DATA QUALITY IN 3D: GAUGING QUALITY MEASURES FROM USERS' REQUIREMENTS

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ABSTRACT:

Producing data of known quality is an essential operation of mapping agencies such as Ordnance Survey. For these data to be of value to our customers, we need to understand what quality measures will allow them to assess whether the data are fit for their purpose. In the case of 3-dimensional (3D) data, this is particularly important as it will inform research into capturing and modelling these data. However, for a data type in its infancy, such as 3D data, it is rare that a clear idea of quality requirements is available since the full range of uses of the data is still unknown. Instead, the potential use contexts of such data need to be investigated. To this end, we have conducted user needs research across a wide range of professional use contexts. This research has been analysed to identify measures and their required quality for use contexts where 3D information about buildings is of particular interest to the user. However, it is often the case that the user cannot realistically make explicit statements anticipating what they would require in terms of 3D data measures and quality elements such as positional accuracy. Instead, it is possible to identify 3D building data characteristics and quality tolerances from implicit statements about use context and objectives from interviews with a wide range of professionals. Characteristics identified include the highest point of a structure and the maximum height of roof ridge, and others such as the the geometric shapes of roofs, buildings and the space between them, which will clearly present some challenges for developing usable quality measures. Preliminary results of this research are presented.

1 INTRODUCTION

It is important for mapping agencies such as Ordnance Survey to provide products that are of value to our customers both in terms of their specification and their quality. When developing new products we should design and test them such that they are fit for our future customers' purposes and that our statements of quality are of relevance to these customers. Therefore, when researching the capture and modelling of data for the future, we require an understanding of the needs of future customers.

We wish to gather information about customer requirements with no, or limited, preconceived ideas on our part. It is not enough to simply ask our current customers how they would like us to measure quality or even of what they would like future data content to comprise because the results from such interviews would be biased towards current requirements and data content. Instead, a user-centred approach has been developed and applied that focuses on how geographic information (GI) plays a part in tasks or decision processes of current and potential future users from a range of professional use contexts. From this, a range of requirements, including data quality requirements, can be drawn either directly or by inference.

Demands for 3D data are increasing and it is clear that we will need to be able to describe the quality of such data. As explained by Devillers and Jeansoulin (2006), in the field of geomatics, distinction can be made between 'internal quality', focused on similarity between 'perfect data' (or 'nominal ground') and data actually produced, and 'external quality' focused on agreement between data produced and user needs. In this paper we attempt to identify measures for 'internal quality' which may also be most meaningful for end users in terms of their assessment of 'external quality'. In terms of data quality criteria, this paper is principally concerned with aspects of positional accuracy; other data quality elements of completeness, logical consistency, temporal accuracy and thematic accuracy (ISO, 2002) are outside the scope of our current work.

Ordnance Survey currently assesses the positional accuracy of 2-dimensional (2D) vector data in terms of absolute and relative accuracies together with geometric fidelity (Harding, 2006). Absolute accuracy compares captured coordinates against actual position relative to a georeferencing system. Relative accuracy compares scaled distance between local data points with measured distance between these points on the ground. Geometric fidelity assesses the 'trueness' of features in data to the shapes and alignments of the real world features they represent.

The focus of 3D research at Ordnance Survey is presently on the capture, modelling and use of the external dimensions of buildings. The research presented here is the initiation of a process of developing quality measures that are relevant to the future users of 3D building data. It should be noted that although the scope of the research is limited to use contexts within Great Britain, many are relevant internationally.

2 AIM AND OBJECTIVES

Our research into quality assessment of 3D data aims to develop a toolkit of measures by which customers can determine the fitness for their purpose of 3D models of the external dimensions of buildings. A second use for these measures will be to assess the effectiveness of any data capture method against known customer requirements.

The work has five main objectives:

1. To gather information about customer needs
2. To identify the characteristics of 3D building data that are of interest to customers within the bounds of our stated aim

3. To design methods to measure these characteristics
4. To perform assessments of the quality of 3D data using these measures
5. To assess the utility of these measures to indicate the fitness for purpose of 3D building data

These objectives can be considered as stages in the research. Potentially, the results from stage 5 will trigger iterations through the entire process.

Stages 1 and 2 are presented in this paper (and described in detail in sections 4 and 5). Owing to the information-gathering nature of this work, the results to be presented in this paper are strictly qualitative. We wish to identify *everything* that could be of value to a customer so that we can design ways of measuring these characteristics.

It is recognised that the majority of GI users do not yet know precisely what they require from 3D building data and therefore it would be premature to perform quantitative analyses into the requirements for different characteristics over the range of use contexts. It is for later stages to identify how well these characteristics truely reflect actual customer requirements and determine the cost/benefit of creating products that are of high quality in any particular characteristic.

