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EUROPEAN ORGANIZATION FOR EXPERIMENTAL  
PHOTOGRAMMETRIC RESEARCH

OEEPE SURVEY ON 3D-CITY MODELS

Report by Claudia Fuchs, Eberhard Gülch and Wolfgang Förstner

PERFORMANCE OF TIE-POINT EXTRACTION  
IN AUTOMATIC AERIAL TRIANGULATION

Report by Christian Heipke and Konrad Eder



Official Publication N° 35

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# OEEPE Survey on 3D-City Models

with 20 Figures, 18 Tables and 4 Appendices

*Report by Claudia Fuchs, Eberhard Gülch and Wolfgang Förstner*

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## Abstract

The scope of this study was to find out the current state of generating and using 3D-city data. For this purpose a questionnaire was sent out to appr. 200 European institutions. The questionnaire was completed by a total of 55 institutions from 17 European countries.

The questionnaire contains two parts, one for the producers and one for the users of 3D-city data.

The tasks of the institutions cover a broad range: mapping, surveying, photogrammetric service, environmental analysis, software development, architecture, computing services, telecommunication and research. The wide range of interest of the participants provides a good basis for a representative evaluation of the present situation in 3D-city modeling. The number of participating users from university is high, which is due to the ongoing research efforts in this field. This is taken into account in the analysis.

The results confirm that 3D-city data are needed, are already used and provided to a large extent.

The need for a better communication between producers and users of 3D-city data has been clearly confirmed. A second phase of the test will give the chance to strengthen this interaction.



# 1 Motivation and Outline of the Survey

Three-dimensional geographical information systems (3D-GIS) are of increasing importance in urban areas. 3D-data seem to be useful for various applications such as city planning, visualization, environmental studies, simulations, or for cellular network planning in telecommunication. They may establish links to large scale<sup>1</sup> building information or facility management systems.

Geo-Information Systems (GIS) up to now provide several tools for storing the third dimension.

The most common way is to provide the 2D-data with an attribute specifying their height. This usually is referred to as a  $2\frac{1}{2}$ D-representation. The classical example is the storage of a Digital Elevation Model, where each point of a planar grid or of a planar irregular triangulated network has one height as attribute. This is sufficient for most terrains, but does not allow to store overhangs, tunnels, or the three dimensional structure at bridges. But already vertical parts, e. g. at walls aside roads or of buildings, cannot be explicitly represented, but within such a  $2\frac{1}{2}$ D-representation need a special coding of break lines.

Truly 3D-representations allow to store the complete geometric structure of spatial objects. They are very common in CAD-systems for constructing machine parts in or for describing complex architectural structures. The two most common representations used in CAD-systems are the CSG (Constructive Solid Geometry) for handling spatial objects and the boundary representation for visualization, rendering and animation<sup>2</sup>. Such truly 3D-representations are not common in classical GIS, except e. g. for those explicitly developed for geological applications.

A link between  $2\frac{1}{2}$ D-representation and 3D-representation, e. g. for data exchange, is non trivial, as 3D-representations carry information not representable in  $2\frac{1}{2}$ D. Thus updating 3D-data may lead to information loss when transferring these changes to  $2\frac{1}{2}$ D. This is a conceptual problem, not a problem of data exchange format.

Only few institutions are using or producing data in a 3D-representation. The reasons are at least twofold: on the one hand, the cost for the acquisition of 3D-data is still high, hindering a regular request for 3D-information. On the other hand, the users requirements are not really known, unclear or at least diverse, which hinders the development of efficient acquisition procedures. Thus, several problems in data acquisition and data management have to be solved for economical and efficient production processes of 3D-data to be useful in the different application fields.

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<sup>1</sup>The notion of scale used for maps usually is said to be not relevant for data in a GIS. However the scale of a map is closely linked to the degree of resolution or generalization, which may be transferred to GIS data. Large scale data in a GIS then are data of high resolution or low generalization.

<sup>2</sup>There also exists a 2D+1D-representation, where planimetric information is not explicitly linked with the height information, but only fused on request, e. g. in case the planimetric data of a cadastre are not linked with the data of the DEM.

In 1994, the OEEPE initiated a survey on 3D-City Models<sup>3</sup> to improve the situation. Documenting users needs should stimulate progress in 3D-data acquisition, and demonstrating modern photogrammetric techniques for 3D-data acquisition will improve the acceptability of 3D-data for the users in the future. The goal of the survey is to find out the state of the art of the acquisition and use of 3D-data in urban areas. The study addresses both 2½D- and 3D-representations, as both representations will have their application in urban areas. We are especially interested in the actual trend in changing from 2½D to 3D<sup>4</sup>.

The survey is performed in two phases:

1. Phase I aims at the collection and analysis of the users requirements in present application fields, in the state of the art in 3D-data acquisition techniques, and also at the detection of new application areas.

In November 1995 we distributed about 2000 invitation letters to which 200 European (and a few Non-European) institutions answered and expressed interest in participating in Phase I. Phase I consists of an *inquiry*, or questionnaire<sup>5</sup>, and a *case study*<sup>6</sup>. The questionnaire is meant to get an overview of the activities, the demands and the potential of producing and using 3D-data in urban areas. The test data, i. e. 3D and 2½D vector data and 2½D raster data (e. g. DTM from stereo analysis of aerial images or from Laser scan data), are prepared for the participants to make experiments with such data in their own environment and for their own applications. Both, the questionnaire and the test data have been prepared at the Institute of Photogrammetry, Bonn University and were distributed in May 1996. A first report of the results was given at the *Workshop on 3D-City Models*<sup>7</sup>, held in Bonn, October 9-11, 1996 (Fuchs 1996).

2. Phase II started in 1997 and is organized by M. Gruber, Institute for Computer Graphics and Vision, TU, GRAZ, Austria. It is planned to analyze the techniques for 3D-data acquisition and for the use of 3D-city models in more detail based on a comparative empirical test where all institutions which are able to produce 3D-data may participate.

The results of phase I, i. e. the evaluation of the questionnaire and the reports on the experiences in the case studies, will be used as a basis for the layout of the second phase of the test.

This report presents the results of the first phase:

From approximately 200 distributed questionnaires we received 55 answers from 17 European countries. The participating institutions are from firms, covering small

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<sup>3</sup>Meeting of the Working Group on 3D-GIS in Delft, 14 September 1994, organized by Prof. Dr. G. Vosselman. Participants: G. Vosselman, W. Förstner, M. Molenaar, T. Sarjakoski

<sup>4</sup>To get a complete impression, we also asked for the need of 2D city data.

<sup>5</sup>The original is attached in Appendix I.

<sup>6</sup>A description of the distributed test data is attached in Appendix II.

<sup>7</sup>The workshop program is attached in Appendix IV

companies as well as big enterprises, administrations and universities. There are 41 institutions which are producers, 21 that are users and 7 institutions that are both. The institutions cover a broad range of tasks (in decreasing order): mapping, surveying, photogrammetric service, environmental analysis, software development, architecture, computing services, telecommunication and research. The number and the range of interests of the participants provide an excellent basis for a representative evaluation of the present situation in 3D-city modeling.

We received only a few comments on the use of the test data. The reason for this was perhaps the time, which did not allow the institutions to handle different formats, interfaces etc. For this reason, the following presentation contains **only** the information we extracted from the completed questionnaires.

In Section 2 we will first give an overview of the questionnaire and its structure. We will refer to this structure when presenting the results in Section 3. The evaluation of the questionnaire contains further information, useful with respect to the individual situations or problems of the producers or users. To demonstrate how the results can be further and individually analyzed we show two examples in Section 4. Section 5 contains a summary of the most interesting results, we will also discuss questions remaining open and give recommendations for Phase II.

## 2 Description of the Questionnaire

In this section we give an overview of the questionnaire. When describing the results in Section 3 we will refer to the questionnaire based on the structure introduced in this overview<sup>8</sup>.

The questionnaire is divided into three parts (cf. Appendix I):

- **Part 1: General part G-1:** This part contains general questions about the institution of the participant and should be completed by **all** participants
- **Part 2: Producers part P-2:** This part contains questions for the producers of city information. Thus, these pages should be completed by the producers only.
- **Part 3: Users part U-3:** This part contains questions for the users of city information. Thus, these pages should be completed by the users only.

G-1 contains three questions:

We asked the participants to specify the *type*, the *tasks* and the *size* of their institutions. We analyze these answers for all participants, but also individually for the group of the producers and the group of the users. These results are summarized in Section 3.1.

P-2 and U-3 each contain the following six questions:

### 1. City objects of interest:

We asked the producers and the users to specify the *classes* of objects they produce/use or they have demand for/interest in (questionnaire: P-2.1/U-3.1).

We asked further to specify the *dimension* of the object models<sup>9</sup> (2D, 2½D

<sup>8</sup>The readers who are familiar with the questionnaire may skip this section. In principle, we use the original numbers of the questions. For a clearer distinction between the general part, the producers part and the users part of the questionnaire, we add the letters G, P, U to the original question number, e. g. we refer to three questions 1.1, 1.2 and 1.3 of the *general* part now as G-1.1, G-1.2 and G-1.3. Accordingly P-2.1 to P-2.6 indicate the six questions of the *producers* part and U-3.1 to U-3.6. indicate the six questions of the *users* part.

<sup>9</sup>Both 2½D and 3D object models are able to represent three dimensional objects. Representing the third dimension using the third coordinate as an attribute of a point with known position in the first two coordinates is referred to 2½D (e. g. the z-coordinate as height and attribute of a 2D point in a plane, represented by x,y-coordinates). In this context 2½D means e. g. a Digital Elevation Model (DEM), cf. page 60, Fig. 15. The most important characteristic is that for each position only one height can be stored, i. e. in 2½D it is not possible to represent *further* characteristics of the object or events in this third dimension. In contrast, the volumetric representation, common to most CAD-systems in machine engineering and architecture, is referred to as 3D-representation (cf. page 61, Fig. 16). E. g. the structure of a complex building is represented by combinations of geometric primitives like boxes, prisms or planar surfaces. This permits representation and therefore access to vertical walls and passages as well as parts of the buildings, such as floors, which e. g. may be useful for managing multi level properties. The most appropriate representation model may differ depending on the application.

and/or 3D) and also to specify the *degree of relevance* of the production/use of these objects for their institutions. In Section 3.3.3 we compare the answers from the producers (cf. Section 3.3.1) with the answers from the users (cf. Section 3.3.2).

2. **Clients and Suppliers:**

We asked the producers/users to characterize the institutions of their clients/suppliers (P-2.2/U-3.2) by specifying the *tasks* of these institutions. The tasks we asked for are identical to the tasks asked for in G-1.2 to characterize the participating institutions themselves. The analysis of the tasks with respect to the different city data acquired or used reflects the actual needs in terms of users and the actual tasks in terms of the producers. The results are summarized in Section 3.2.

3. **Technical Environment:**

We asked the participants to specify the technical environment available for the production/use of city data (P-2.3/U-3.3). The correlation of the technical environment with the type of input data and the type of output data gives an indication of the actual potential for the acquisition and use of data. The results are summarized in Section 3.4.1.

4. **Input Data:**

We asked for the type of input data, i. e. the *data sources* (e. g. image data) of the producers and the type of input data, i. e. the *city data*, of the users (P-2.4 and U-3.4). This is to document the current availability of the different data sources and the availability of 3D-city data. The results are summarized in Section 3.4.2.

5. **Output Data:**

We asked for the type of output data, i. e. the *city data* provided by the producers (P-2.5) and the type of output data or the *scopes* of the users when using city data (U-3.5). The results are summarized in Section 3.4.2.

6. **Requirements of City Data:**

Finally we asked in more detail for

1. the requirements of **building data** when producing/using the data (P-2.6.1/U-3.6.1), and for
2. the production/use and the requirements of **other** city objects than buildings (P-2.6.2/U-3.6.2).

This information is to establish the type of object information produced and used today. We will compare the provided data with the needed products named by the users. The results for buildings are summarized in Section 3.5, the requirements for other city objects in Section 3.6.

To make it as easy as possible for the participants to complete the questionnaires, in most cases we provided *predefined* answers. Thus, completing the questionnaires just

required indication crosses. In all cases it was possible to give instead or additional comments, or to define new classes (summarized in the class "**Others**"). A more detailed description of the questions and the predefined answers will be given later in the report, namely before presenting the results of the different questions.

### 3 Analysis of the Questionnaire

This section presents the results of the analysis<sup>10</sup> of the completed questionnaires. In general, we follow the structure of the questionnaire as introduced in the previous section and directly compare the results derived from the producers and the users answers. What has been analyzed is shown in Fig. 1: The elements of the diagonal of the matrix correspond to the summary of all answers concerning single questions, the elements of the off-diagonals reflect comparisons or correlations between answers to different questions.

In Section 3.1 we first focus on *general information* about the participating institutions.

For a comparison or evaluation of the producers and the users activities and interests it is important to know whether the clients named by the producers fit the users and whether the suppliers named by the users fit the producers. Therefore Section 3.2 presents the analysis of the *tasks of the institutions* of the *producers* and the *users* (G-1.2) with respect to the *tasks of the institutions* of the *clients*, named by the *producers* (P-2.2), and the *tasks of the institutions* of the *suppliers*, named by the *users* (U-3.2).

In Section 3.3 we focus on the *type of city objects* of interest to acquire or to use, presently or in the near future. We will compare the answers given by the producers with the answers given by the users. As participants sometimes have no interest or are only partially interested in the acquisition or use of city data we also analyzed the reasons for having *no* interest in certain object classes. The results have been extracted from the questionnaire parts P-2.1 and U-3.1. Some of these results are further analyzed comparing the answers with respect to the *type* and *task* of the participating institutions, thus with the answers given in G-1.1 and G-1.2.

In Section 3.4 we focus on the *state of the art* in the acquisition and the use of city data. It contains an overview of the *technical environment* of the producers and the users (P-2.3 and U-3.3), the *input data* and the *output data* of the producers and the users, i. e. the data sources for the production (P-2.4), the acquired city data (P-2.5), the used city data (U-3.4) and the results or scopes of the users (U-3.5).

Section 3.5 summarizes the requirements in the production or use of *building data* in more detail (P-2.6.1 and U-3.6.1). We combine these results with other information we have derived so far. In Section 3.6 we give an overview of the results concerning the requirements in *city objects other* than buildings, i. e. we give a summary of the answers from P-2.6.2 and U-3.6.2.

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<sup>10</sup>The answers of the returned questionnaires have been acquired and analyzed with EXCEL 5.0



### 3.1 Participants

In total, 55 institutions took part. The institutions are from 17 European countries (Germany (17), France (7), Austria (6), Netherlands (5), Finland (4), Northern Ireland (2), Slovenia (2), Sweden (2), Belgium, Bulgaria, Denmark, Greece, Italy, Lithuania, Norway, Switzerland, UK, unknown). From the 55 institutions who completed the questionnaire, 41 institutions answered the producers part, 21 the users part. Thus, 7 participants took part who were both producer and user of city data.

