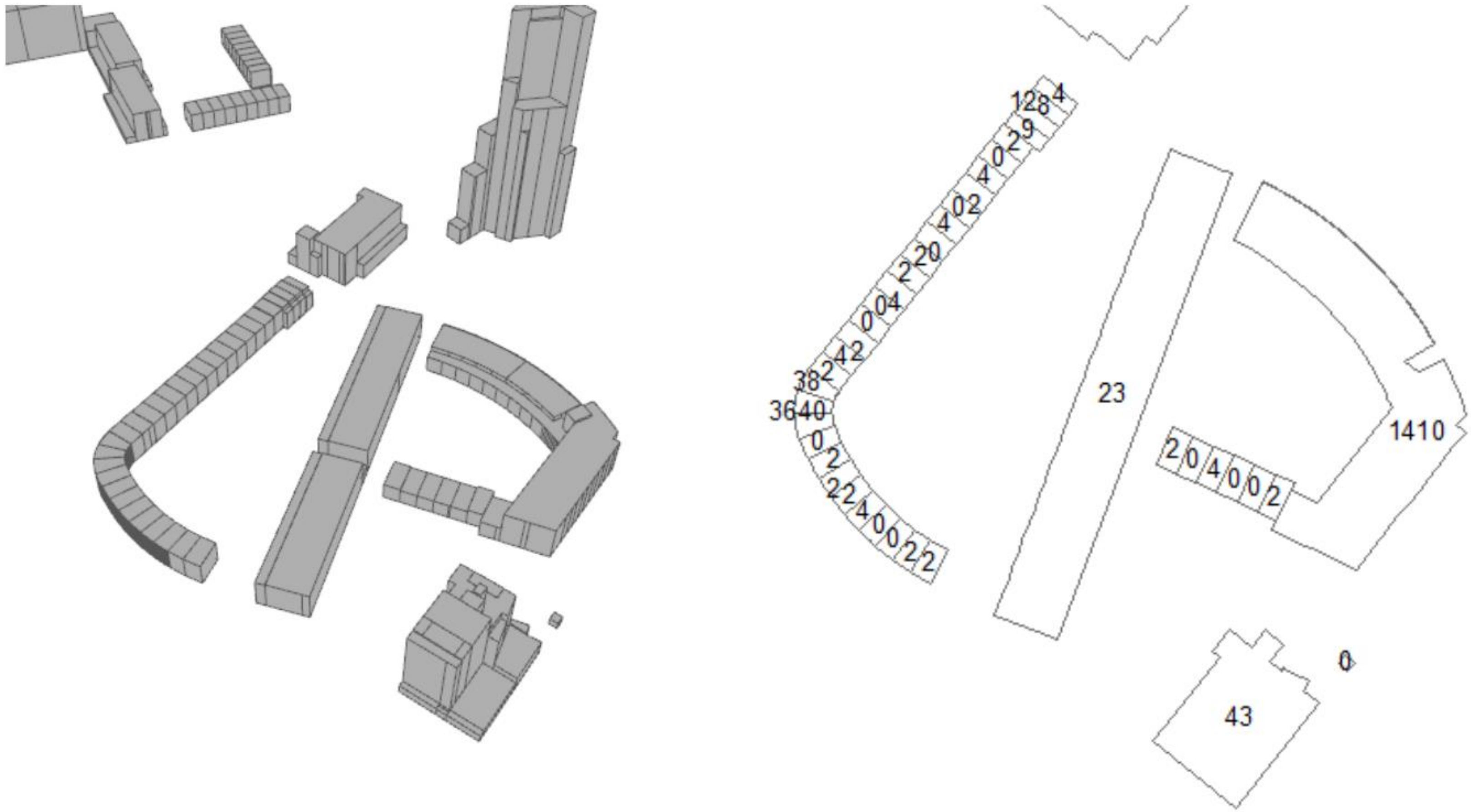
Frequency distribution of minimum feature length under 1m by percentage of buildings