3 QUALITY ASSESSMENT OF 3D DATA

The quality assessment of 3D data involves the assessment of both the geometry and topology of the model. Much work has focussed on assessing the quality of the geometric aspects of models. This includes assessing the deviation of points in the model from the corresponding points in the verification data for height (Avrahami *et al.*, 2005; Hu *et al.*, 2005; Kaartinen *et al.*, 2005; Taillandier, 2005), for horizontal distance (Avrahami *et al.*, 2005; Haithcoat *et al.*, 2001) and in three dimensional space (Alberto Guarnieri and Remondino, 2004; Hsieh, 1996a; Hsieh, 1996b; Jamet *et al.*, 1995). Also, relative distances between points (or lengths of edges) are measured (Haithcoat *et al.*, 2001; Hu *et al.*, 2005; Kaartinen *et al.*, 2005; Tucci *et al.*, 2001; Ragia and Winter, 1998) (and Bell *et al.*, 2003 for dental data). Alternatively, qualitative measures have been derived to indicate the condition of roof facets (Boudet *et al.*, 2006).

One very popular method of assessing the geometric fidelity of captured 3D data is to subdivide the model and the verification data into voxels (or the ground plans into pixels) and calculate a number of measures of the omission and commission of these voxel (or pixel) parts of buildings (e.g. Haithcoat *et al.*, 2001; Kaartinen *et al.*, 2005; Lin and Nevatia, 1996; McGlone and Shufelt, 1994; Meidow and Schuster, 2005; Schuster and Weidner, 2003; Shufelt, 1996; Shufelt and McKeown, 1993; Meidow and Schuster, 2005). These measures (detection rate, branch factor, miss factor, quality percentage, see Schuster and Weidner, 2003) are useful all-round measures because they are combined measures of the positional accuracy of the object's bounding geometry and of the object's structure (which can be used to characterise the quality of the topology).

Commission and omission of buildings themselves is important when the modelling algorithm includes a detection stage before data are captured. This is often the case, and so where the above pixel and voxel decomposition measures have not been used to determine building-set completeness, this has been measured separately (Haithcoat *et al.*, 2001; Müller and Zaum, 2005; Noronha and Nevatia, 2001; Schuster and Weidner, 2003; Vosselman and Dijkman, 2001).

Topological accuracy is difficult to measure. It is probably a large aspect of what is being qualitatively measured by studies that rely on visual assessment (Ahlberg *et al.*, 2004; Baillard *et al.*, 1999; Baillard and Zisserman, 2000; Kim, 2001). Taillandier (2005) explicitly calculated the proportion of buildings with a correctly modelled shape. A more sophisticated version of this is to compare the apparent roof types between the model and verification data (Haithcoat *et al.*, 2001). Explicit measures of topology only seem to have been defined by Ragia (Ragia and Winter, 1998; Ragia and Förstner, 1999) and here in 2 dimensions with a view to extending the problem to 3 dimensions. These measures include the topology between buildings (buildings that are connected, overlapping, etc) and within buildings (the topology of the boundary).

With a wealth of possible measures of quality available, it is easy to see why several studies have undertaken to find some definitive quality measures that all 3D data capture studies should use (McGlone and Shufelt, 1994; McKeown *et al.*, 2000; Schuster and Weidner, 2003; Meidow and Schuster, 2005). Most of these have arrived at the same measures - those quantifying the omission and commission of voxels or pixels within the building boundary. These measures are useful for comparing 3D models. However, they do not necessarily indicate how well the data will fit customer requirements or give customers a means of assessing the fitness for purpose of the data.

4 GATHERING INFORMATION ABOUT CUSTOMER NEEDS

GI is essentially an abstraction of the real world. Certain natural and man-made features are modelled and represented with the intention of providing people with information that they can use. The usability of GI depends on many factors, but key usability considerations must include the content and quality of those data. It is important, then, that research into the capturing and modelling of 3D data takes into account both the potential usage of such data and what the user may perceive as constraints on its usability in terms of what is captured and modelled and to what quality.

By investigating and applying user needs research to quality requirements for 3D data we anticipate two outcomes: firstly, the data provider can assess the quality of data with particular attention to details of interest to the user and, secondly, it is possible to provide quality statements that are meaningful to the user, thus facilitating decisions on fitness for purpose.

The range of current and potential uses for GI is vast, spanning professional and leisure related contexts. An ongoing user needs research project at Ordnance Survey aims to provide a detailed understanding of what aspects of GI matter in professional task contexts, including object geometry and attribution in spatial and temporal dimensions. The principal purpose of this work being to provide consistently captured user needs data to inform data modelling and capture research. In this paper we use qualitative information captured from this user needs research to identify key factors of external buildings geometry for which quality of 3D data would be critical to fitness for purpose in sampled user and task contexts. The user needs research approach is outlined in the following section.