In this section we first give a characterization of the the participating institutions. The information is extracted from the general part G-1, cf. App. I, page 85, of the questionnaire which was to be completed by all participants and which contains the three following questions:

- G-1.1 *Type of institution*: the participants were asked to classify their institutions into one of the following three classes: **Firms** (Firm, Company and Industry), **Administration** (Administration and Government Agencies), **University** (University and Research).
- G-1.2 *Task of institution*: the participants were asked to specify their tasks (possibly several) from the following eleven classes: **Mapping, Surveying, Photogrammetric Service, Planning, Software Development, Computing Service, Environmental Analysis, Architecture, Public Utility, Telecommunication, Others** (to be specified).
- G-1.3 *Size of institution*: the participants were asked to specify the size of their institutions. Here it was possible to give one answer out of five classes depending on the **number of employees**: < 10, 10 – 30, 30 – 100, 100 – 300, > 300 employees.

#### Results:

##### 1. Characterization of the participants with respect to the *type of institution* (G-1.1), cf. Fig. 2 and Table 1:

The participants are equally distributed with respect to the type of institution: 18 participants are from firms/companies/industry (in short from firms), 16 participants from government/administration (in short from administrations), 20 participants from universities/research institutions (in short from universities). One participant did not specify his institution. In the following figures and tables we indicate the cases where participants did not answer a certain question with *n. A.* (*no answer*).

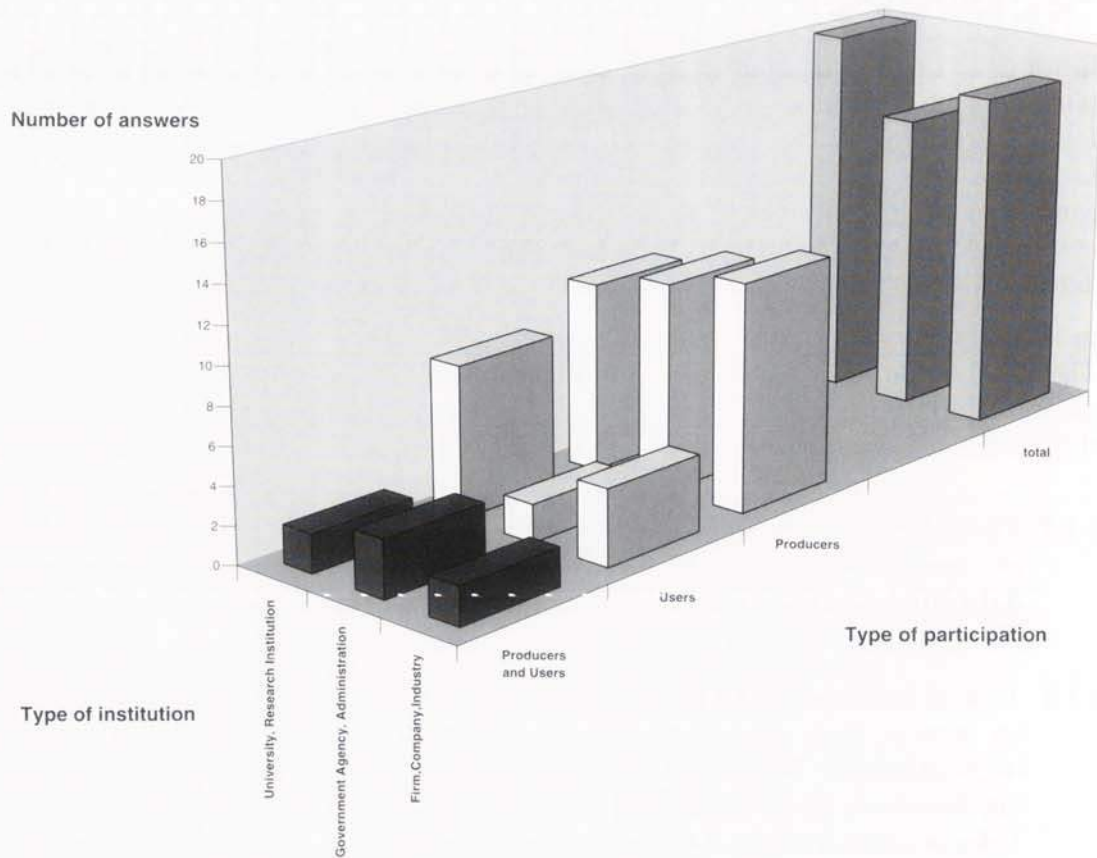


Figure 2: Characterization of the participating institutions with respect to the type of participation (users, producers and participants being both producers and users) and the type of institution (firm, administration, university). The bar heights reflect the number of participating institutions of the different types.

Type of institution	total [#]	Producers [#]	Users [#]	Producers & Users [#]
Firms, etc.	18	12	4	2
Administrations, etc.	16	11	2	3
Universities, etc.	20	10	8	2
no answer (n.A.)	1	1	0	0
total	55	34	14	7

Table 1: Characterization of the participating institutions with respect to the type of institutions. The values correspond to the number of answers from all 55 participants. The last column contains the answers of the participants who took part as both producers and users.

Tasks of Institution	total [#]	Firm [#]	Administration [#]	University [#]
Mapping	35	12	13	10
Surveying	28	10	11	7
Photogrammetric Service	21	9	8	4
Planning	19	7	6	6
Software Development	18	9	2	7
Computing Services	9	5	3	1
Environmental Analysis	20	5	5	10
Architecture	11	3	5	3
Public Utilities	7	1	4	2
Telecommunications	8	3	2	3
Others	15	5	0	10
no answer (n.A.)	0	0	0	0
total	191	69	59	63

Table 2: Characterization of the participating institutions with respect to the tasks of institutions (values corresponds to the number of answers). It was possible to give several answers per institution.

Most of the **users** (48%) are from university. 28% are from firms and 24% from administration. In contrast, the **producers** are approximately equal from firms (34%) and administrations (34%) universities (29%).

## 2. Characterization of the participants with respect to the task of institution (G-1.2), cf. Fig. 3 and Table 2:

Analyzing the participants with respect to the tasks of their institutions, most participants have tasks in mapping (35) or surveying (28). Photogrammetric service (21), environmental analysis (20), planning (19) and software development (18) are other major tasks, whereas we have had only few participating institutions with tasks in architecture (11), computing services (9) and telecommunication(8). Tasks mentioned by the participants as "Others" are mostly education and research, but also simulation, sensor development, computer graphics.

The tasks of the participants are as one could expect, except that the number of institutions with tasks in environmental analysis is surprisingly high. Tasks in mapping, surveying and photogrammetric services are significantly more often answered by the producers than by the users, whereas planning and environmental analysis are tasks for both producers and users.

**Specialists<sup>11</sup>:** The number of institutions with only one task is quite low. We have one specialist each in mapping, surveying, software development and telecommunication.

<sup>11</sup>In the following we name the participants which indicates only one possible answer out of several as *specialists*.

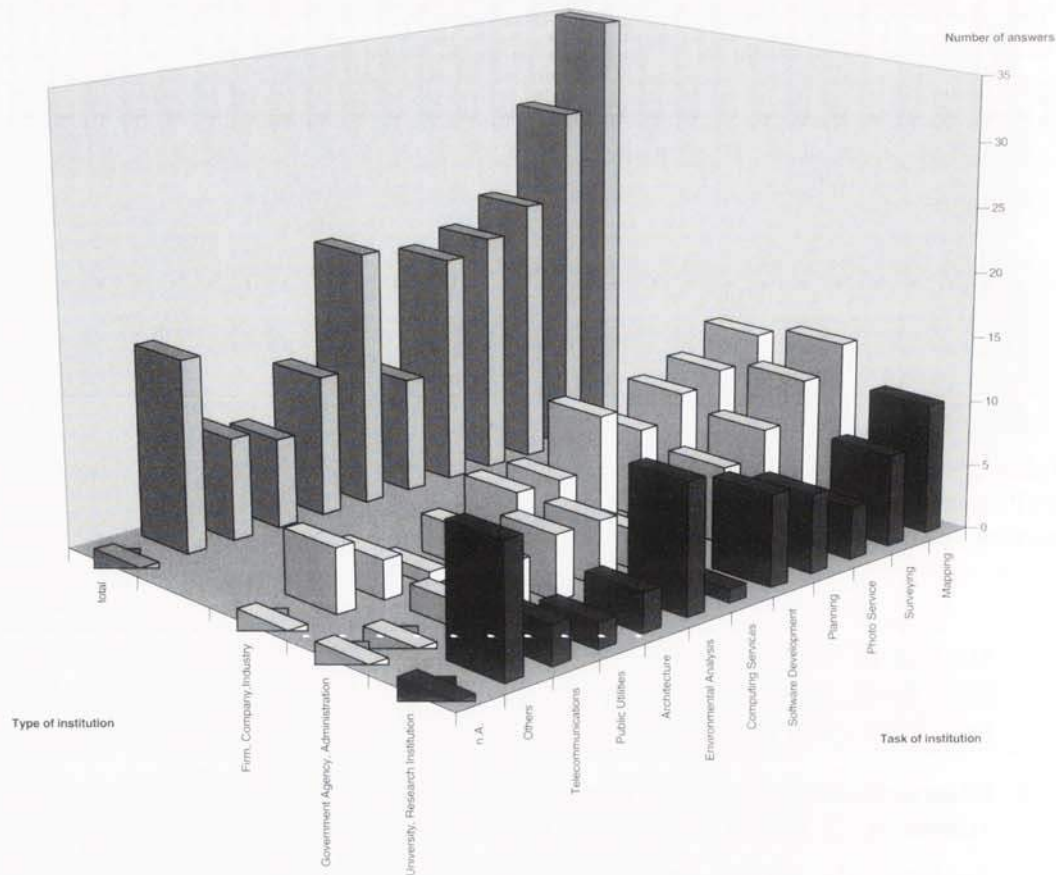


Figure 3: Characterization of the participating institutions with respect to the type of institution (firm, administration, university) and the tasks of the participating institutions (11 classes). See also comments in text. The bar heights reflect the number of participants of the different types. (n.A.: no answer).

### 3. Characterization of the participants with respect to the *size of institution* (G-1.3), cf. Table 3:

With respect to the size of the participating institutions, as expected, administrations have mostly more than 100 employees and universities at most between 10 and 30 employees. In contrast, firms cover all classes, i. e. both, small firms but also big enterprises took part.

Comparing the *tasks* with the *type* of institution, mapping, surveying, photogrammetric services and planning cover equally all three types (firm, administration, university). That is not the case for the environmental analysis: here we have 50% from universities and only 25% from each of firms and administrations.

Size (number of employees)	total [#]	Firm [#]	Administration [#]	University [#]
# empl. < 10	8	3	2	3
10 ≤ # empl. < 30	14	3	1	10
30 ≤ # empl. < 100	10	4	2	4
100 ≤ # empl. < 300	12	3	6	3
# empl. ≥ 300	9	4	5	0
no answer (n.A.)	2	1	0	0
total	55	18	16	20

Table 3: Characterization of the participating institutions with respect to the size of institutions, i. e. number of employees. One of the two participants who did not answer could not be classified to any institution type.

**Remark:** The number, the diversity, and the range of interests of the participants provide a good basis for a representative evaluation of the state-of-the art in 3D-city modeling. The majority of the users are from traditional application fields, essential new applications have, however, not yet emerged. The number of participating users from universities is high, which is due to the ongoing research efforts in this field. It does not reflect the real market situation. This is taken care of in the following analysis.

### 3.2 Participants and Clients/Suppliers-Characteristics

For the comparison and evaluation of the producers and the users situation it is important to know whether the clients named by the producers fit the group of the users and whether the suppliers named by the users fit the group of the producers. We therefore compare in this section the *tasks of the institutions* of the producers and the users with the *tasks of the clients* named by the producers (P-2.2) and the *tasks of the suppliers*<sup>12</sup> named by the users (U-3.2), cf. Fig. 4. This information is extracted from the comparison of G-1.2 (cf. page 21) with P-2.2 and U-3.2 of the producers and the users part respectively:

P-2.2 (cf. App. I, p. 87) We asked the **producers** to specify the task of the institutions of their **clients**, i. e. the institutions to whom they sell the data. In accordance with G-1.2 it was possible to specify several tasks. The predefined tasks are identical to the eleven classes in G-1.2 (cf. page 21), but here we add the class **own institution**, as the city data produced may be also used by the same participating institution.

U-3.2 (cf. App. I, p. 96) We asked the **users** to specify the task of the institutions of their **suppliers**, i. e. the institutions from whom they get the city data. In accordance with G-1.2 it was possible to indicate several tasks. The predefined

<sup>12</sup>We always mean *data* suppliers. The study is not discussing the non-mapping activities of the users, especially software development or computer services.

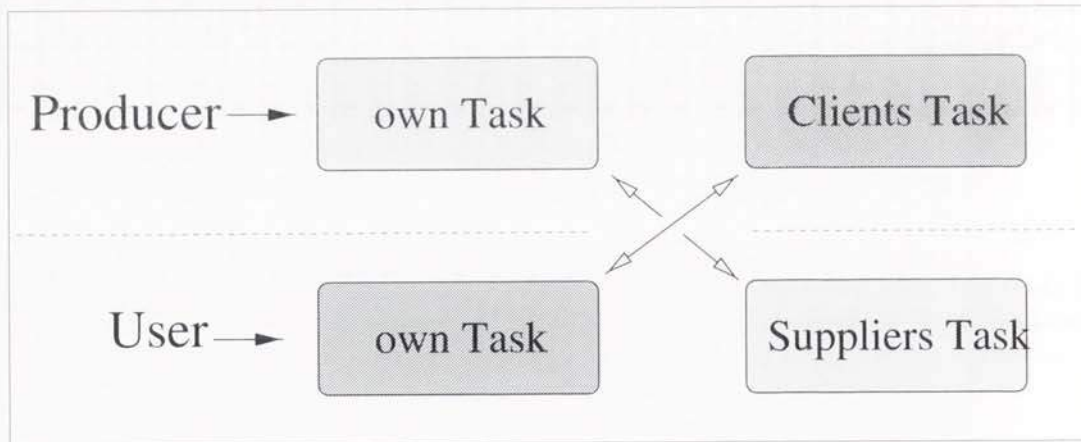


Figure 4: Relationships between the participating producers and users and the clients named by the producers and the suppliers named by the users. To compare the users needs with producers activities it is necessary that the tasks of the clients fit the group of users and vice versa that the tasks of the suppliers fit the group of producers.

tasks are identical to P-2.2, and we also add the class **own institution**, as the city data used may be also produced by the same participating institution.

### Results:

The goal of this analysis is to determine, whether it is applicable or valid to compare or evaluate the situation of the producers and users directly. This is the case if the percentages of the tasks of the clients and the users, and, vice versa, the tasks of the producers and the suppliers are approximately equal.

Table 4 contains the tasks named by the producers and the users for their own institution and for the institutions of their clients and their suppliers:

- **Producers and Suppliers of Users:**

Comparing the task of producers with the task of suppliers named by all user participants we have often similar percentages. Only fewer suppliers are from surveying, environmental analysis, software development and computing services. Users get more data from architecture than we have producers from architecture.