Discussion – Minimum feature length



An example of short edges in Adelaide dataset

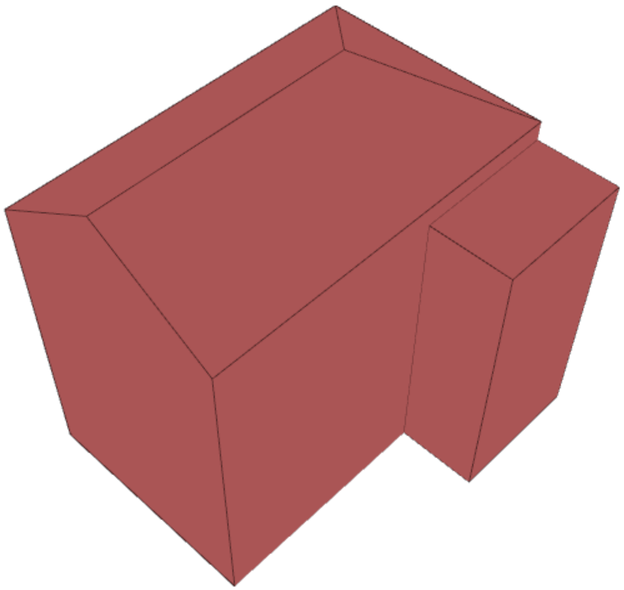
Discussion – Minimum feature length

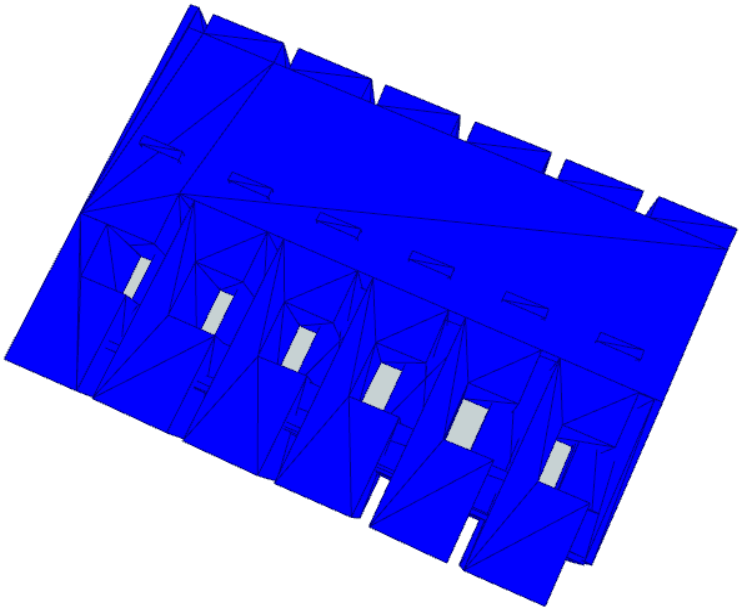


Curved surfaces represented by multiple short straight segments in Rotterdam

Euler characteristic

$$E = v - e + f$$





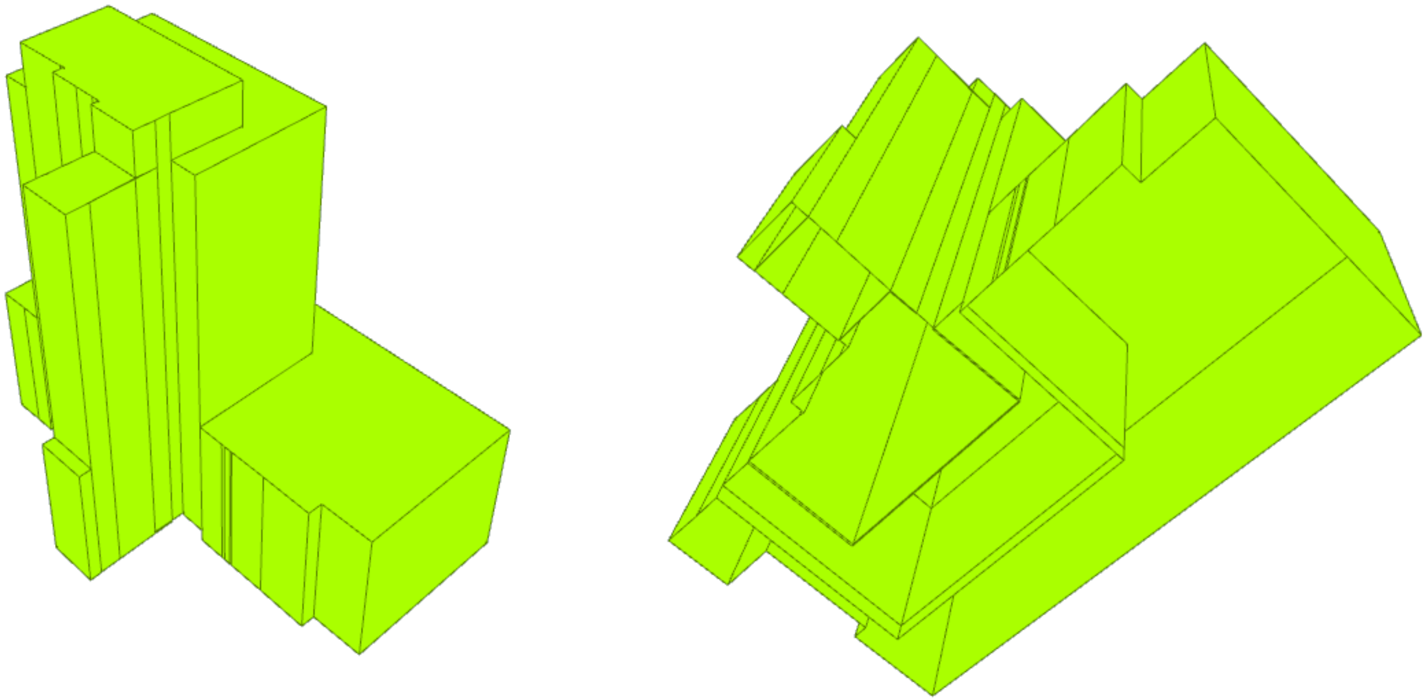
Simple (left) vs. non-simple polyhedral (right)