4.1 Approach

Our approach has drawn on and adapted a number of qualitative user-centred research techniques, including aspects of task analysis and User Centred Design. These focus on eliciting user requirements in the context of user tasks. People's needs for GI in professional task contexts were investigated using a combination of document analysis and semi-structured interviews. Where accessible, documents describing task procedures and task environment were analysed for geographical terms used (e.g. reference to 'building', 'road'). They also provided an overview of task aims and objectives prior to interview visits. Using a semi-structured interview format, this preliminary understanding was expanded by visiting and interviewing a specialist in the task. For example, in the context of the task 'fire service emergency planning' an emergency planner from a regional fire service was interviewed.

The emphasis of the interview was on investigating in greater depth the geographical things, referred to in this paper as 'concepts' (e.g. 'building', 'road') that play a part in the task and the attribution that needs to be known about these concepts. 3D aspects of geographical concepts are investigated alongside all other relevant attribution, including the terminology used by the task specialist to identify objects. In exploring these concept dimensions and attributes, the user was encouraged to be explicit about critical data quality thresholds for concepts where possible, or give a sense of what would be fit for purpose for other concepts in the task context.

The approach enabled the capture of qualitative information from which a holistic picture could be developed of what geographical things matter to the user in the use context. The same interview format was used with each user and use context, to ensure consistency of user needs information across the different professional contexts. Details of the methodology and findings are currently in internal company documentation but for further discussion please see Harding and Pickering (2007).

4.2 Sampling

To ensure a sample which was representative of the breadth of the UK GI user population, we had a number of issues to contend with. Most significant among these were the very large breadth of user-task contexts in which GI can contribute and the unknown shape and stratification of the user population. Further, the cost of user organisations giving us access to their employees for 1-2 hours of their working time, together with the cost of research staff time in recruiting participants, travel and qualitative analysis had to be considered.

Given these unknowns and constraints we employed a combination of purposive sampling and staged stratification (see Moser and Kalton, 1971). We began by identifying key overall tasks that could involve GI, and in which a number of different organisations would play a part: we called these 'supertasks' (for example 'emergency planning and response', 'urban design and development'). We then took advice from internal market experts, taking into account Ordnance Survey's role and responsibilities (Ordnance Survey, 2004) to prioritise the most significant supertasks in terms of apparent market need for GI and relevance to future societal and technological trends.

We used the stratification of supertasks as a basis for purposive sampling of key lower level tasks with a critical geographical element, together with the organisations involved in carrying out those tasks. Each supertask could encompass a number of contributing lower level tasks and organisations involved in those tasks. For example, the supertask 'emergency planning' encompasses the task of 'emergency planning for events' by police forces and 'emergency preparedness' by health service organisations, among other tasks. We then identified individuals to interview whose roles within their respective organisations were directly engaged in the identified task. It is from interviews focused on lower level tasks that the data quality characteristics for 3D building exteriors identified in this paper are drawn.

Included in the sample are professional tasks that are fundamentally carried out within a 3D problem space. Such tasks include urban design and development projects, emergency response and flood risk assessment. Others within the sample are not so obviously concerned with 3D space, such as managing road traffic congestion. However, in most cases there is still a requirement for some data with a 3D element within these tasks, for example height clearance under building overhangs is required in the context of highways asset management.

Organisations within which we interviewed people ranged from large government departments, through to small commercial consultancies. In summary, proportions of organisations involved to date break down as follows: central government 27.5%; local authority 32.5%; commercial business 30%; other 10% (to date these are mainly health service related organisations).

At the time of writing, the interview process continues and it should be noted that results of research presented in this paper are drawn from the first 37 interviews. There is a slight bias in the presented results towards urban planning and design (≈20%) and flood risk analysis (≈15%) use contexts. Other user-task contexts that were found to have some 3D requirement included: police deployment; police crime analysis; fire, police and ambulance emergency response; telecommunications networks planning; GPS signal propagation analysis in traffic management and risk modelling for insurance purposes.

Though the scope of this research includes the actual and potential UK user community for GI, the focus on user and task types means that the sample is likely to have counterparts in other countries (e.g. emergency planning by fire services, urban design by architects and planners). While task processes may differ to some extent between different countries or regions, the types of geographic concepts involved and 3D aspects of information ideally required about them may have considerable parallels.