- **Users and Clients of Producers:**

Comparing the task of users with the task of clients, named by the producers we have greater differences. Only in planning and in environmental analysis similar percentages are given. There are significantly more clients in mapping and architecture, and especially in public utilities and telecommunication, than we have users with these tasks. Vice versa there are more users in software development and computing services than clients in these tasks named by the producers. This indicates that the users and the clients of the produc-

Tasks	producers [%]	suppliers [%]	users [%]	clients [%]
Own Institute	-	71 (73)	-	61 (55)
Mapping	76 (72)	77 (45)	43 (45)	59 (52)
Surveying	63 (59)	29 (45)	29 (36)	37 (41)
Photogrammetric Service	49 (34)	52 (73)	10 (9)	22 (28)
Planning	29 (34)	33 (27)	57 (64)	63 (69)
Software Development	32 (28)	14 (18)	38 (36)	12 (17)
Computing Service	19 (34)	5 (0)	14 (18)	2 (3)
Environmental Analysis	37 (17)	23 (27)	57 (45)	56 (59)
Architecture	15 (17)	29 (27)	33 (45)	46 (48)
Public Utilities	12 (10)	14 (18)	14 (18)	61 (79)
Telecommunication	12 (14)	5 (9)	19 (27)	44 (52)
Others	24 (3)	5 (-)	24 (9)	12 (31)

Table 4: Tasks of producers, users and their clients and suppliers. 100% in mapping in the column of the producers/users would mean that all producers/users classified their institution with mapping. 100% percentage in mapping in the column of the clients/suppliers would mean that all producers/users classified the institution of their clients/suppliers with mapping. The values in the brackets () are the percentages when omitting all participants from university (cf. text).

ers are not the same institutions! This result is also supported by the fact that we have 48% users from universities and only about 25% each from administrations and firms. Thus the group of the users is possibly not representative for the analysis of the market situation. To determine the influence of this inequality we have analyzed the answers of only those participants who are not from universities. These values are listed in Table 4 in brackets ().

- **Without Universities:**

Comparing the percentages with and without university we have **without** universities fewer producers in photogrammetric services and environmental analysis but more in computing services. Without universities the clients classified by the producers are more from public utilities.

Without universities we have fewer users in environmental analysis and a higher proportion of architects. Without universities the suppliers classified by the users are more from surveying and photogrammetric services.

Comparing the percentages of the tasks of the producers with the percentages of the tasks of the suppliers named by the users we have now significantly more producers from mapping agencies (72% vs. 45%) and computing services (34% vs. 0%) and significantly fewer from photogrammetric services than suppliers with these tasks (34% vs. 73%). Comparing the percentages of the tasks of the users with tasks of the clients named by the producers, we have now significantly less users in public utilities and telecommunication, than we have clients with these tasks.

**Specialists:** The mean number of the tasks of clients named by the suppliers is 5. Only one producer produces only for his own institution. Computing services was

mentioned (once) together with eleven other tasks.

Three users said they get data only from their own institution, four users get data exclusively from photogrammetric services.

**Remark:** Because there are differences between the user groups as recognised by the producers and the organisations classifying themselves as users we do not compare further the tasks of these two groups in respect of the specific objects in which they are interested. We are able to compare the producers and users as separate groups.

### 3.3 City Objects of Interest

Questions P-2.1 and U-3.1 of the questionnaire aim at identifying the collection of **city objects** which are of interest at present, in the near future, or not at all. We prepared three questions in this part:

P-2.1 cf. App. I, pages 86, 87 : We asked the producers for:

- object classes which are **presently** acquired
- object classes the producers **have a request for**, thus which are definitely of interest in the **near future**
- object classes the producers have **no interest in** and **reasons** for having no interest.

U-3.1 cf. App. I, pages 95, 96 : We asked the users for:

- object classes which are **presently** used
- object classes the users **have a need for**, thus which are definitely of interest in the **near future**
- object classes the users have **no interest in** and **reasons** for having no interest.

As shown in App. I on pages 86, 87, 95 and 96, we asked for six *classes* of city data, namely **buildings, vegetation, traffic network, public utility**, objects for **telecommunication**<sup>13</sup>, and **others**. We also asked for the objects produced or used by the participants with respect to the *dimensionality* of the object models (**2D**, **2½D** and/or **3D**) and the *degree of relevance* of the production or use of these data for the institutions (in the range or **weight** from 1 for no relevance to 5 for high degree of relevance).

<sup>13</sup>In the questionnaire we did not define the object class "telecommunication". It is after the analysis not clear to us which kind of data this class really contains. However, there are several participants who indicated production or use of these objects.

As **reasons** in case the participants have no interest in certain object classes we provided the following five predefined answers (several answers possible): **1. no need, 2. too expensive or not economical, 3. no information sources**, e. g. no data sources (e. g. images, 3D-city models) available, **4. no evaluation technique**<sup>14</sup> available, **5. Others**.

### 3.3.1 Results of expression of Producers Interests

**Objects in general, with interest to be produced:** The diagram in Fig. 5 shows the answers of the 41 producers concerning present or future interests in city data and the data of no need<sup>15</sup>. In this analysis we did not take into account the dimensionality of the object models, i.e. we counted the number of participants who produced the objects **at least in one** of the three dimensional model types (2D, 2½D and/or 3D). The dimensionality of the object models is treated below.

A total of 95% of all producers answered that they are already creating building data, 90% capture traffic network data and 78% capture vegetation data. Fewer participants (49%) produce data for public utilities and 37% for telecommunication purposes. Other objects mentioned by the producers are industrial facilities, relief and landscapes, waterways and cadastral boundaries. The percentage of producers who would like to capture the named objects differs only slightly. The range is between 29% for Telecommunication and 20% for Traffic Network and Vegetation. 49% of the producers would like to capture other objects than they are already capturing. This indicates that there is definitely interest in more data than is actually available.

**Specialized Producers:** Asking how many producers are specialized, i. e. only producing one type of the predefined objects, we only found two producers who produce only building data. All other objects are associated with at least one other object type.

**Objects not required:** Only 5% of all producers answered that they have no need to produce building data. Another 15% and 20% respectively answered they have no need to produce traffic network data (mainly firms) and vegetation data (mainly administrations) and 29% and 37% have no need for public utilities and telecommunication data (firms and universities).

As the percentages are influenced by the type and tasks of the participants, they do not reflect the market situation in general. E. g. the high percentage in the class

<sup>14</sup>Here we mean the evaluation of the data sources and not the assessment of the produced city models. This point was not clearly formulated and possibly lead to misunderstandings.

<sup>15</sup>Producers general requirement is "to create data with maximum usefulness to an appropriate level of quality at minimum cost!" In this context usually no mention seems to be made of quality requirements. Most producers *should* be driven by demand, but the current geospatial data market is distorted by producers creating what they *think* is required by users.

*no need* for telecommunication purposes could be expected due to the low number of participants in this application field<sup>16</sup> (cf. Section 3.1). Another reason for not collecting data might be the lack of well defined models for 3D objects ranging from simple blocks through 'wire frame' representations to a 'full' 3D representation. This especially relates to buildings but could also apply to forests (e.g. heights of each tree *or* average height *or* maximum height, etc.).

**Reasons for not producing objects:** Fig. 6 shows the reasons for not producing city data. The major reasons for not producing building data are the high costs and the lack of economic techniques (which is the most common reason). Though not as significantly as for buildings, the cost is the most often indicated reason for all objects (besides having no need, cf. also Fig. 5). Additionally the lack of information sources was mentioned often: in every class of objects there exist producers who have no access to the information or data sources to produce these objects! The lack of evaluation methods for telecommunication, public utilities and traffic network was seldom but more often mentioned than for buildings and vegetation.

With respect to the *type* of institutions (cf. Table 5) **firms** relatively often mentioned the production of vegetation data being too expensive. The same reason, but more significant, are named by the **administrations** for producing building data. Further the administrations indicated to have no information sources available for building, traffic network and vegetation data. Except for building data also the **universities** have a lack of information sources.

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<sup>16</sup>Normalization is not really possible here, as there are participants who produce or would like to produce different objects with different degrees of relevance and also with different power or extent.

Type of 3D city information produced [ % of 41 producers ]

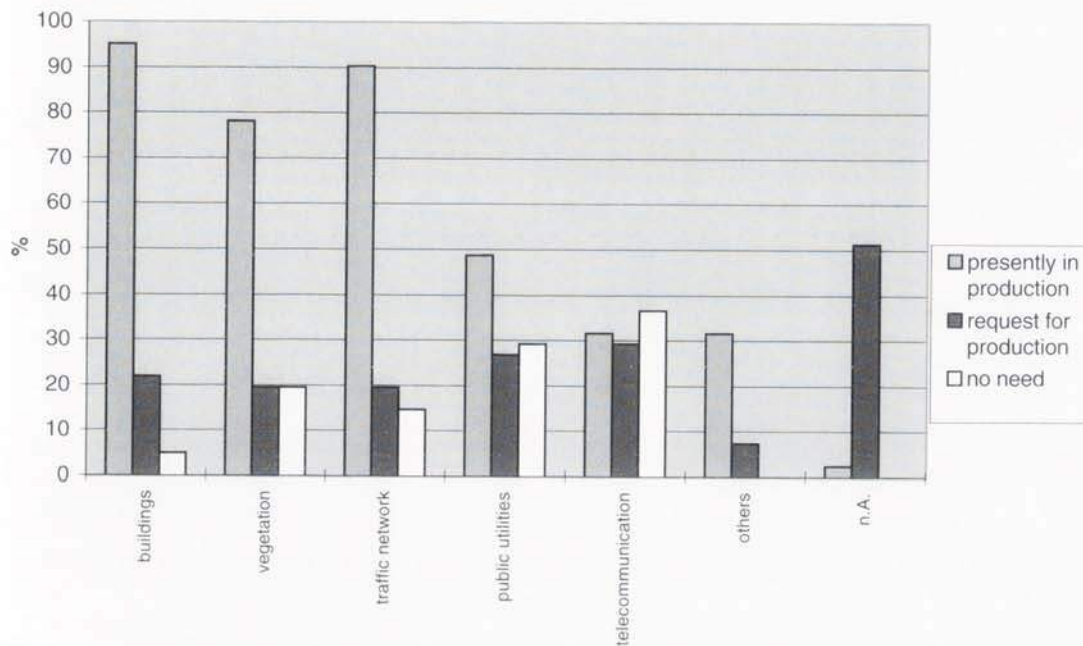


Figure 5: Objects of interest to the producers (independent from the dimensions of the object models). The grey bars correspond to the objects acquired at the moment, the dark bars correspond to the objects for which the producers have a demand with a definitive interest in production in the near future. The light bars correspond to the objects *not* of interest at present and in the near future. The heights of the bars reflect the percentages of producers (from a total of 41). E. g. 95% of 41 producers (39 producers) acquire building data at the moment. (n.A.: no answer).

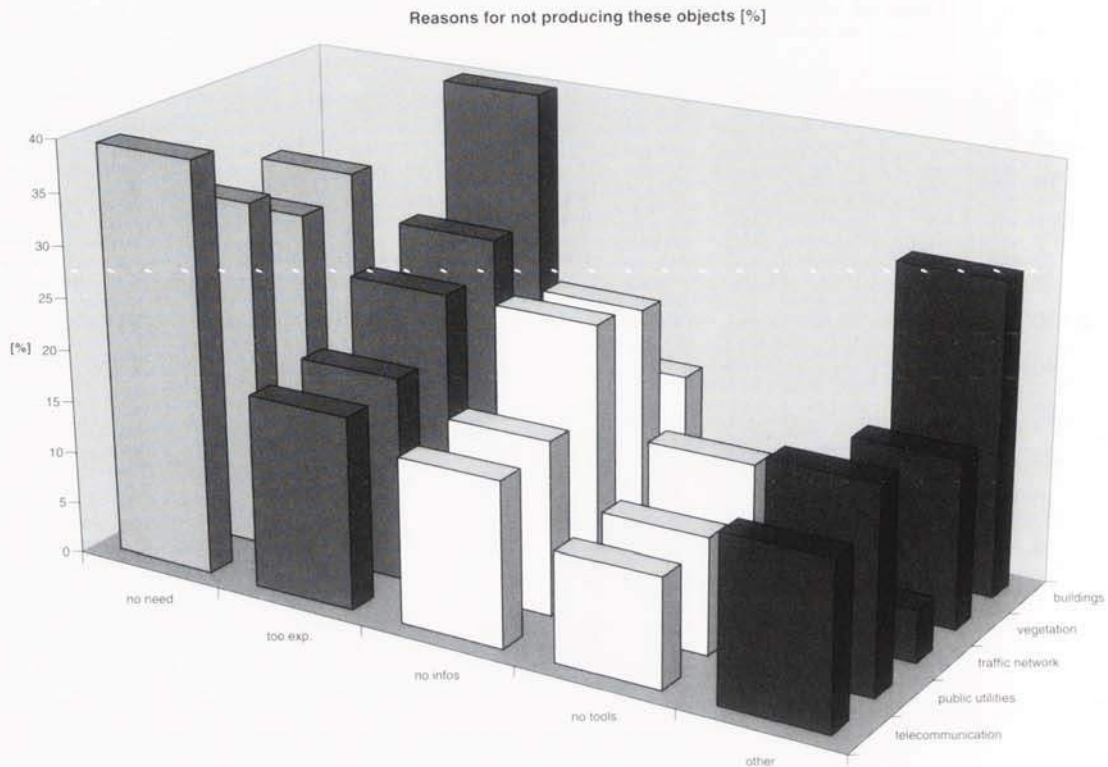


Figure 6: Reasons for having no interest in the production of the different object classes with respect to the application. No information sources ("no infos") means that the producers have no data sources available for the production. No evaluation method ("no tools") means having no technique to produce the city models. Too expensive ("too exp.") means a lack of an economical acquisition technique. The percentages are calculated for each object type separately, thus, the sum for each object class equals 100%. For a more detailed analysis cf. Table 5.

<i>Reasons for not producing these objects [ % ] / Type of Institutions</i>					
<i>firm, company, industry</i>					
	<i>no need</i>	<i>too exp.</i>	<i>no infos</i>	<i>no tools</i>	<i>other</i>
buildings	5	5	5	0	5
vegetation	4	8	4	0	0
traffic network	15	5	5	5	0
public utilities	17	6	6	3	0
telecommunication	21	5	8	3	0
<i>government agency, administration</i>					
	<i>no need</i>	<i>too exp.</i>	<i>no infos</i>	<i>no tools</i>	<i>other</i>
buildings	5	35	10	5	20
vegetation	20	16	12	0	12
traffic network	5	15	15	10	5
public utilities	0	11	3	6	14
telecommunication	5	11	0	5	13
<i>university, research institution</i>					
	<i>no need</i>	<i>too exp.</i>	<i>no infos</i>	<i>no tools</i>	<i>other</i>
buildings	0	0	0	0	5
vegetation	8	4	8	0	4
traffic network	5	0	5	0	0
public utilities	14	0	8	3	6
telecommunication	11	0	8	3	3

Table 5: Reasons for having no interest for the production of city data with respect to the type of institutions. The values in the three tables reflect the percentages of producers coming from firms (top), administrations (middle) and universities (bottom). The reasons from the left column to the right column correspond to the predefined answers in the questionnaire, i. e.: "no need", too expensive ("too exp."), no information sources ("no infos") available, no evaluation technique available ("no tools"), and "other". For a summary cf. Fig. 6.

Objects of interest with respect to dimension and degree of relevance, cf. Table 6:

1. **2D-Models:**

- (a) **Presently** producing: The number of producers of 2D objects, except for telecommunication, is relatively high. The most often indicated city data is traffic network data, followed by buildings and vegetation. They are mostly produced by mapping, surveying and photogrammetric services, from both firms and administration institutions.
- (b) **Would like to** produce: The number of 2D objects which the participants would like to produce is low. The maximum is given for telecommunication: here two firms and two administrations indicated interest. Universities have no interest to produce 2D data at all.