Euler characteristic

	BER	ADE	TOR	WAS	FRA	ROT	NY1	NY2	MON	SHE
E	%	%	%	%	%	%	%	%	%	%
< -4	22.65	28.01	98.46	17.02	0.00	12.84	0.00	0.75	1.43	0.00
-4	0.15	2.04	0.00	2.91	0.02	3.26	0.00	0.57	0.31	0.06
-3	0.15	2.36	0.01	3.90	0.04	3.87	0.00	0.03	0.61	0.00
-2	0.42	2.52	0.00	5.37	0.09	5.74	0.02	5.22	0.73	0.25
-1	0.54	2.41	0.00	7.43	0.26	10.22	0.00	0.05	1.03	0.63
0	1.69	2.52	0.00	9.07	1.11	22.71	0.15	20.62	2.26	1.01
1	0.76	2.67	0.00	28.95	2.45	26.13	0.00	0.02	3.25	31.57
2	90.22	3.66	1.40	10.83	89.17	13.87	99.83	71.43	86.94	8.99
3	0.15	2.87	0.00	4.44	0.55	1.19	0.00	0.01	0.12	3.71
4	3.48	3.52	0.00	2.05	3.87	0.12	0.00	0.59	2.15	1.95
5	0.05	3.61	0.02	1.47	0.22	0.03	0.00	0.00	0.04	2.01
6	0.96	3.94	0.00	1.14	1.29	0.01	0.00	0.12	0.61	4.84
7	0.02	3.52	0.01	0.92	0.06	0.01	0.00	0.00	0.02	2.39
8	0.35	3.11	0.00	0.56	0.40	0.00	0.00	0.16	0.28	3.08
9	0.04	3.04	0.01	0.84	0.07	0.00	0.00	0.03	0.00	6.10
> 10	0.79	30.20	0.08	3.10	0.42	0.00	0.00	0.39	0.22	33.40