5 IDENTIFYING CHARACTERISTICS OF INTEREST

Results from our approach are structured in internal interview records. A key part of each interview record is an information profile. This lists all geographical concepts identified as significant to the task by the interview participant, together with geometric dimensions (including information required in the vertical dimension) and other attribution needed in relation to that concept. These information profiles were derived directly from qualitative data that were derived in a concept-mapping exercise within the interview format. In order to inform research into capture requirements and quality assessment of 3D buildings data, the interview records and their information profiles were interrogated to identify concepts of relevance to 3D building data and from this quality characteristics and accuracy tolerances were extracted and interpreted.

As mentioned above, in some instances the user is able to provide a quantitative indication of tolerances which would apply to information about specific 3D elements of an object. In these cases that information is captured. Often, however, it is difficult for the user to precisely identify specific 3D buildings features required or quantify tolerances. In these cases it was necessary to infer 3D features and tolerances from other contextual information captured for the task. An important element of future research will be to validate prototype 3D buildings data and quality measures with users in the context of their tasks.

6 SPATIAL CHARACTERISTICS OF BUILDINGS OF INTEREST TO FUTURE USERS OF 3D DATA

Our approach allowed us to derive a set of geometric characteristics of building exteriors that are relevant to one or more use contexts. They comprised characteristics of individual buildings and of the set of buildings that make up a city model.

These characteristics have been divided into types of geometric accuracy to align them with international standards, as listed below. For each, we give examples of use contexts for which the user needs research has identified that the characteristic is relevant. This is followed by a brief description of what the characteristic is and notes pertinent to any quality measure to be derived for this characteristic.

6.1 Geometric fidelity

The principle of geometric fidelity is that any real-world alignment or shape must be accurately reflected in the data to the required specification, for example:

- detail that is square on the ground must be represented as square in the data, and shapes must be accurate;
- alignments that are straight in real life must be represented as straight lines within the data;
- lines of sight that pass through points on the ground should pass through the map positions of the corresponding points; and adjacent features should be in sympathy with each other as regards alignment, distance apart and orientation.

Characteristic 1: Inter-building geometric shape

Context Use contexts include: analysis of visual impact of a proposed building and other developments; line of sight analysis for police deployment and crime analysis; the modelling of availability of natural light for urban planning and design purposes.

Notes This characteristic of a 3D dataset is required to determine whether one location can be seen from another. Specific mention has been made of requirements to determine line of sight from windows (see characteristic 4). Millimetre level accuracies would be required for the more demanding applications. For natural light analysis, some measure of absolute positional accuracy will also be required.

Characteristic 2: Roof geometric shape

Context Use contexts include visualisation for urban design and development, emergency response and modelling such as in telecommunication network planning and hazard analysis.

Notes Roof geometry, including horizontal overhangs relative to building façades, is generally inferred to be required to positional accuracies of between $\pm$0.1m and $\pm$0.2m. However, for some line of sight applications, millimetre level accuracy is required as indicated above. For some users a classification of roof type may be sufficient as an attribute or symbolic depiction to distinguish, for example flat roofs from ridge and apex style roofs.

Characteristic 3: Complete building geometric shape

Context Use contexts include urban planning, design and development, emergency response.

Notes Of particular interest are the shapes of roofs and façades, and in this way this characteristic incorporates that of roof geometric shape above. In effect this characteristic can be assumed to mean a 3D building model, but the level of detail required varies from extrusions of the building footprint (up to roof geometry) to realistic geometry of façades including windows, doorways etc. (see characteristic 4). For some users, detail is more important on façades facing road ways or other public networks. For example dimensions of building overhangs impinging on road ways are important to transport route planning and road asset management. As a part of building geometry, some use contexts, such as fire service response, require interior unroofed spaces enclosed by the building (e.g. courtyards), or roofed spaces which pass through more than one structural floor (e.g. atria) to be included in 3D building models.

6.2 Relative positional accuracy

The following characteristic largely falls under relative positional accuracy. This is a measure of the positional consistency of a data point in relation to other near points of detail. Relative positional accuracy compares the scaled distance between features measured from the test data with distances measured between the same features in the reference data. Certain aspects of this characteristic are also relevant to absolute positional accuracy and geometric fidelity.

Characteristic 4: Position and dimensions of doors and windows

Context Use contexts include emergency services planning and response, crime analysis, visualisation for urban planning, design and development, flood risk analysis.

Notes This includes doors and windows on any floor which offer access for emergency services, line of sight for urban planning, the height at which water would flow into a building and the amount of light penetration into a building. Location and dimension of roof skylights are also of interest in some use contexts. For some users, point locations of access points in the building façade may be sufficient, but where geometry of exterior doors and windows is required a positional accuracy requirement for better than $\pm$0.2m is stated generally for location. In flood risk use contexts an accuracy of $\pm$0.1m should be aimed for. For tasks requiring critical decisions based on line of sight or precise calculations of access to natural light, centimetre to millimetre accuracy is required. Positions of balconies are of interest to some users since they are points of access or locations from which views may be afforded.