2. **2½D-Models:**

- (a) **Presently** producing: For building data and traffic network data there are fewer objects produced in 2½D than in 2D and 3D. Firms and universities acquire more buildings and vegetation whereas administrations, as one could expect, are mostly interested in the production of public utilities data. With respect to the task of the institutions, buildings, vegetation and traffic network data are mainly produced by mapping, surveying, photogrammetric services but also significantly by software development institutions.
- (b) **Would like to** produce: In 2½D there is a significant interest for public utilities and telecommunication, followed by vegetation. These participants are mainly administration institutions and with the tasks of mapping, surveying and environmental analysis.

3. **3D-Models:**

- (a) **Presently** producing: Most 3D data produced at the moment are buildings, followed by traffic network data. These data are mainly acquired by firms. Only few administrations and universities acquire 3D data. If they do, they focus on the production of building data. Buildings are produced by mapping agencies, surveying agencies, photogrammetric services, planning agencies, or agencies concerned with environmental analysis.
- (b) **Would like to** produce: Except for vegetation there is significant interest for buildings, traffic network, public utilities and telecommunication data. Maximum interest on 3D buildings is indicated by administrations, they on the other hand have no interest for vegetation in 3D (they prefer 2½D vegetation data). Buildings and traffic network data are produced by institutions with the same tasks as already mentioned for the presently producing participants and additionally from architects.

Mean Degrees of Relevance (range: 1-5) 41 producers							
<i>Objects acquired</i>							
	2D	#	2.5D	#	3D	#	total #
buildings	4,59	18	4,87	15	4,52	24	4,63 57
vegetation	3,93	16	3,86	14	3,44	10	3,78 40
traffic network	4,00	20	4,46	13	4,85	13	4,37 46
public utilities	3,50	12	4,22	9	3,20	5	3,69 26
telecommunication	4,25	4	3,75	4	4,00	6	4,00 14
others	4,67	6	5,00	6	4,33	9	4,62 21
<i>Objects not acquired at present</i>							
	2D	#	2.5D	#	3D	#	total #
buildings	5,00	1	4,50	2	4,00	9	4,17 12
vegetation	3,00	3	3,00	4	4,50	2	3,33 9
traffic network	4,00	2	4,00	2	3,80	6	3,88 10
public utilities	3,67	3	3,67	6	3,00	5	3,43 14
telecommunication	3,00	4	3,60	5	3,75	4	3,46 13
others	0,00	0	3,00	1	3,00	3	3,00 4

Table 6: Objects of interest with respect to the different *dimensions* of the object models and the *mean degrees of relevance* of these object models for the producing institutions. The 2D, 2½D and 3D columns contain the *mean degrees of relevance* of these object models, the values in the # columns correspond to the *number of answers* from a total of 41 producers. It was possible to answer for several dimensionalities of object models.

#### 4. Degree of relevance of producing city data:

- Presently** producing: Maximum degree of relevance of 4.9 was determined for building data 2½D and traffic network data in 3D. Also buildings in 2D and 3D are of high relevance with 4.6 and 4.5 resp. A minimum degree of relevance was found with 3.2 in 3D public utility data. For public utilities there was a clear preference for 2½D data.
- Would like to** produce: 9 from 41 participants would like to produce 3D building data with a mean degree of relevance of 4.0. Other mean levels of relevance are insignificant due to the small number of answers. That is the case e. g. for the 2D building level of relevance of 5.0, which is the relevance of only one participant who, additionally, also has interest to produce 3D data<sup>17</sup>.

<sup>17</sup>This also holds for the high degrees of relevance named for vegetation in 3D, where only 2 participants have interests for producing those data at the moment or in the near future. The level of relevance of producing vegetation at the moment is more certain. It lies between 3.9 in 2D and 3.4 in 3D.

**Remark:** The majority of **producers** currently acquire building data, traffic network data and vegetation data as 3D city objects in 3D,  $2\frac{1}{2}$ D and 2D. There is a definite lack of economical techniques for **producing** 3D-city data. In addition a surprisingly great lack of data sources, i.e. no access to data, is to be observed. The most increasing interest in the near future can be found for buildings and vegetation in 3D, followed by vegetation in  $2\frac{1}{2}$ D, traffic network in  $2\frac{1}{2}$ D and public utilities in 2D. These data must be interpreted with respect to the types of institutions and tasks of the producers.

### 3.3.2 Results of expression of Users Interests

**Objects in general of interest to use, cf. Fig. 7:** The diagram shows the answers of the 21 users concerning the present or future interests of city data and the data of no need to use. In this analysis we did not take into account the dimension of the object models, i. e. we counted the number of participants who use the objects at least in one of the three model types (2D,  $2\frac{1}{2}$ D and/or 3D). The dimension of the object models is treated below.

Around 95% of the users answered that they are already using building data. Another 76% indicated that they are using traffic network data and 71% vegetation data. Fewer participants (33%) use data for public utilities and 29% for telecommunication purposes. Other objects mentioned by the users are e. g. land cover, walls and fences, DEM's and reliefs, and hydrography. Asking for objects the participants would like to use, 52% answered vegetation data. 43% answered building data, followed by public utilities and telecommunication (29%) and traffic network (24%).

All together 76% of the users indicated they need further data than they are already using. That means that there is definitively an interest for more data than is actually available at present.

**Specialized Users:** Asking about how many users are specialized, i. e. using only one type of the predefined objects, only one participant uses only building data and only one participant uses only traffic network data. All other objects are associated with at least one other object type.

**Objects not required:** Only one of the users from a university has no need for using building data and only one institution (university) has no need for vegetation data. 15% of the users answered that they do not need traffic network data (more firms than administrations). Telecommunication and public utilities (both, firms and administrations) are not needed by approximately 30% of the users.

Type of 3D city information used [ % of 21 users ]

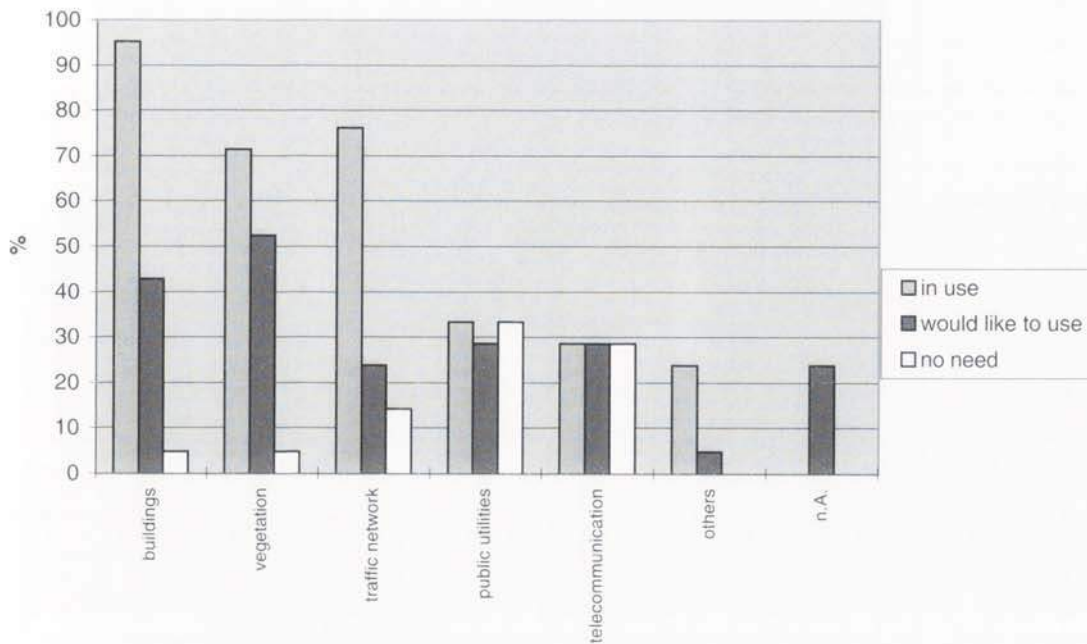


Figure 7: Objects of interest for the users (independent of the dimensionality of the object models). The grey bars correspond to the objects used at the moment, the dark bars correspond to the objects which the users would like to use, thus, with a definitive interest in using them in the near future. The light bars correspond to the objects *not* of interest at present and in the near future. The heights of the bars reflect the percentages of users (from a total of 21) who have interest or no interest. E. g. 95% of 21 users (20 users) use building data at the moment. (n.A.: no answer).

**Reasons for not using the objects:** Fig. 8 shows the reasons for not using city data. For building data the most frequently given reason is the lack of information sources! Though not as significant, cost was also often mentioned for both buildings and vegetation. Additionally in every class of object there exist users who indicated that they have no evaluation methods ("no tools") of using the data. "No need" was indicated most frequently only for telecommunication and public utilities.

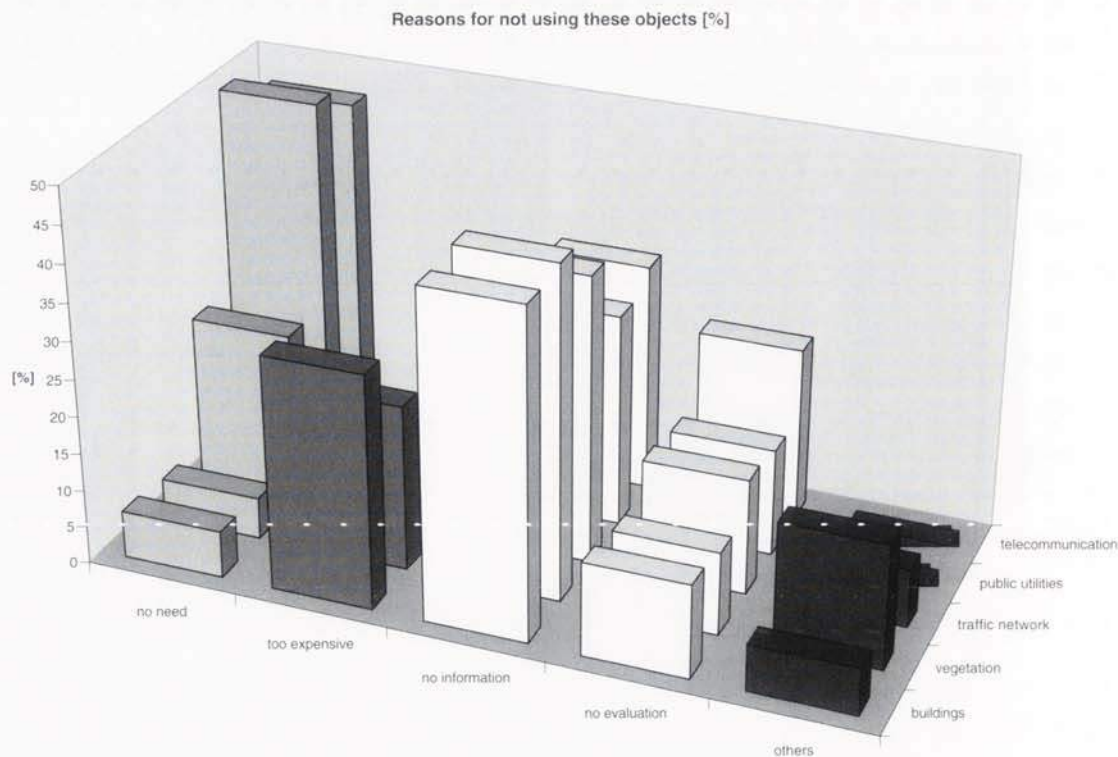


Figure 8: Reasons for having no interest in the use of the different object classes. No information sources ("no information") means that the user have no city data available or no access to it. No evaluation method ("no evaluation") means having no means of using the 3D city data. The percentages are calculated separately for each object type, thus, the sum for each object class equals 100%. For a more detailed analysis cf. Fig. 7.

Comparing the answers with the *type* of institutions (cf. Table 7), **firms** indicated that using building and vegetation data is too expensive, for all objects there are firms who have no information sources, i.e. no city models, available<sup>18</sup>. Except for public utilities the **administrations** have no information sources available, especially for building and vegetation data. For all objects there are institutions who have no evaluation methods or tools for using the data. The most often given reason from **university** and research institutions was that they do not have access to the information sources. But also here, for all objects there are institutions, who indicated they have no evaluation methods available.

<sup>18</sup>The study does not allow to tell, whether the cost of data is too high, or whether the cost of using the data (e.g. software, data check/correction, processing operator) is too high compared with the value of the application to the user organisation

<b>Reasons for not using these objects [ % ] / Type of Institutions</b>					
<b>firm, company, industry</b>					
	<b>no need</b>	<b>too exp.</b>	<b>no infos</b>	<b>no tools</b>	<b>other</b>
buildings	0	13	6	0	0
vegetation	6	11	11	0	6
traffic network	15	0	8	0	0
public utilities	21	0	7	0	0
telecommunication	15	0	8	0	0
<b>government agency, administration</b>					
	<b>no need</b>	<b>too exp.</b>	<b>no infos</b>	<b>no tools</b>	<b>other</b>
buildings	0	6	13	6	6
vegetation	0	0	11	6	6
traffic network	8	8	8	8	0
public utilities	21	0	0	7	0
telecommunication	15	0	8	15	0
<b>university, research institution</b>					
	<b>no need</b>	<b>too exp.</b>	<b>no infos</b>	<b>no tools</b>	<b>other</b>
buildings	6	13	25	6	0
vegetation	0	11	22	6	6
traffic network	0	8	23	8	8
public utilities	7	7	21	7	0
telecommunication	15	0	15	8	0

Table 7: Reasons for having no interest in the use of city data with respect to the type of the participating institutions. The values reflect the percentages of users from firms (top), administrations (middle) and universities (bottom). The reasons from the left column to right column correspond to the predefined answers in the questionnaire, i. e.: "no need", "too exp." (too expensive), "no infos" (no information sources available), "no tools" (no evaluation technique available), and "other". For a summary cf. Fig. 8.

Objects of interest with respect to the dimension and degree of relevance, cf. Table 8:

1. **2D-Models:**

- (a) **Presently** using: The number of users of 2D objects is higher than of  $2\frac{1}{2}$ D and 3D data. Traffic network data is most often used, followed by vegetation and buildings. There is no clear preference who uses the objects with respect to the task of institution. Comparing the answers with the type, administrations and universities use building data, firms and universities use vegetation data and all three types use traffic network data.
- (b) **Would like to** use: The number of additional 2D objects which the participants would like to use is low. The maximum is indicated by the administrations (mainly for planning and architectural tasks) for telecommunication and public utility data.

2.  **$2\frac{1}{2}$ D-Models:**

- (a) **Presently** using: In general, there are fewer objects produced in  $2\frac{1}{2}$ D than in 2D. The objects mostly used in this dimension are buildings and vegetation data. Within this group universities are using significantly more data than firms and administrations. This could be expected as significantly more users in this survey are from universities. Buildings are mainly used for environmental analysis tasks, followed by telecommunication and architecture.
- (b) **Would like to** use: The need for  $2\frac{1}{2}$ D data is evenly distributed for all objects. In particular institutions with environmental analysis tasks indicated a need for *all* object types.