Distribution of Euler characteristic

Euler characteristic



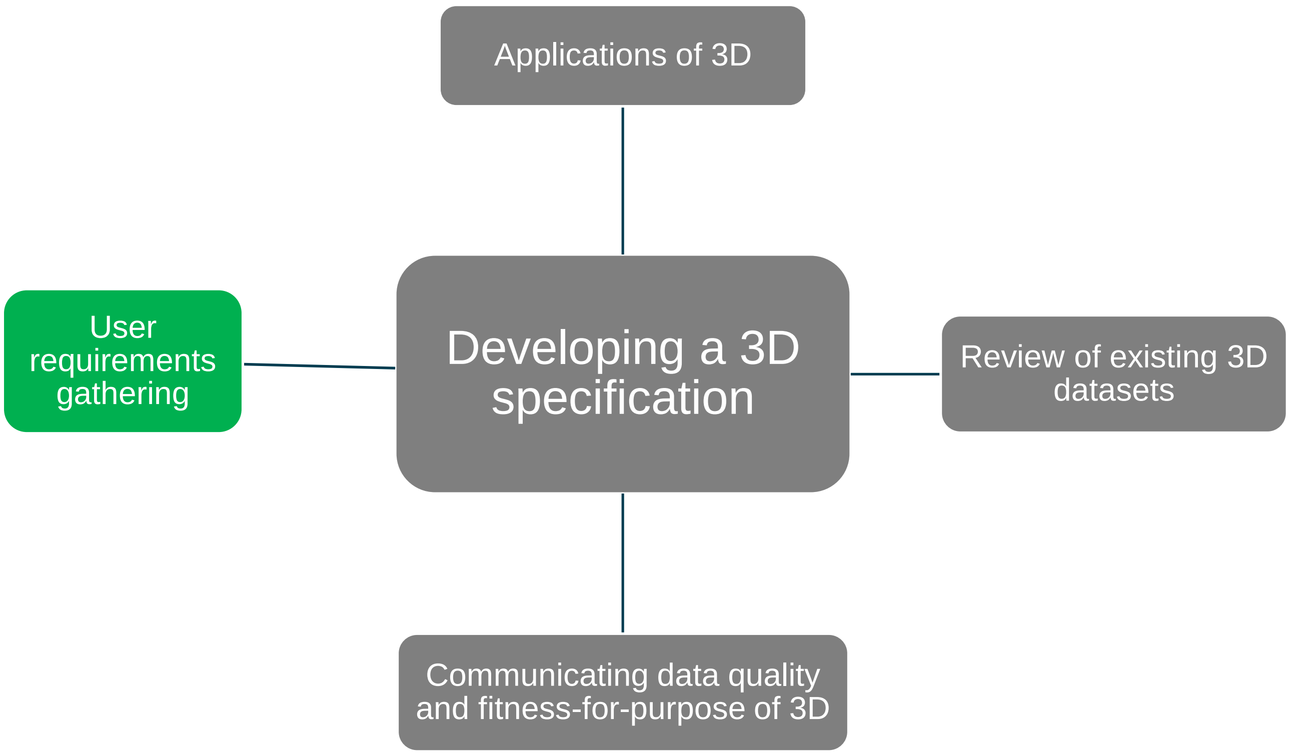
Sheffield – Example of walls extending down into the building

Communicating data quality and fitness-for-purpose of 3D - Summary

- Simple geometry metrics can provide better contextual information for potential users carrying out **fitness-for-purpose evaluations**.
- Explorations into existing 3D city models shows in practice that there is a need for **clearer and less ambiguous 3D specifications** and detailed clarification in exception cases.
- There is a need to consider **the impact of the choice of modelling tools** on visual satisfaction and the performance of a model.
- Further work on **other geometry-based metrics** is required (e.g. volume, ratio between roof and ground vertices, topology/Euler characteristic)

User requirements gathering

What do users want or need from 3D geographic information?



Online questionnaire #1

- Initial aim of 100+ responses
- Uptake and full completion of questionnaire has been disappointing
  - 68 complete responses: 35 stopped at open-ended questions
- Reasons for non-response could be due to presence of open-ended questions. Lack of incentive, beyond altruism

Use of Geographic Information Survey

Thank you for your interest in taking part in this research on your interactions with GIS.

The aim of the survey is to understand better the uses of and requirements for geographic information.

By completing this survey, you are contributing to my Engineering Doctorate research carried out in collaboration with Ordnance Survey. The research will be used to inform the development of future geographic information datasets at Ordnance Survey with the aim to produce better and more useful products for the user.

Summarised results will also be shared with participants of this survey as soon as possible after the end of the survey period and should provide you with an insight into the use of geographic information in many different sectors.

This short survey should only take **12-15 minutes** to complete. The main part of the survey comprises of a total of **11 questions:** 7 multiple choice questions and 4 open-ended questions. A short section at the end will collect contact details and background information.

Please be open, honest and as detailed as you can in your responses – all the data collected is kept confidential and results published will be anonymous. **Confidentiality and anonymity will be maintained and it will not be possible to identify you from any publications.** Any data held will be encrypted and stored only at UCL. Once the study is complete, the data will be destroyed.

Please ask me if there is anything that is not clear or if you would like more information on.

Thank you in advance for your time,

Kelvin Wong
EngD Virtual Environments, Imaging and Visualisation Researcher, University College London

Please click "Start" to begin.

****

Participation & withdrawal: If you agree to take part you will be asked whether you are happy to be contacted about participation in future studies. Your participation in this study will not be affected should you choose not be re-contacted.It is up to you to decide whether to take part or not; choosing not to take part will not disadvantage you in any way. If you do decide to take part you are still free to withdraw at any time and without giving a reason. You may withdraw your data from the project at any time up until it is transcribed for use in the final report (September 2017).

Data Protection Act 1998: The personal information that you give for this survey will only be used for the purposes of the survey and will not be transferred to an organisation outside of UCL. The data will be transferred to the Department conducting the survey who will retain it in compliance with the UCL Records Retention Schedule. The data will also be stored by UCL Information Services for six months and will then be removed from the Opinio system.