6.3 Absolute positional accuracy

The characteristics in this section, and their quality requirements, are relative to a chosen Geodetic Datum or Terrestrial Reference System, such as the British National Grid with Ordnance Datum Newlyn, or ETRS89. That is, the quantities described are defined with respect to a national or regional data volume.

Characteristic 5: Highest point of structure

Context Use contexts include visualisation of proposed buildings in urban design and planning and in signal modelling for telecommunications network design.

Notes The highest point may include lift stacks if present. There has been little indication in the use contexts analysed so far that chimneys are to be considered as the highest point of a building (however heights of chimneys where they are separate structures are required in some use contexts). For some users, the measurement should be relative to ground level and for others relative to sea level with an accuracy ranging from ±0.2m to ±1.0m (inferred from the statement that the horizontal accuracy of Ordnance Survey large scales data is sufficient).

Characteristic 6: Maximum height of roof ridge

Context Use contexts include visualisation of proposed buildings in urban design and planning, modelling GPS signal propagation and in emergency planning.

Notes In some cases maximum height of the roof ridge will correspond to the highest point of the structure (as with characteristic 5), and the acceptable accuracy range is similar. While maximum height of roof ridge is a suggested measure, for visualisation purposes the geometry of roof ridges is of use (this is considered under characteristic 2). Accuracy levels are inferred to be between ±0.2m and ±1.0m, as with characteristic 5, since the use context and reference are the same.

Characteristic 7: Height of building to base of roof (eave height)

Context Use contexts include visualisation of proposed buildings in urban design and planning, visualisation for police incident planning.

Notes This is the height where the roof adjoins the building. As above accuracy levels of between ±0.2m and ±1.0m are considered as adequate by users.

Characteristic 8: Ground floor height

Context Flood risk assessment.

Notes It is uncertain at present what constitutes the ground floor, e.g. lowest generally inhabited level above ground, or lowest level above ground level which is enclosed, such as a garage in the bottom of a town house. Centimetres can be important, so an accuracy of approximately ±0.1m at least would be desirable, relative to ground level.

7 DISCUSSION OF METHODOLOGY FOR IDENTIFYING 3D DATA QUALITY IMPLICATIONS

Qualitative analysis of information profiles from the 37 task-focused interviews has identified eight characteristics of 3D building data. These results represent a significant stage in our research to develop customer-focused quality measures.

The 1-2 hour interviews used did not allow for exhaustive questioning about the detail of each requirement. Instead it provided a holistic view of user tasks, concepts and attribution needs that can be used to determine requirements for GI data for data capture and modelling work beyond the current research. The focus on concepts, dimensions and attribution in the information profiles from the interview records ensured that extracting 3D building characteristics from these records was a simple process. However, some special attention was required in a few cases.

Some characteristics of 3D building exteriors were stated explicitly in the interviews as significant to the task context, such as 'highest point of structure'. In other cases, interpretation was required when the descriptions of concepts did not explicitly state all of the factors that would influence them. For example, doors and windows are of interest to some use contexts as 'access points' (e.g. in emergency response and crime analysis). From this, we can infer that their dimensions are as important as their location.

Other characteristics that were stated explicitly, namely 'Roof face pitch direction' and 'depth of roof overhang', were amalgamated into a single characteristic 'roof geometric shape' (characteristic 2). In this example, the two roof characteristics were given as part of a list of concepts that included 'roof shape' and represented only one interview and so it was considered pertinent to include these in a more generic characteristic. Another example of this is the characteristic 'roof area', which was required for wind damage modelling. This was also amalgamated into characteristic 2. Whether such generalisations are adequate should ultimately be determined by research into usability of the data and their corresponding quality measures.

Some accuracy conditions were stated explicitly. Where no explicit accuracy condition was stated in the interviews, it was sometimes possible to use GI capture and modelling experience (and some assumptions) to infer this. For example, it was stated that "it can take only 10-20cm water depth outside a property to cause damage internally". Therefore it was inferred that the required accuracy for a building threshold level is ±0.1m. In another case, the highest point in a structure can initially be assumed to require an accuracy of ±0.2m, since the customer for this measurement has stated that this level of accuracy is adequate for horizontal data. In other cases, accuracy requirements will need to be determined from the testing of available data in users' task contexts.