3. **3D-Models:**

- (a) **Presently** using: Most 3D data already used at the moment are buildings, followed by traffic network data (this corresponds well with the producers view). Buildings are mainly used by universities and firms (with tasks in planning, software development, and for others, e. g. simulation, computer graphics). Traffic network is mainly used by administration and universities (with tasks in environmental analysis).
- (b) **Would like to** use: The data which they would most like to use is building and vegetation data. No users, though there are some participants in this application, have a need for 3D public utilities data and data for telecommunication purposes.

Building data is needed by firms, administrations and universities. Vegetation is needed by firms and universities, but not needed by the administrations. With respect to the task of institutions these data are of interest for participants from planning, environmental analysis and architecture, telecommunication and software development.

Mean Degrees of Relevance (range: 1-5) 21 users							
<i>Objects used</i>							
	2D	#	2.5D	#	3D	#	total #
buildings	3,89	9	4,50	8	4,50	10	4,30
vegetation	3,50	10	3,67	6	4,00	2	3,61
traffic network	4,08	12	4,50	2	3,00	7	3,76
public utilities	4,33	6	5,00	2	3,50	2	4,30
telecommunication	4,67	3	3,50	2	4,00	2	4,14
others	3,80	5	5,00	3	4,50	4	4,33
<i>Objects not used at present</i>							
	2D	#	2.5D	#	3D	#	total #
buildings	0,00	0	4,00	2	4,29	8	4,23
vegetation	2,00	1	4,33	4	3,57	7	3,69
traffic network	0,00	0	3,67	3	4,50	2	4,00
public utilities	3,67	3	3,00	3	0,00	0	3,33
telecommunication	2,67	3	3,33	3	0,00	0	3,00
others	0,00	0	0,00	0	5,00	1	5,00

Table 8: Objects of interest to the users with respect to the different dimensions of the models and the mean degrees of relevance of these object models for the users. The 2D, 2½D and 3D columns contain the *mean degrees of relevance* of these object models, the values in the # columns correspond to the *number of answers* from a total of 21 users. It was possible to answer for several dimensions of object models.

#### 4. Degree of Relevance of using city data:

- (a) **Presently using:** The mean degree of relevance for using buildings in 2½D and 3D was estimated as 4.5, whereas the level of relevance for 2D building is 3.9. Most participants use 2D vegetation with a level of relevance of 3.5. In 2½D and 3D the number of users decrease but with increasing degree of relevance. The minimum degree of relevance was found for 3D traffic network with 3.0, here with a mean degree of relevance of 4.0 and significantly more answers, the traffic network data in 2D seems to be more important (or established).
- (b) **Would like to use:** There is a significant interest for 3D building data (mean degree of relevance of 4.3). The maximum degree of relevance was found for 3D traffic network data, which however is only indicated by 2 users, therefore statistically insignificant. Vegetation in 3D is needed most but with a lower degree of relevance as 2½D.

**Remark:** The majority of **users** currently needs 3D, 2½D and 2D building data, traffic network data and vegetation data as city objects. The lack of information sources, as well as the high costs (for buildings and vegetation acquisition) currently hinder a broader use. But there is as well a lack of tools for using 3D city data, which is probably due to the limited availability of those types of data. The most increasing interest can be found for buildings and vegetation in 3D, followed by vegetation in 2½D, traffic network in 2½D and public utilities in 2D. These results must be interpreted with respect to the institution types and tasks of the users.

### 3.3.3 Comparison between Producers and Users Interests

**Object classes of general interest:** The objects of interest for both the producers and the users are listed in Table 9. The values reflect the percentage of indicated objects with respect to the number of producers and users, e. g. 95% of the producers and 95% of the users answered to already producing or using building data.

Objects	Present		Future	
	Producers [%]	Users [%]	Producers [%]	Users [%]
Buildings	95 (100)	95 (100)	22 (28)	43 (55)
Vegetation	78 (86)	71 (73)	20 (21)	52 (55)
Traffic Network	90 (97)	76 (82)	20 (17)	24 (18)
Public Utilities	49 (62)	33 (36)	27 (31)	29 (27)
Telecommunication	32 (41)	29 (36)	29 (34)	29 (45)
No answer	2 (-)	- (-)	51 (52)	24 (36)

Table 9: Objects of interest for producers and users. The values are percentages of the number of producers resp. of users (e. g. 100% in the column of the producers would mean all producers have an interest.). The values in brackets ( ) indicate the percentages of the participants when omitting all participants from universities or research institutions (cf. Section 3.2, p. 27).

Comparing the percentages of **present** activities, in traffic network and public utilities there are significantly more producers than users. Buildings, vegetation and telecommunication data are acquired and used (approximately) equally at the moment. In the column of required object types in the **future**, in buildings and vegetation we have significantly more replies from users than from producers, while the percentages for the other objects are similar. At present there is more activity in using buildings and traffic network data whereas in the future also vegetation data in 2D and 2½D will be required. Analyzing the columns of the users it must be taken into account, that 48% of the users are from universities. This might be the reason for the relatively low percentages named for the present production of public utilities and telecommunication purposes.

Focusing on the producers, which are equally from firms, administrations and uni-

versities, for each object type approximately 25% of the participants, and in total 50% of the producers have an interest in capturing more city data than at the moment. Similar every fourth user indicated a need for traffic network, public utilities and telecommunication data.

To analyze the influence of the different types of users the values in brackets in Table 9 reflect the percentages when omitting all participants (producers and users) from university. The values indicate that the influence is not significant. Further, the differences show that producers from universities acquire less public utility data and that users from universities have less need for telecommunication data but in total will have a greater need for other types of data in the future.

**Objects of interest with respect to the dimensions of the models for the different object classes and the degrees of relevance:** The comparison between producers and users present and future demands with respect to the **different dimensional models** and the **degrees of relevance** leads in detail to the following results:

1. **Buildings** are of greater interest for producers in 2D,  $2\frac{1}{2}$ D and 3D with slightly more relevance in  $2\frac{1}{2}$ D. Users indicated  $2\frac{1}{2}$ D and 3D with the same degree of relevance, 38% of users have an interest in 3D buildings in the future.
2. While at present **vegetation** data have the lowest level of relevance in 3D, it is of higher interest (for universities and firms) to produce these data in the future. Presently the users are using vegetation data more often in 2D and  $2\frac{1}{2}$ D. In the future 33% of the users have a need for vegetation data in 3D, but then with a lower level of relevance.
3. **Traffic network** data is produced mainly in 2D while  $2\frac{1}{2}$  and 3D have a higher degree of relevance to users. 15% of producers are interested in producing these data in 3D in the future. 50% of users use traffic network data in 2D at the moment and 30% use the data in 3D but with lower relevance. In the future approximately 10% answered that they will have a need for  $2\frac{1}{2}$  and 3D data, with more importance attached to 3D.
4. Though few more producers acquire 2D data for **public utilities** they indicate  $2\frac{1}{2}$ D data to have a higher degree of relevance. There is also interest for producing 3D data presently and in the future. 50% of the users use 2D data. 10% use 3D data at the moment, but no user indicated further interest in those data in the future.
5. In **telecommunication** the present and future production and use exist in all dimensions. At the moment with the highest level of relevance in 2D, in the future in 3D. 10% use 3D data at the moment, but < 10% of the users are interested in 3D data in the future.

Objects of interest to at least 10 % of the producers and 10 % of the users				
Participants	Producers		Users	
Dimensions	Present	Future	Present	Future
3D	B, V, TN, TC, PU	B, TN, PU,	B, TN	B, V
2½D	B, V, TN, PU	PU, TC	B, V	V, TN, PU, TC
2D	B, V, TN, PU		TN, V, B, PU, TC	PU, TC

Table 10: **Objects of interest** to at least 10% of the producers and at least 10% of the users, presently and in the future. Abbreviations are used as follows: B = Buildings, V = Vegetation, TN = Traffic Network, PU = Public Utility, TC = Telecommunication.

Objects with degree of relevance of > 3.5 (range 1 - 5)				
Participants	Producers		Users	
Dimensions	Present	Future	Present	Future
3D	TN, B, TC	V, B, TN	B, V, TC, PU	TN, B, V
2½D	B, TN, PU, V, TC	B, TN, PU, TC	PU, TN, B, V, TC	V, B, TN
2D	B, TN, V, PU	B, TN, PU	TC, PU, TN	PU

Table 11: **Objects of high degree of relevance**, i. e. at least 3.5 within a range from 1 for no relevance to 5 for high degree of relevance, for producers and users, presently and in the future. Abbreviations are used as follows: B = Buildings, V = Vegetation, TN = Traffic Network, PU = Public Utility, TC = Telecommunication.

Table 10 contains all objects of interest for at least 10% of the producers or the users; Table 11 shows the objects which are of high degree of relevance (at least with a mean value of 3.5 in the range from 1 to 5). Table 12 shows the intersection of the two, thus, only the objects which are of interest to at least 10% of the producers or the users **and** of high degree of relevance (> 3.5). The table reflects the following situation:

- **Buildings** in 2½D and 3D are highly requested by producers and users both at present and in future.
- **Traffic Network, Vegetation, Telecommunication, Public Utility** are needed but the required dimensionality of modeling object types appears to be unclear:
- **Conclusions**
  - In **Vegetation** and **Traffic Network** we have diverging interests in 2½D and 3D (3D vegetation is required but with lower relevance, Traffic Network data is required at present in 2D and in future of interest to the producers, but not needed by the users).
  - In **Public Utility** data we have found diverging interests for 2D and 2½D.
  - In **Telecommunication** the demands with respect to the dimensionality remain unclear.

Objects of interest to at least 10 % and with degree of relevance > 3.5				
Participants	Producers		Users	
Dimensions	Present	Future	Present	Future
3D	B, TN, TC	B, TN	B	B
2½D	B, V, TN, PU	PU, TC	B, V	V, TN
2D	B, V, TN, PU		TN, PU, TC	PU

Table 12: **Objects of interest and high degree of relevance:** Objects of interest to at least 10% and with a degree of relevance of at least 3.5 for producers and users, presently and in the future. Abbreviations are used as follows: B = Buildings, V = Vegetation, TN = Traffic Network, PU = Public Utility, TC = Telecommunication.

**Remark:** There is a common future need for building data in 3D. Traffic network data in 3D and 2½D, Vegetation in 2½D and Public Utilities data in 2½D and 2D are important for producers or users in future. The present and future needs for 3D city data for producers and users, however, do not correspond well, probably due to the fact, that the clients of the participating producers are not corresponding to the participating users and the suppliers of the participating users do not correspond to the participating producers. It has been shown that the definition of 2½D and 3D representation probably appeared unclear. Thus, when interpreting the given results distinguishing between the different dimensional models we must be aware of a certain error rate in the answers. In view of the ongoing survey the conceptual differences and the need for semantically and technically well defined exchange and storage formats require much more investigation and clarification.

### 3.4 State of the Art in Acquisition and Use of City Data

In this section we focus on the *state of the art* in the acquisition and the use of city data. It contains a summary of the answers to the questionnaire concerning the *technical environment* of the producers (P-2.3) and the users (U-3.3), the *input data* and the *output data* of the producers and the users, i. e. the data sources of the producers (P-2.4), the produced city data (P-2.5), the city data as input data for the users (U-3.4) and the output of the users, i. e. the results or purposes of the users (U-3.5).

#### 3.4.1 Technical Environment

##### 1. **Producers** (Questionnaire P-2.3, cf. App. I, p. 87):

To describe the **Technical Environment** of the **producers** we asked for the *hardware* and the *software* available for the production of city data. For specifying the *hardware*, we distinguish between **Photogrammetric Equipment** (Analytical Plotter (AP), Digital Photogrammetric Station (DPS), Scanners,

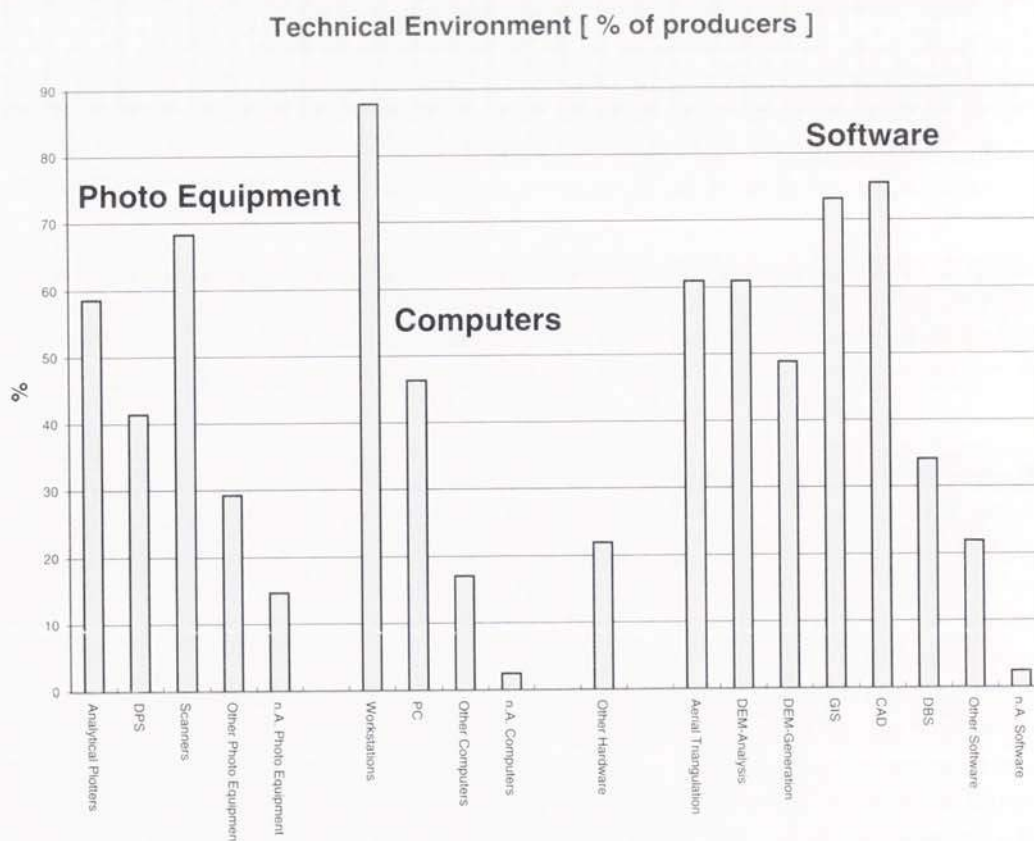


Figure 9: Technical Environment of the producers as a percentage. E. g. 41% of the producers have Digital Photogrammetric Workstations (DPS). For more detailed information cf. Table 13. (n.A.: no answer).

others) and **Computers** (Workstations, PCs<sup>19</sup>, others). For characterizing the *software* which is available for the production we asked for **Aerial Triangulation**, **DEM-Analysis** or **Visualization**, **Automatic DEM Generation**, **GIS**, **CAD**, **DBS**, **Others**.

#### Results:

Fig. 9 shows the technical environment of the producers in summary. Table 13 shows the technical environment of the producers in comparison with the type and the tasks of their institutions.

<sup>19</sup>We did not predefine the answer PC in the questionnaire, but we extracted the PCs, named by the participants as "Others" for an individual analysis.