Online questionnaire #1

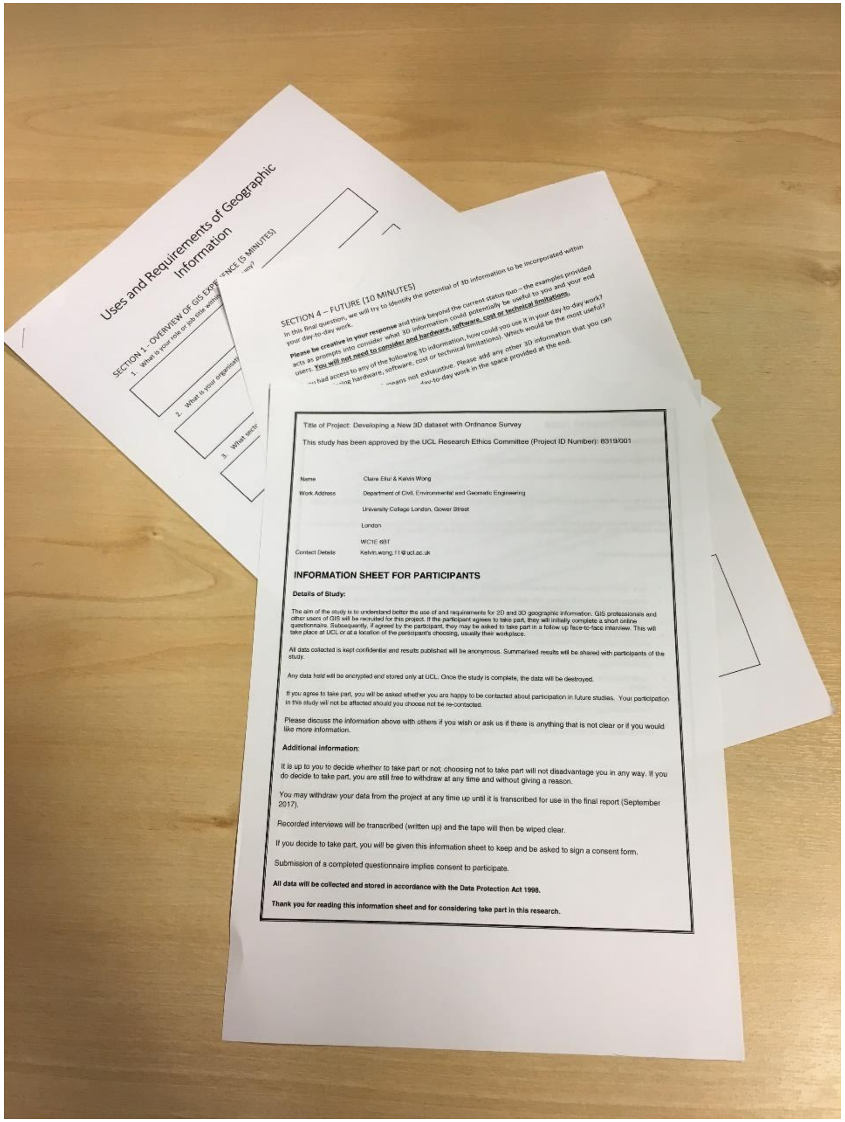
- **23% actively use 3D**. Of the 57% who don't use 3D, 92% have expressed interested in using 3D in the future
- **54%** have at least a **basic understanding of 3D**.
- **69%** consider their work to have **a 3D component** (contrasting to only 23% actively using 3D)
- Barriers to 3D include:
  - 1) **Role** currently does not include 3D (29%) and;
  - 2) **Did not know** it existed (35%).

Participants were asked to elaborate on further in free texts. Some of the comments include:

- *It often **exceeds level of detail required** i.e. we get an answer in 2D that is accurate enough. Additional cost is not worth it.*
- *Some of **my colleagues do this** for the team.*
- *Our modelling software provides enough 3D information.*
- ***3D software is still slow** and requires a lot of pre- processing of the data. Also, often not required for the type of business questions that are being asked.*
- *Height of buildings for modelling would be useful but required at national scale; **costs are an issue**.*
- *A lot of the use cases we have **would not benefit from the additional overhead** of dealing with 3D.*

In-depth interviews

- Semi-structured interviews with identical questions to the questionnaire were conducted (13 people, 7 unique applications)
- On average 1 hour in length.
- Transcribed, coded and analysed using thematic analysis framework



Theme 1 – Current state of 3D GI

- The participants were **either actively involved** with existing uses of 3D within their organisations **or were aware of** work done by colleagues involving 3D.
- There is an understanding of which part of their work contained inherently **3D components but are represented in 2D**.
- In addition, some data which are **captured in 3D**, are presented only in 2D.
- There was, however, a **lack of clear developed examples** of the use of 3D GI.