From the above discussion it is clear that extracting what is of value to different users requires a range of strategies and a degree of interpretation. The interpretation is essential to (a) assimilate the different terminology used in different task contexts, (b) account for the fact that users do not yet know exactly how they will undertake their task in the future and (c) incorporate the emphasis given by the interviewee. Whilst this limits our results, it is essential to allow the research to move onto the following stages of measurement design, and hypothesis and usability testing. These later stages will test the measures that are designed for their usability to potential customers of 3D building data. By documenting at each stage of the interpretation process, we will be able to refer to the task contexts for which each characteristic is required and modify the measures if necessary.

8 DISCUSSION OF RESULTS

The 8 characteristics presented provide a valuable insight into the requirements of potential customers for 3D building data and are an essential starting point for developing measures against which the quality of such data can be assessed. This list will focus our quality assessment research on those characteristics of value, rather than the capture technique.

We divided the characteristics into types of geometric accuracy, to align them with international standards for geographic data quality. However, it can be seen that whether absolute positional accuracy, relative positional accuracy or geometric fidelity is appropriate depends on the use context rather than the characteristic. This will need further consideration in the work developing measures for these characteristics and may result in more than one measure for those characteristics.

The characteristics identified could be used to guide what is captured and modelled. Whilst much research has been focused on capturing individual buildings it is clear that the positioning of buildings relative to each other is of importance where line-of-sight assessments are to be made. If the characteristic of inter-building geometric shape were to prove important, either commercially or for other reasons, capture techniques should be developed to ensure a high accuracy in this respect. Conversely, research into capturing roof detail such as chimneys is quite common. However, mention of such roof detail in the task focused interviews was limited to very specific task contexts, including line of sight analysis, detailed telecommunications signal propagation and identifying access points.

Measuring quality is intrinsically linked to data specification, and we have attempted here to identify characteristics that are generic to any specification. However, by working within our stated scope - external geometric characteristics of 3D buildings - we have already made assumptions about the specification of 3D building data. In so doing, we have excluded non-geometric characteristics, such as number of storeys, that are of more interest to certain users.

The requirement for different characteristics of 3D data quality is likely to change with different buildings, in different locations for different users. We have not concerned ourselves with this in the current research. Whilst of interest when assessing usability of data, these different requirements do not affect the ways in which the quality of the data is measured.

The next stage of this research is to design measures for the identified characteristics and this has already been initiated. In general, we expect that the characteristics grouped under absolute and relative positional accuracy should be fairly simple to measure. Conversely, those grouped under geometric fidelity are likely to be more challenging.

Clearly, the work of Meidow and Schuster (2005) and their predecessors that compare voxels contribute to the solution for determining geometric fidelity. Developments of these and other techniques will be required to ensure that the resulting accuracies relate directly to the stated characteristics. Whilst absolute positional accuracy measures are likely to be in units such as meters and degrees, geometric fidelity measures are likely to be percentages, probabilities and possibly some more qualitative statements.

No data set is perfect for every purpose and often a 'one size fits all' approach is taken by data providers. However, such compromises do not have to be made in how the quality of the data is described if the quality measures are independent of the use context. The usability, both to the producer and customer of 3D data, of the measures that will result from the continuation of this work is yet to be determined. Usability testing of the measures themselves will be required to determine if they allow a data provider to assess the data quality against customer needs and allow customers to determine the data's fitness for their purpose. However, there may ultimately be some compromise between usability of the measures and keeping the computation of these measures simple.

There may be some merit in performing similar research for 2D topographic data with a view to developing more customer-friendly quality measures for these data. Such research could also be useful for developing current 2D product specifications for use contexts beyond those for which they were originally designed.

9 CONCLUSION

A qualitative methodology has been consistently applied to identify the needs of data users in a range of use contexts. From this, it has been reasonably straightforward to build a list of characteristics of 3D building data that are likely to be of relevance to future users. The interviews are ongoing and new tasks are being studied, so these results should develop over time. However, we are confident that the presented work accounts for the needs of some key potential use contexts for 3D data.

The strength of the methodology is that the focus is on use contexts rather than particular customers. In addition, the requirements of users were determined by analysing their tasks and what they need to achieve by the tasks (now and in the future), rather than by asking directly what would be their current data requirements. Therefore, the results are not biased towards a specific market sector or limited by users' views on their current data and software systems. The weakness of the approach, which is unavoidable, is that a degree of interpretation was required to obtain the 3D data characteristics. Any subjectivity introduced by this stage should be eliminated by testing measures and measured data for usability in a range of task contexts.

We have presented here the results of the first stage of our research. These are eight characteristics of 3D buildings data that are relevant to a range of use contexts. The list of characteristics for 3D building data quality provides a valuable insight into the requirements of potential customers of 3D data. They allow us to ground our research in the reality of customer needs. The next stage of the research is to design quality measures that can encapsulate these characteristics and use these to test developments in 3D data capture research. Perfecting the measures will no doubt be an iterative process that will assess how well statements of quality match the usability of 3D data.