Technical Environment of the producers															
	Task of Institution [ % of Task ]											Type of Institution [ % of Producers ]			
	Mp	Sv	Ph	Pl	SW	CS	EA	Ar	PU	Tc	O	total	firms	gov.	unis
Analyt. Plot.	70	73	95	58	31	38	53	17	33	50	70	59	64	57	58
DPS	43	50	60	33	31	38	33	17	50	50	30	41	29	57	33
Scanners	70	69	70	58	69	88	60	50	67	100	80	68	64	79	58
Oth. Pho. Equ.	33	38	40	33	15	38	20	33	17	0	30	29	36	29	25
n.A. Photo Equ.	3	2	0	2	4	1	4	3	1	0	10	15	14	7	25
Workstations	93	88	95	67	69	75	80	50	83	100	100	88	71	93	100
PC	43	42	40	83	46	63	73	83	67	25	30	46	50	36	50
Other Comp.	23	19	20	17	15	25	13	0	0	0	30	17	14	14	25
n.A. Computers	0	0	0	0	1	0	0	0	0	0	0	2	7	0	0
PC & Workst.	37	31	35	50	23	38	53	33	50	25	30	37	29	29	50
Other Hardware	20	23	25	25	15	25	20	33	17	25	30	22	21	21	25
Aerial Triang.	70	81	95	50	38	38	40	17	33	75	70	61	71	50	58
DEM-Analysis	67	69	85	42	54	38	60	0	33	75	80	61	71	43	67
DEM-Gen.	50	42	55	33	62	50	47	0	33	50	70	49	64	14	67
GIS	80	73	80	92	69	88	80	67	100	75	80	73	71	86	58
CAD	77	69	75	92	85	100	67	100	83	50	70	76	93	71	58
DBS	40	38	45	50	38	50	40	50	50	25	30	34	50	36	17
Other Software	17	19	15	33	23	25	27	50	50	50	20	22	21	29	17
n.A. Software	0	0	0	0	0	0	0	0	0	0	10	2	0	0	8

Table 13: Technical Environment of the producers in comparison with the *tasks* (left table) and *types* (right table) of their institutions. The values reflect the percentages calculated in the classes separately. E. g. 70% of the producers with tasks in mapping and 64% of the producers being a firm have analytical plotters. The tasks and the types correspond to the predefined classes in the questionnaire, i. e. the *task classes* are: mapping (Mp), surveying (Sv), photogrammetric service (Ph), planning (Pl), software development (SW), computing service (CS), environmental analysis (EA), architecture (Ar), public utility (PU), telecommunication (Tc), others (O). The *type classes* are: firm, administration/government (gov.), and university (unis). For a summary cf. Fig. 9. (n.A.: no answer).

- **Photogrammetric Equipment:**

59% of the producers have Analytical Plotters (AP), 41% producers use Digital Photogrammetric Stations (DPS) and 68% have scanners in use. The high number of scanners is possibly due to the non-specified scanner types. Thus, it may also contain desktop scanners and not only photogrammetric scanners.

Approximately 70% of those who indicated having the equipment also specified the number of machines they have. In this group the mean number of AP of a producer is 3.6, of DPS it is 2.6 and of scanners it is 1.9. Other equipment, named by the producers, are mainly analog plotters and analog and digital cameras.

Only 15% of the producers do not use photogrammetric equipment at all.

- **Computers:**

Only 12% of the producers do not have workstations. Those who have no workstation have a high number of PC's (e. g. 30). 37% of the producers have both workstations and PCs.

- **Software:**

Only 24% of the producers have **no** GIS or CAD. 39% have **no** software for Aerotriangulation or DEM Analysis/Visualization.

49% **have** software for automatic DEM generation. 34% use DBS and 22% specified other software, e. g. orthophoto generation, virtual reality (VR), pattern recognition, Fotomass, Laser Scan LITES-2.

- **With respect to the type of institutions:**

Maybe the most interesting result is here, that already 41% of producers use DPSs. They include 50% from administrations and 25% from universities or firms. From the 49% who produce DEMs automatically most are from firms and universities. Only 10% are from administration.

From the producers who do not use photogrammetric equipment 50% are from university.

- **With respect to the task of institutions:**

In mapping, surveying and photogrammetric services the availability of APs, DPSs and workstations is highest (between 60% and 90% for APs, 37% and 57% for DPSs, and between 80% and 90% for workstations). But also 43% of the institutions with tasks in public utility use DPSs and except for planning and architecture more than 50% use workstations. The percentage of having scanners is with 78% highest in computing services. Workstations are mostly established in mapping, surveying and photogrammetric service. GIS is mostly established in public utilities and computing services, CAD also in computing services. Architects mostly have CAD on PC platforms.

## 2. Users (Questionnaire U-3.3, cf. App. I, p. 96):

To describe the **Technical Environment** of the **users** we asked them for the *hardware* and for the *software* available for the use of city data. For specifying the *hardware*, we distinguish between **Computers** (workstations, PCs, others) and **Specialized Hardware** (stereo display, large format plotters, others). For characterizing the *software* available we asked for **DEM-Analysis or Visualization**, **GIS**, **CAD**, **DBS**, simulation software (wind, noxious, noise, electromagnetism, light), others.

### Results:

Fig. 10 shows the Technical Environment of the users in general. Table 14 shows the answers of the producers in comparison with the type and the tasks of their institutions.

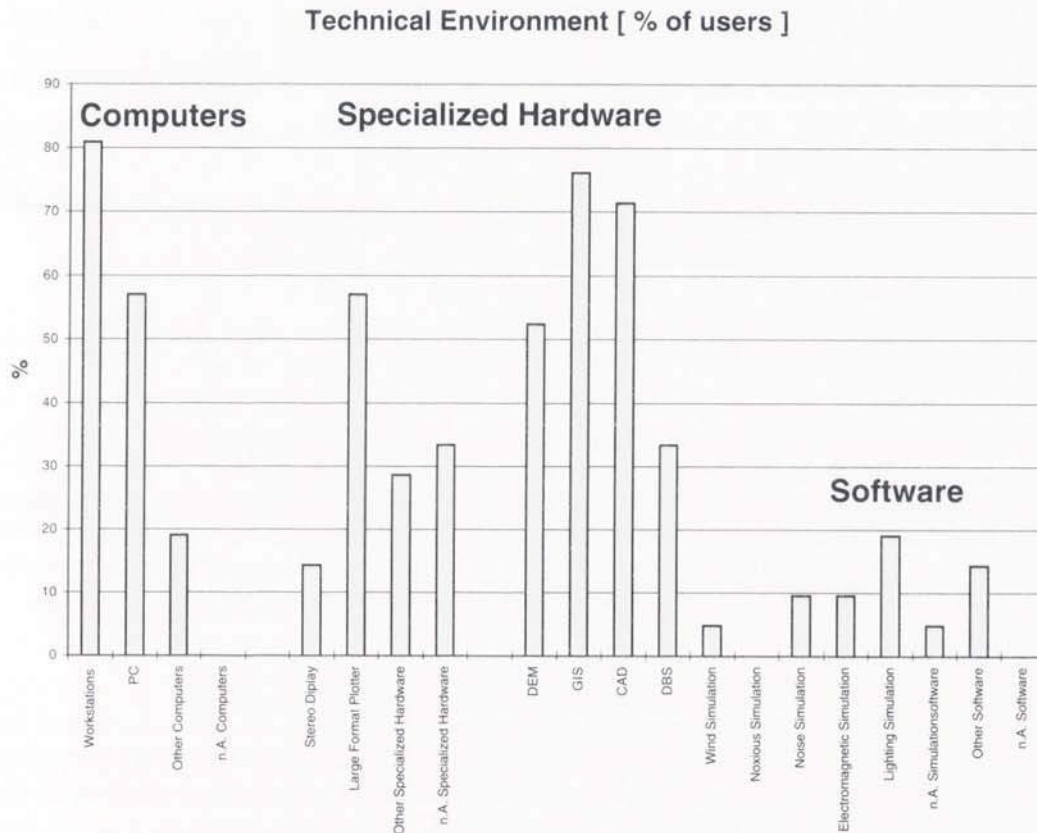


Figure 10: Technical Environment of the users in percentage. E. g. 81% of the users have workstations. (n.A.: no answer).

<i>Technical Environment of the users</i>															
	<i>Task of Institution</i> [ % of Task ]											<i>Type of Institution</i> [ % of Users ]			
	<i>Mp</i>	<i>Sv</i>	<i>Ph</i>	<i>Pl</i>	<i>SW</i>	<i>CS</i>	<i>EA</i>	<i>Ar</i>	<i>PU</i>	<i>Tc</i>	<i>O</i>	<i>total</i>	<i>firms</i>	<i>gov.</i>	<i>unis</i>
Workst.	90	67	100	83	50	33	75	57	67	100	100	81	50	80	100
PC	60	33	0	8	63	67	67	100	33	0	40	57	50	60	60
Other Comp.	30	0	0	0	0	0	17	14	0	40	40	19	17	0	30
n.A. Comp.	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0
PC & Workst.	50	0	0	8	13	0	42	57	0	0	40	38	0	40	60
Stereo Display	10	33	50	67	13	33	17	14	33	40	0	14	17	40	0
L. Form. Pl.	70	50	50	50	50	33	58	71	67	80	20	57	67	80	40
Oth. Spec. HW	40	33	0	17	38	67	42	43	67	20	0	29	0	40	40
n.A. Spec. HW	20	33	50	42	38	33	25	14	0	20	80	33	33	0	50
DEM	60	33	50	100	25	33	58	43	33	100	40	52	50	40	60
GIS	90	83	50	92	75	100	83	86	100	60	40	76	83	100	60
CAD	70	50	0	50	88	100	75	100	67	40	60	71	67	60	80
DBS	40	17	0	0	38	33	33	29	33	20	20	33	17	40	40
Wind Simu.	10	0	0	0	0	0	0	8	14	0	0	5	0	0	10
Noxious Simu.	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0
Noise Simu.	10	0	0	0	25	0	17	0	0	0	0	10	17	0	10
Elm. Simu.	10	0	0	8	0	0	0	0	0	20	20	10	33	0	0
Light. Simu.	30	17	0	8	25	33	25	14	33	20	40	19	0	0	40
n.A. Simu.SW	10	0	0	8	0	0	8	0	0	0	0	5	0	0	10
Other SW	20	17	50	0	13	0	25	14	0	0	20	14	0	0	30
n.A. SW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 14: Technical Environment of the users related to their *tasks* (left table) and the *type* (right table) of their institutions. The values reflect the percentages calculated in the classes separately. E. g. 90% of the users with tasks in mapping and 50% of the users being a firm have workstations. "PC & Workstations" means institutions have both type of computers. The tasks and the types correspond to the predefined classes in the questionnaire, i. e. the *task classes* are: mapping (Mp), surveying (Sv), photogrammetric service (Ph), planning (Pl), software development (SW), computing service (CS), environmental analysis (EA), architecture (Ar), public utility (PU), telecommunication (Tc), others (O). The *type classes* are: firm, administration/government (gov.), and university (unis).

- **Computers:**

19% of the users have no workstations, while 38% have no PCs! One user indicated he had no computer. The mean number of workstations (59% indicated the number of machines) is 5.6, while the mean number of PCs is 20.7 (from 83% using PCs). 38% of the users have both workstations and PCs.

- **Specialized Hardware:**

Only 14% of the users have machines with stereo display, but 62% have large format plotters.

- **Software:**

Approximately 75% have GIS and CAD. Except for noxious simulations, there exists at least one participant who uses each one of the predefined simulation software. Other software, named by the users are solar simulation and simulation for GPS positioning.

- **With respect to the type of institutions:**

Comparing the environment with respect to the type of institution we must take into account the different distribution of the user types<sup>20</sup>. In relation, 100% from universities 80% from administrations and 50% from firms have workstations. All users from firms have either workstations or PCs. Stereo display is mostly available in administrations with 40% (in universities and firms the percentage is < 17% !). All administrations have GIS. CAD and GIS software is mostly used by universities with 80% and 60% resp. The percentages are at about 20% more than for administrations and 10% more than for firms. 40% of universities and administrations and 18% of firms use DBS.

Administrations participating in this survey do not use simulation software at all, which is mainly applied by universities, except for noise and electro magnetic field simulations.

- **With respect to the task of institutions:**

In photogrammetric services, mapping and telecommunication the availability of workstations are highest with 100%, 90% and 90%, resp. Here the minimum is given for architects who all use PC's.

The highest percentage of institutions using stereo display was found at photogrammetric services with 50%. Large format plotters are mostly available in telecommunication 80%, architecture 71% and mapping 70%.

All institutions with tasks in telecommunication use DEM software. In general high percentages of 80–100% are found for the use of GIS, except for photogrammetric services (50%).

All institutions with architectural tasks use CAD software. DBS are mostly in use for planning (50%) and mapping (40%). No institution with photogrammetric services<sup>21</sup> uses CAD or DBS.

Lighting simulation software is the most often mentioned by different tasks (all except photogrammetric service). All users of simulation software are from mapping.

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<sup>20</sup>Please remember: 48% users are from university, 28% from firms and 24% from administrations.

<sup>21</sup>answering this questionnaire

**Remark:** A high percentage of digital photogrammetric software and equipment (photogrammetric workstations) on the producers side can be observed. The most used software by the producers is GIS, CAD, Aerial triangulation, DEM analysis, automatic DEM and orthophoto generation. The most used software by the users is GIS, CAD and DBS. Simulation software is in majority applied by universities. The equipment of the users is mainly workstations and PC's, **partly with stereo display.**

### 3.4.2 Input Data and Output Data

This section is to document the current availability and use of the different data sources, i. e. input data of the producers (P-2.4), city data (output data of producers (P-2.5) and input data of users (U-3.4) and also to document the different scopes of the users when using the city data (U-3.5).

- **Input Data for the Production** (Questionnaire P-2.4, cf. App. I, p. 88):

To get information on the data sources used by the **producers** for the acquisition of city data we asked the **producers** whether they use **Images**, **Range Data**, and/or **Others** (e. g. surveying data or maps). For the different sources we asked further for the following details:

- **Images**, cf. App. I, pages 88-89:

We asked here to specify the images concerning the **type** (aerial, terrestrial), the **scale** (five scale classes), the **channels** (B&W, color), **format** (analog, digital), the **resolution** in digital images (five resolution classes) and the **number** of processed images per year (five classes).

In case the producers **do not use images** as input data we asked for the **reasons**. Here we provide the same five predefined answers as provided in question P-2.1, Table 3.

- **Range Data**, cf. App. I, pages 89-90:

We asked here to specify the range data concerning the **type** (aerial, terrestrial), the **point density** (five density classes), and the **area** of processed data per year (seven classes).

In case the producers **do not use range data** as input data we asked for the reasons. Here we provide the same five predefined answers as provided in question P-2.1, Table 3.

- **Maps**, cf. App. I, page 90:

Here we asked the producers to specify the **map type**, the **map scale** and the **format** (analog, digital).