Theme 2 – Barriers to and benefits of 3D GI Adoption (1)

- Part of the design of the interview was identify areas where inadequacies from 2D representation could be potentially solved with the use of 3D information. The inadequacies found, however, focused more on **inherent 2D data quality issues**.
- These 2D data quality issues **are not readily or easily solved by the use of 3D**.

Theme 2 – Barriers to and benefits of 3D GI Adoption (2)

- The participants also identified other barriers to the adoption of 3D beyond the data itself. These may be **organisational or business-related barriers** which are difficult to overcome by individuals.
- The participants, however, were able to **identify a number of benefits** of implementing 3D within their organisation and day-to-day work. The responses, however, were **relatively vague and lacked concrete examples** of benefits.

Theme 3 – Potential uses of and user requirements for 3D

- The participants **were positive about 3D** and had many ideas of potential uses of 3D within their fields.
- Specifically, the interest is in not only **building-centric information, but also surrounding infrastructure e.g. roads and utilities**
- **A distinction** must be made whether the interest is due to the usefulness of any additional information 3D provides, or that the information would be useful as it is currently unavailable.

Final stage: Online questionnaire #2
Usefulness of 3D information

Type: 4-question online questionnaire
Survey period: Monday 20th February to Monday 1st May
202 responses

Usefulness of 3D information

Thank you for your interest in taking part in this PhD research in collaboration with Ordnance Survey. The aim of the survey is to understand better the usefulness of 3D information.

This survey has 4 short questions and will take around 1 minute to complete.

Thank you in advance for your time,

Kelvin Wong
EngD Virtual Environments, Imaging and Visualisation Researcher, University College London

UCL Ordnance Survey

All responses will be anonymous - including organisation name and any comments you may include. **Confidentiality and anonymity will be maintained and it will not be possible to identify you from any publications.** Any data held will be encrypted and stored only at UCL. Only results aggregated by sector will be published. You can optionally leave your email address for a follow-up with the results upon the completion of the study.

Icons credit:
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Windows & doors geometry; Texture and/or photo; Interior geometry; Ownership and cadastral information; Address with 3D location; Bridges, flyovers and underpasses; 3D road geometry and; Trees & other biomass geometry icons by Freepik
Roof geometry icon by Scott de Jonge
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Maximum roof height; Base of roof height and; Roof shape type icons based on icon by Gregor Cresnar
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Questions 1 & 2

1. What is your organisation's name?

2. What sector would you describe yourself to be in?

- [ ] Academia
- [ ] Acoustic engineering
- [ ] Air quality engineering
- [ ] Archaeology
- [ ] Arts and entertainment
- [ ] Cadastre & land management
- [ ] Emergency services
- [ ] Environmental services
- [ ] Facilities management
- [ ] Forestry
- [ ] Government & Local council
- [ ] History and heritage
- [ ] Infrastructure and transport
- [ ] Insurance
- [ ] Leisure
- [ ] Natural disasters and severe weather
- [ ] Navigation and routing
- [ ] Oil & Gas
- [ ] Solar
- [ ] Subsurface applications
- [ ] Urban planning
- [ ] Virtual reality & gaming
- [ ] Other

Question 3

3. Please rate the usefulness of the following 3D information according to your organisation's sector and day-to-day work:

3D GEOMETRY		Extremely useful	Very useful	Moderately useful	Slightly useful	Not at all useful	Not applicable
Roof geometry		○	○	○	○	○	○
Windows & doors geometry		○	○	○	○	○	○
Texturing		○	○	○	○	○	○
Interior geometry		○	○	○	○	○	○
3D road geometry		○	○	○	○	○	○
Maximum roof height	Max h	○	○	○	○	○	○
Base of roof height	Base h	○	○	○	○	○	○
Trees & other biomass geometry		○	○	○	○	○	○
Underground utilities geometry		○	○	○	○	○	○
Street furniture		○	○	○	○	○	○

Application requirements matrix

	GEOMETRY											ATTRIBUTES			
	HEIGHT		BUILDING				ROADS	SUBSURFACE	TREES & OTHER BIOMASS	UTILITIES	STREET FURNITURE	BUILDING			LAND COVER
	ABSOLUTE MAX	ABSOLUTE BASE OF ROOF	ROOF STRUCTURE	WINDOWS & DOORS	TEXTURE	INTERIOR						NUMBER OF FLOORS	CADASTRE & OWNERSHIP	ADDRESS	
Local Council															
Asset Management															
Environmental															
Transport planning															
Sub-surface & geology															
Urban Planning															
Leisure															