Until the application of 3D data to different user tasks is established, we cannot be certain of the required accuracy and precision of 3D models. However, we have established a basis on which to build research into capturing and modelling 3D data that are relevant to our future customers.

DISCLAIMER

REFERENCES

Ahlberg, S., U. Sönderman, M. Elmqvist, and Å. Persson, 2004. On modelling and visualisation of high resolution virtual environments using LiDAR data. In *Geoinformatics 2004 Proceedings of the 12th International Conference on Geoinformatics - Geospatial information research, Bridging the Pacific and Atlantic*, University of Gävle, Sweden.

Alberto Guarnieri, A. V. and F. Remondino, 2004. Photogrammetry and ground-based laser scanning: Assessment of metric accuracy of the 3D model of Pozzoveggiani Church. In *FIG Working Week 2004*, Volume TS26 Positioning and Measurement Technologies and Practices II - Laser Scanning and Photogrammetry, Athens, Greece.

Avrahami, Y., Y. Raizman, and Y. Doytsher, 2005. Extraction of 3D spatial polygons based on the overlapping criterion for roof extraction from aerial images. In U. Stilla, F. Rottensteiner, and S. Hinz (Eds.), *International archives of photogrammetry, remote sensing and spatial information sciences. (Object extraction for*

3D city models, road databases and traffic monitoring - concepts, algorithms and evaluation), Volume XXXVI. Joint workshop of ISPRS and DAGM.

Baillard, C., C. Schmid, A. Zisserman, and A. Fitzgibbon, 1999. Automatic line matching and 3D reconstruction of buildings from multiple views. In *ISPRS Conference on Automatic Extraction of GIS Objects from Digital Imagery*, Volume 32, pp. 69–80.

Baillard, C. and A. Zisserman, 2000. A plane-sweep strategy for the 3D reconstruction of buildings from multiple images. In *The international archives of the photogrammetry, remote sensing and spatial information sciences*, Volume XXXIII.

Bell, A., A. F. Ayoub, and P. Siebert, 2003. Assessment of the accuracy of a three-dimensional imaging system for archiving dental study models. *Journal of Orthodontics* 30(3), 219–223.

Boudet, L., N. Paparoditis, F. Jung, G. Martinoty, and M. Pierrot-Deseilligny, 2006. A supervised classification approach towards quality self-diagnosis of 3D building models using aerial digital imagery. In W. Förstner and R. Steffen (Eds.), *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information*, Volume XXXVI, Bonn, Germany. ISPRS Commission III.

Devillers, R. and R. Jeansoulin, 2006. Spatial data quality: Concepts. In R. Devillers and R. Jeansoulin (Eds.), *Fundamentals of Spatial Data Quality*, London, pp. 31–42. ISTE.

Haithcoat, T., W. Song, and J. Hipple, 2001. Building extraction - LIDAR R&D program for NASA/ICREST studies project report 09/16/01. Technical report, Interdisciplinary Center for Research in Earth Science Technologies.

Harding, J., 2006. Vector data quality: A data provider's perspective. In R. Devillers and R. Jeansoulin (Eds.), *Fundamentals of Spatial Data Quality*, London, pp. 141–159. ISTE.

Harding, J. L. and E. K. Pickering, 2007. Spatial information usability: Towards a usability assessment framework based on usability factors in contexts of use. *Cybergeo* in press, `http://www.cybergeo.presse.fr/`.

Hsieh, Y., 1996a. Design and evaluation of a semi-automated site modeling system. In *ARPA Image Understanding Workshop*, Volume 1, pp. 435–459.

Hsieh, Y., 1996b. SiteCity: A semi-automated site modelling system. In *1996 IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, San Francisco, CA, pp. 499–506.

Hu, Y., V. Tao, and Z. Xu, 2005. Accuracy assessment of mapping results produced from single imagery. In *ASPRS 2005 Annual Conference*, Baltimore, Maryland.

ISO, 2002. *ISO 19113:2002 Geographical Information Quality Principles*. Geneva: International Organization for Standardization.

Jamet, Dissard, and Airault, 1995. *Automatic Extraction of Man-Made Objects from Aerial and Space Images.*, Chapter Building extraction from stereo pairs of aerial images: accuracy and productivity constraint of a topographical production line., pp. 231–240. Birkhaeuser Verlag.