**Results**, cf. Fig. 11:

The most input data for the producers are aerial image data with 76%, followed by map data (54%), data from classical surveying methods (46%), and

Type of data sources [ % of producers ]

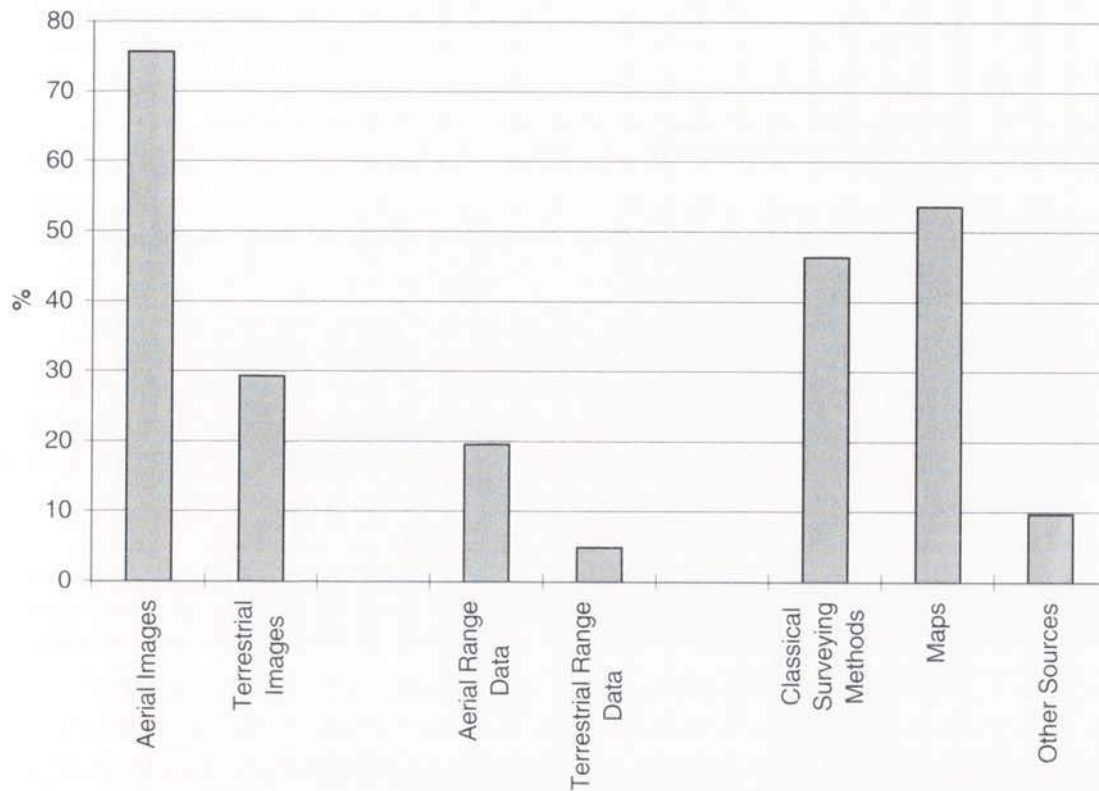


Figure 11: Type of input data, i. e. data sources the producers use for the acquisition of city data. E. g. 76% of the producers use aerial images.

terrestrial image data (29%). Aerial/terrestrial range data are used as data sources by only 20%/5%. Other sources named by the producers are e. g. digital picture processors and GPS.

**Specialists:** 12% of the producers reported that they are only using aerial image data. There are two producers who only use map data, and one producer each who only uses terrestrial images, aerial range data or data from classical surveying. The mean number of data types each producer needs as data sources is about four (from six predefined classes + others).

**Reasons not to use the different data sources,** cf. Fig. 12: While only 20% of the producers answered that they do not use images, 61% of the producers do not use range data<sup>22</sup>.

<sup>22</sup>additionally 7% gave no answer at this point

From those who do not use image data 38% answered that image data are too expensive and 38% answered that image data are not available.

From those who do not use range data 40% answered they have no need for range data, but also 36% are interested in using these data if they were available or cheaper. Still 24% of the producers who do not use range data as data sources indicated to have no evaluation technique available.

In total, **additionally** 12% of all producers would like to use image data if available and cheaper, and 25% of the all producers would like to use range data! Only two producers indicated they have really no need for image data as input sources!

We now specify the input sources named by the producers in more detail:

- **Image data:** From those who use images as data sources there are more producers using digital images (70%) than analog image data (55%)! Also color image data are used by just 55%, though B&W images are as expected more established with 80%. Other image types named by the users are CIR (Colour Infra Red) and Video.

Within the aerial images 56% image data are used in scale range from 1 : 5 000 to 1 : 20 000. Only 6% of the used images are in the scales  $> 1 : 2\,000$  and only 4% of the used images are in the scales  $< 1 : 50\,000$ . Within the terrestrial images all image scales are about evenly used.

85% of all digital images are used with a resolution of  $10\mu m$  to  $50\mu m$ .

The number of processed images is different, though there are about 35% who process over 300 per year!

- **Range data:** The range data used as input data are equally distributed over the density classes. There is one producer who uses aerial range data with a point density of higher than 30 cm (DTMs).

Most producers who use range data answered that they process between 100 and 300 km<sup>2</sup> per year. In total over 1000 km<sup>2</sup>/year is processed by the 10 producers. At the workshop some companies reported processing about  $> 6000$  km<sup>2</sup>/year.

- **Classical surveying and maps:** 30% use both, data from classical surveying and map data. Analog and digital map data are equally used, approximately 75% use both digital and analog map data.

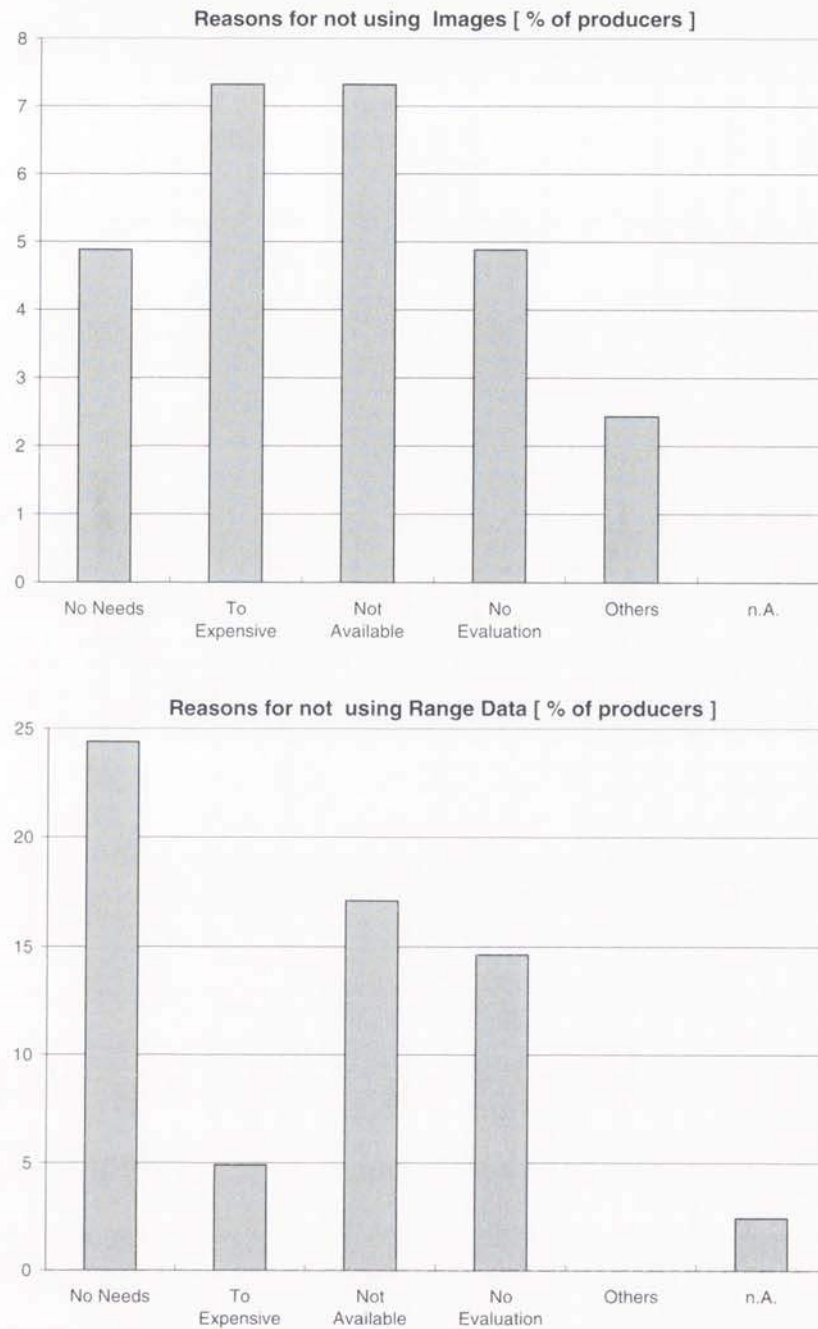


Figure 12: Reasons for the producers not to use image data (upper diagram) or range data (lower diagram) as input data for the acquisition of city data. The heights of the bars reflect the number of answers in percentages by the producers. "No evaluation" means no evaluation tools available. It was possible to indicate several reasons. (n.A.: no answer).

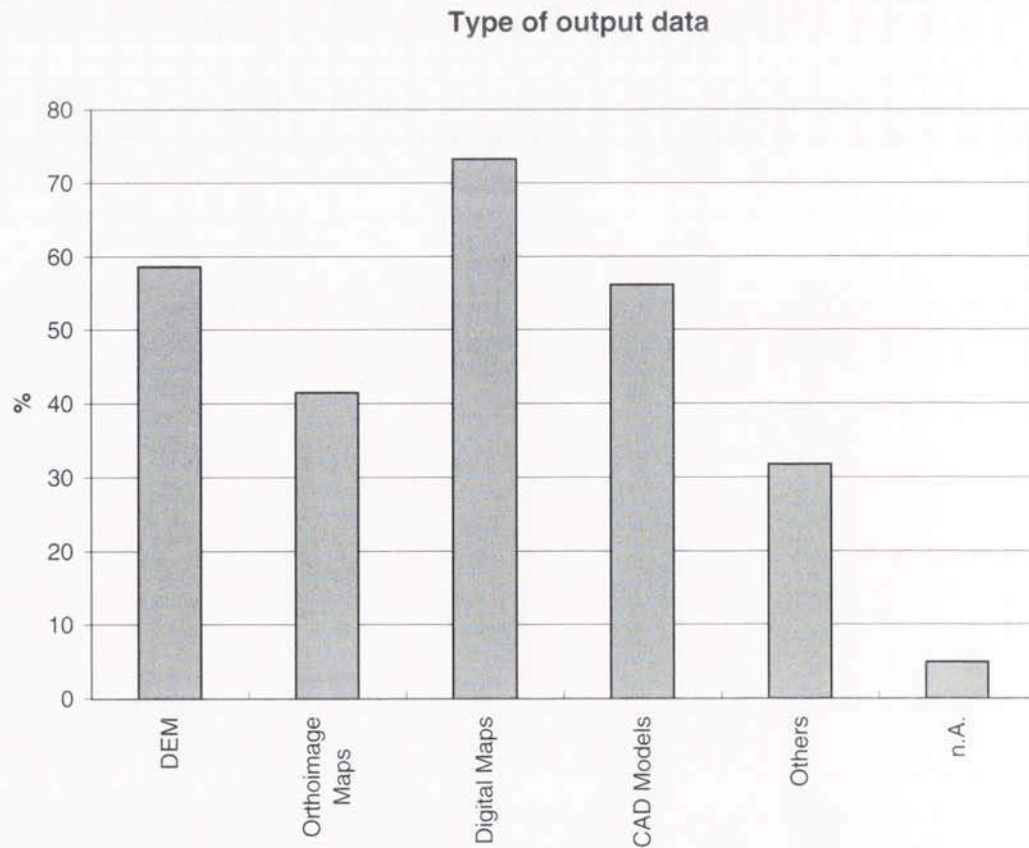


Figure 13: Type of output data, i. e. the city data provided by the producers. The values reflect percentages, e. g. 72% of the producers produce digital maps. (n.A.: no answer).

• Output Data of the Producers, (Questionnaire P-2.5, cf. App. I, p. 90):

To get information on the type of output data we asked the **producers** to specify the **type** of the city data they deliver to their clients. It was possible to give five answers: **Digital Elevation Models, Orthoimage Maps, Digital Maps, CAD Models, Others** (to specify). These classes are identical to the type of input data of the users (cf. next item).

**Results, cf. Fig. 13:**

The most output data type named by the producers are Digital Maps with 73%, followed by DEMs (59%) and CAD Models (56%). 41% are producing Orthoimage Maps. The other 32% output data types contain e. g. VR models, surface reflectance models, data for GIS, architectural details, engineering designs and landscapes.

**Specialists:** 10% answered that they are only producing digital maps and one answered that he produces only CAD models. The average number of different types of output data is between 3 and 4.

• **Input Data for the Users** (Questionnaire U-3.4, cf. App. I, p. 97):

To get information on the type of input data we asked the **users** to specify the *type* of the city data they get from their suppliers. It was possible to give five answers: **Digital Elevation Models, Orthoimage Maps, Digital Maps, CAD Models, Others**. These classes are identical to the type of output data generated by the producers (cf. P-2.5)

**Results, cf. Fig. 14:**

The most input data type named by the users are Digital Maps with 76%, followed by DEMs and CAD Models with each 57%. Only 24% are using Orthoimage Maps. Also 24% named other input data types they use (mainly aerial images).

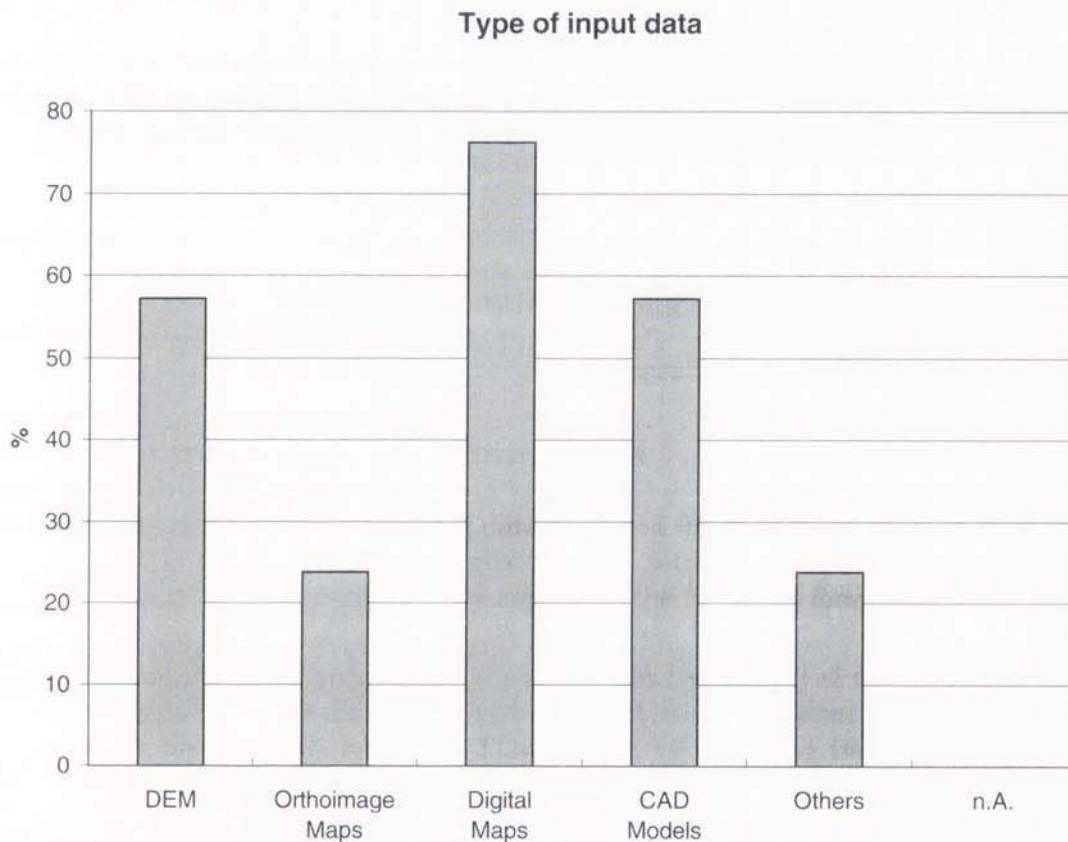


Figure 14: Type of input data, i. e. the city data in percentages of the users. E. g. 76% of the users use digital maps as input data. (n.A.: no answer).