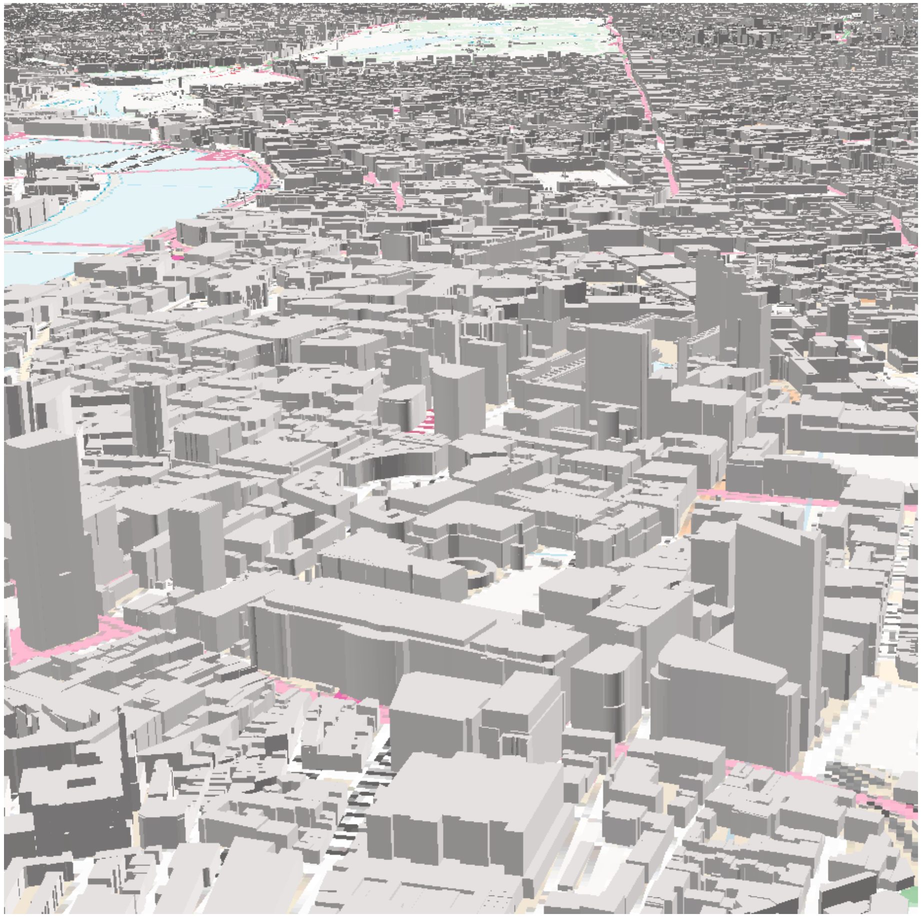
Application requirements matrix

	GEOMETRY											ATTRIBUTES			
	HEIGHT		BUILDING									BUILDING			
	ABSOLUTE MAX	ABSOLUTE BASE OF ROOF	ROOF STRUCTURE	WINDOWS & DOORS	TEXTURE	INTERIOR	ROADS	SUBSURFACE	TREES & OTHER BIOMASS	UTILITIES	STREET FURNITURE	NUMBER OF FLOORS	CADASTRE & OWNERSHIP	ADDRESS	LAND COVER
Local Council	X	X	X				X					X	X	X	
Asset Management	X		X	X		X	X						X	X	
Environmental	X	X	X	X		X	X	X	X	X					X
Transport planning	X	X					X			X	X		X	X	
Sub-surface & geology							X	X		X					
Urban Planning	X						X	X		X		X	X	X	X
Leisure	X		X		X		X		X						X