Kaartinen, H., J. Hyyppä, E. Gülch, G. Vosselman, H. Hyyppä, L. Matikainen, A. Hofmann, U. Mäder, A. Persson, U. Söderman, M. Elmqvist, A. Ruiz, M. Dragoja, D. Flamanc, G. Maillet, T. Kersten, J. Carl, R. Hau, E. Wild, L. Frederiksen, J. Holmgaard, and K. Vester, 2005. EuroSDR building extraction comparison. In Gröger and Kolbe (Eds.), *Proceedings of the 1st International Workshop on Next Generation 3D City Models*.

Kim, Z., 2001. *Multi-view 3-D object description with uncertain reasoning and machine learning*. Ph. D. thesis, Faculty Of The Graduate School, University Of Southern California.

Lin, C. and R. Nevatia, 1996. Buildings Detection and Description from Monocular Aerial Images. In *ARPA Image Understanding Workshop*.

McGlone, J. and J. Shufelt, 1994. Projective and object space geometry for monocular building extraction. In *Proc. IEEE Computer Vision and Pattern Recognition*, pp. 54–61.

McKeown, D. M., T. Bulwindle, S. D. Cochran, W. A. Harvey, C. McGlone, and J. A. Shufelt, 2000. Performance evaluation for automatic feature extraction. *International Archives of Photogrammetry and Remote Sensing* Volume XXXIII(Part B2), 379–394.

Meidow, J. and H.-F. Schuster, 2005. Voxel-based quality evaluation of phtogrammetric building acquisitions. In U. Stilla, F. Rottensteiner, and S. Hinz (Eds.), *International archives of photogrammetry, remote sensing and spatial information sciences. (Object extraction for 3D city models, road databases and traffic monitoring - concepts, algorithms and evaluation)*, Volume XXXVI. Joint workshop of ISPRS and DAGM.

Moser, C. A. and G. Kalton, 1971. *Survey Methods in Social Investigation*. Aldershot, UK: Gower.

Müller, S. and D. W. Zaum, 2005. Robust building detection in aerial images. In U. Stilla, F. Rottensteiner, and S. Hinz (Eds.), *International archives of photogrammetry, remote sensing and spatial information sciences. (Object extraction for 3D city models, road databases and traffic monitoring - concepts, algorithms and evaluation)*, Volume XXXVI. Joint workshop of ISPRS and DAGM.

Noronha, S. and R. Nevatia, 2001. Detection and modeling of buildings from multiple aerial images. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 23(5), 501–518.

Ordnance Survey, 2004. Ordnance survey framework document. Published by Ordnance Survey, UK. `http://www.ordnancesurvey.co.uk/aboutus/reports/frameworkdocument/docs/frameworkdocument2004.pdf`.

Ragia, L. and W. Förstner, 1999. Automatically assessing the geometric and structural quality of building ground plans. *Bulletin de la Societe Francaise de Photogrammetrie et Teledetection* 153, 22–31.

Ragia, L. and S. Winter, 1998. Contributions to a quality description of areal objects in spatial data sets. In *Proceedings of ISPRS Commission IV Symposium*, Stuttgart, Germany, pp. 7–10.

Schuster, H.-F. and U. Weidner, 2003. A new approach towards quantitative quality evaluation of 3D building models. In *ISPRS Commission IV Joint Workshop Challenges in Geospatial Analysis, Integration and Visualization II*, Stuttgart, Germany. ISPRS.

Shufelt, J. and D. McKeown, 1993. Fusion of monocular cues to detect man-made structures in aerial imagery. *Computer Vision, Graphics and Image Processing* 57(3), 307–330.

Shufelt, J. A., 1996. Exploiting photogrammetric methods for building extraction in aerial images. *International Archives of Photogrammetry and Remote Sensing* XXXI(B6/S), 74–79.

Taillandier, F., 2005. Automatic building reconstruction from cadastral maps and aerial images. In U. Stilla, F. Rottensteiner, and S. Hinz (Eds.), *International archives of photogrammetry, remote sensing and spatial information sciences. (Object extraction for 3D city models, road databases and traffic monitoring - concepts, algorithms and evaluation)*, Volume XXXVI. Joint workshop of ISPRS and DAGM.

Tucci, G., G. Guidi, D. Ostuni, F. Costantino, M. Pieraccini, and J.-A. Beraldin, 2001. Photogrammetry and 3D scanning: Assessment of metric accuracy for the digital model of Danatello's Maddalena. In *Proceedings of the 2001 Workshop of Italy-Canada on 3D Digital Imaging and Modeling Application of: Heritage, Industry, Medicine, & Land*, Padova, Italy.

Vosselman, G. and S. Dijkman, 2001. 3D building model reconstruction from point clouds and ground plans. *International Archives of Photogrammetry and Remote Sensing* XXXIV-3/W4, 37–43.