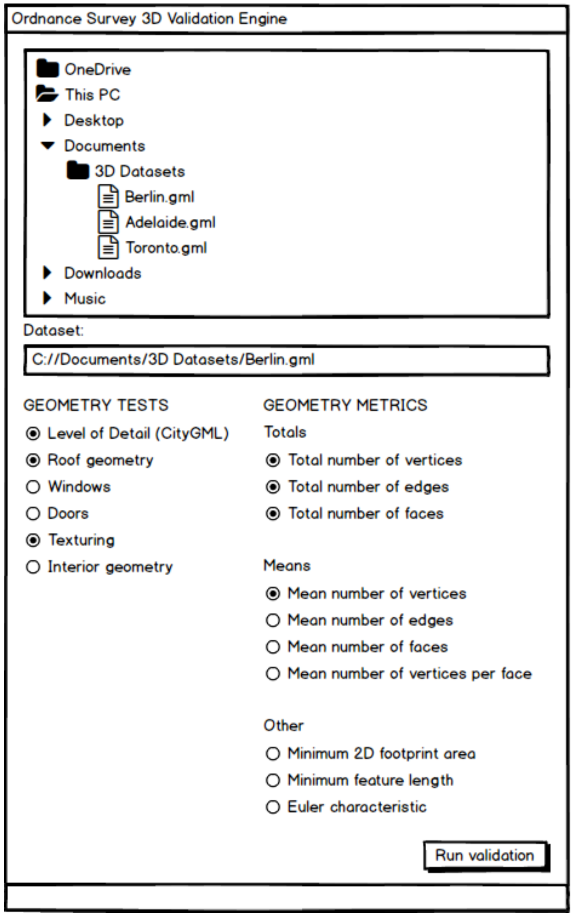
Next steps…

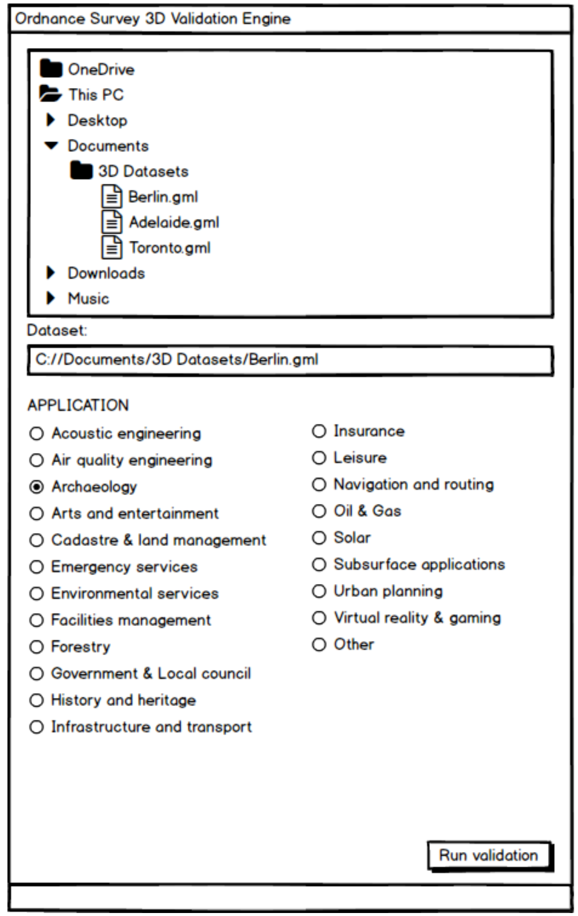
Forming a specification and creating sample data

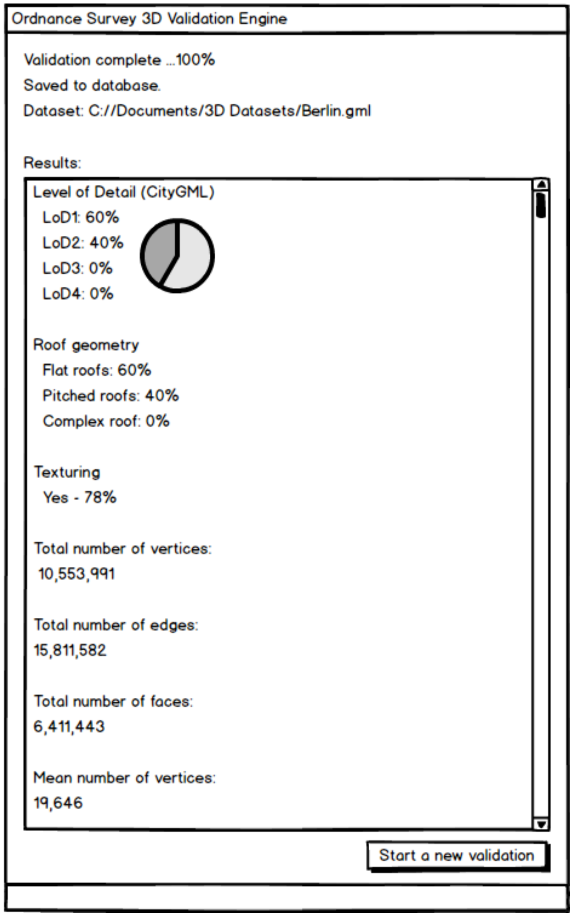
- The literature review, existing 3D dataset review, both questionnaires and interviews will feed into an initial specification
- A number (3?) of sample datasets will be produced to their respective application-specific specification



Development of 3D data tester







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