**Specialists:** 10% of the users indicated that they are only using Digital Maps resp. CAD models as input data. DEMs and Orthoimages are only used together with other data types.

- **Output Data of the Users** (Questionnaire U-3.5, cf. App. I, p. 98):

We asked the **users** to *comment* on the **purposes** or scopes of their use of city data and to specify the **type of output data** or **results**. We did not predefine answers here.

**Results:**

The following list is a summary of the different scopes reported by the users. The items are sorted by the number of similar answers.

- Prediction of electro-magnetic field strengths. The results are plans of cellular networks (firms, telecommunication). One firm specified the type of result being 3D building data, buildings with differentiation between flat roofs and ridge roofs.
- Integration and visualization in GIS (several universities). The type of results are 3D CAD data for visualization and generation of solid body models.
- Visualization of plannings or projects, evaluation of plans and projects (several universities and administrations). The results are 3D models, digital maps, transport plans, maps of environmental impact studies.
- Design of urban GIS, urban DB and city planning (university).
- Architectural plannings and presentations (firm). The results are maps, 3D animation and 3D models.
- Design of parallel algorithms and programs to gain speed (administrations).
- Achievement of more acceptance and easier interpretation of town planning sketches and infra structural planning sketches (firm). The results are 3D perspective views, video and recently also VR. These data are generated based on DEMs and CAD models. Output types are plots or animations.
- Simulation of GPS positioning, i. e. analyzing the effects of reflection of GPS signals near no buildings with respect to precision and accuracy of the position estimation. Result: Errors of simulated GPS positioning (university).

- **Comparison of Producers Output Data and Users Input Data:**

The percentages of the provided type of output data of the producers and the type of input data of the users given by the two groups of the participants fit well (cf. Table 15). We got only in the class of "other" data types significantly more specifications by the producers than by the users: other output data named by producers are e. g. virtual reality models, surface reflectance models, architectural details, engineering designs and landscapes, while here the majority of the users said they also use aerial images as input data.

Type	producers [%]	users [%]
DEM	59	57
Orthophoto Map	41	24
Digital Map	71	76
CAD-Model	56	57
Others	32	24

Table 15: Comparison between the types of output data provided by the producers and the type of input data applied by the users. The values reflect the number of answers in percentage of the producers and in percentage of the users.

**Remark:** The most used input data for the producers are aerial images, map data, classical surveying and terrestrial images. Aerial images are used in analog or digital form and in large to medium image scales, where digital data are used more frequently than analog data. Map data is used in analog and digital form. Aerial and terrestrial range data are only used by a small number of producers but with a surprisingly huge output of several 1000 km<sup>2</sup>/year. Many producers regard range data as currently too expensive. The percentages of the provided type of output data of the producers and the type of input data of the users fit well for DEM, Digital Map and CAD-models (cf. Table 15). This means 2½D raster- as well as vector-information is used, in addition to Orthophotomaps and others. The type of results named by the users cannot be classified as strongly. Most results concern analysis and visualization of city planning and architectural planning as well as simulations for telecommunication. The realization is mostly done by integration into GIS and CAD Systems.

### 3.5 Requirements for Building Data

To clarify the requirement of building data we asked the producers/users in part P-2.6.1/U-3.6.1 of the questionnaire to give us more detailed information. In general, the definition of the requirements may consist of the following four aspects:

1. The **quantitative resolution** (or geometric resolution) of the objects, i. e. the degree of generalization of the acquired/needed objects in terms of the *size of object details or parts*. That means we asked for the size an object detail must have *at minimum* to be acquired or needed by the participants. We distinguished between the resolution **in planimetry** (the footprint) and the resolution **in height**. Further, we asked for the *minimum size an object* must have *in total* to be in general an object of interest.
2. The **qualitative resolution** of the objects, i. e. the degree of generalization of the acquired/needed objects in terms of the **types of objects** or **types of object parts**.
3. The **accuracy** of the data the participants acquire/need. We asked the partic-

ipants to specify the accuracy of the data they produce/use. We distinguished between the accuracy of the data **in planimetry** (X,Y-coordinates) and the accuracy **in height** (Z-coordinate). We suggested the use of standard deviations or relative errors, but did not define how to characterize the accuracy.

4. The mode of **representation** of the data provided/used: here we distinguished between **raster representations** and **vector representations** (cf. Fig. 15 and 16).

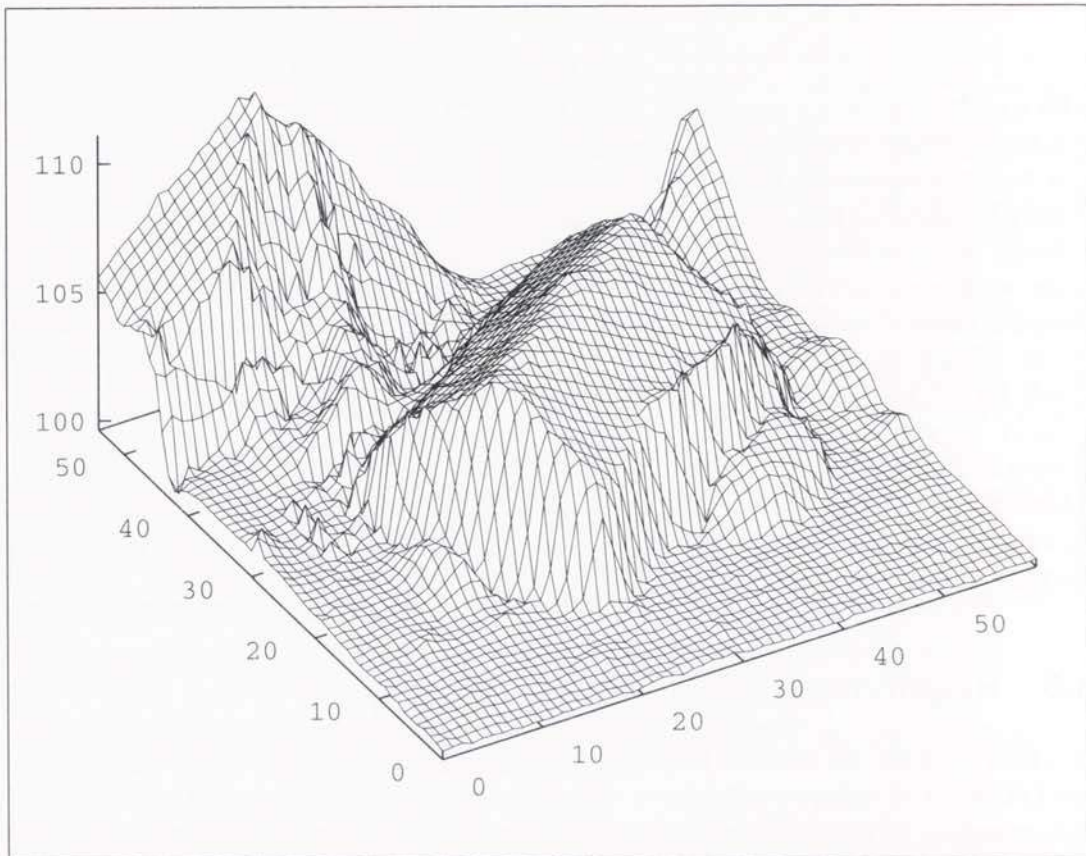


Figure 15:  $2\frac{1}{2}$ D Raster representation (Digital Elevation Model, DEM) of a building, units in meters.

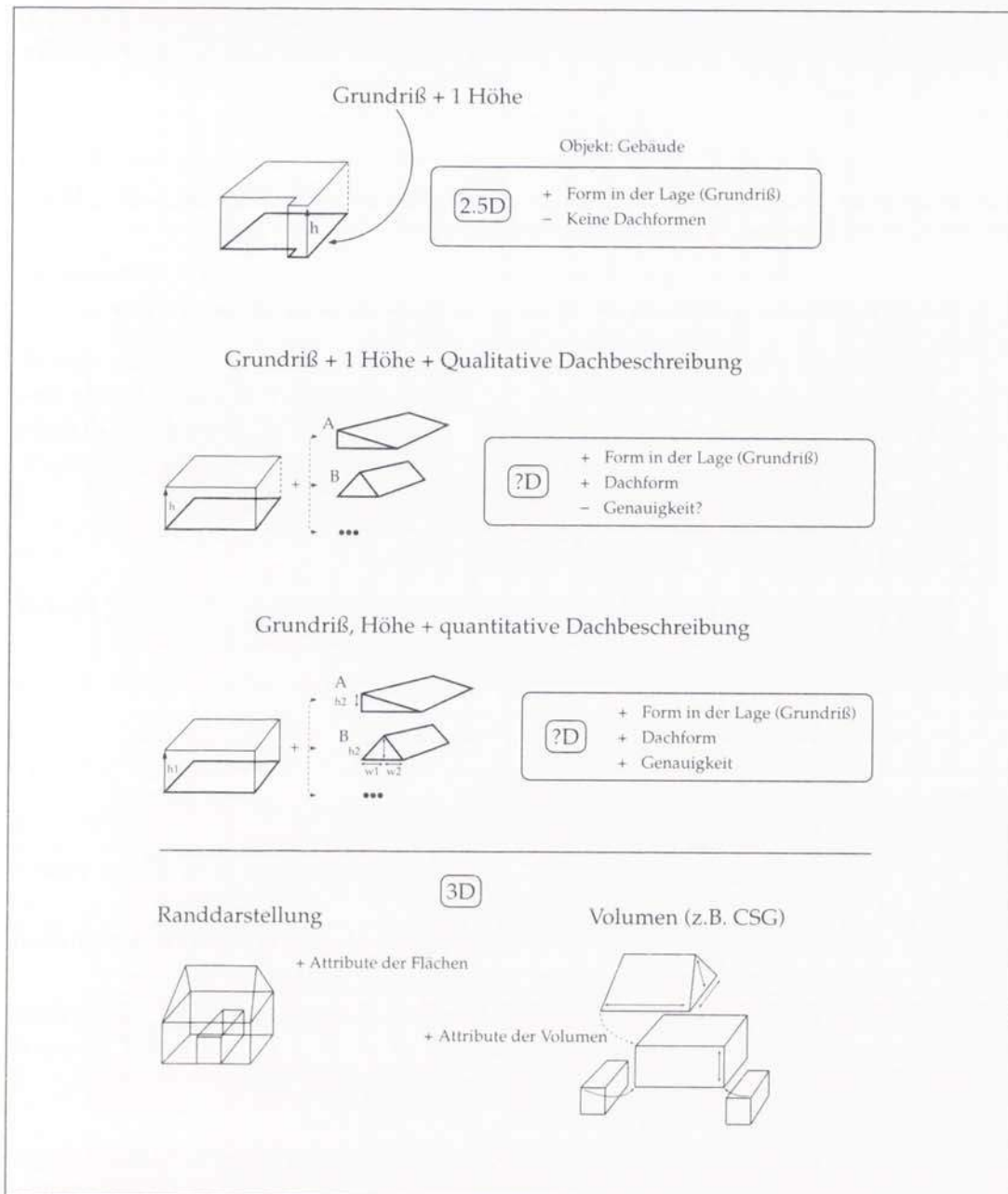


Figure 16: Examples for vector representation of buildings. Boundary and volumetric representations allow representation of interior building parts such as passages, while the other examples only describe the outer shape of the buildings in different degrees of approximation.

For the four aspects to describe the **requirements of building data** we provided the following predefined answers (Questionnaire P-2.6.1, cf. App. I, pp. 91-92, for the producers, and U-3.6.1, cf. App. I, pp. 98-99 for the users):

1. **Quantitative resolution:** It was possible to choose one answer out of seven classes for both planimetry and height: **0.0 - 0.1 m**, **0.1 - 0.2 m**, **0.2 - 0.5 m**, **0.5 - 1 m**, **1 - 2 m**, **2 - 5 m**, **> 5 m**

Additionally the participants were asked to specify the minimum area and the minimum height a building must have to be of interest to acquire/use.

2. **Qualitative resolution:** Here we distinguished between building details which are **in general of interest** and details which are of interest only **depending on the size** of the details. We asked for the following ten details: garages, greenhouses, patios, roofs, roof overhangs, roof elements, passages, front elements, floors, others (to specify)

3. **Accuracy:** no further specification (cf. below).

4. **Representation:** We distinguished between two different classes of **raster** representations and seven different classes of **vector** representations.

(a) **Raster:** (cf. Fig. 15):

- i. DEM with **regular** grid (cf. Fig. 15)
- ii. DEM with **irregular** network

(b) **Vector** (cf. Fig. 16):

- i. **ground plan (footprint) + 1 building height** as attribute (without describing the roof shape further)
- ii. **ground plan + 1 building height + a qualitative** description of the **roof shape** (just the type of the roof shape)
- iii. **ground plan + building height + a quantitative** description of the **roof shape** (e. g. the actual heights of gables and eaves or the actual direction of the gable)
- iv. **boundary representation** of the building
- v. **volumetric representation**, i. e. a building representation by volumes, e. g. in Constructive Solid Geometry (CSG) representation

Similar to the questionnaire we focus first on the quantitative and qualitative resolution, and then on the accuracy and representation of the data. We will directly compare the producers and the users views.

### 3.5.1 Quantitative Resolution

To describe the quantitative or geometric resolution we asked for four characteristic values: the maximum size and the maximum height of details in the buildings,

surfaces or contour lines which could be ignored in the acquisition, and the minimum size and the minimum height a building (as a whole) should have to be of interest to acquire.

1. **Maximum size of details** in the surface or contours which could be ignored:

The comparison is shown in Fig. 17. The two histograms of the resolutions in planimetry and height of the producers have two peaks: one between 0.5 *m* and 1 *m* and the second between 2 *m* and 5 *m*. In contrast the histograms of the users have only one peak: between 0.5 *m* and 1 *m* in planimetry and in height between 1 *m* to 2 *m*.

Thus, producers and users require most often the building data with a resolution in planimetry between 0.5 *m* and 1 *m*. In the height most **users** require the data with a resolution of 1 *m* to 2 *m*, whereas the maximum of the resolution in height in the acquisition of the data by **producers** is more precisely given, between 0.5 *m* to 1 *m*.

The most significant difference between producers and users requirements is evident in the class of 1 *m* to 2 *m*. Producers requirements in the height accuracy seem to be higher than the requirements in the height accuracy most users need. In general the requirements of the users could be larger as the producers are able to provide data with higher degree of detail.

2. **Minimum size and minimum heights of single buildings:**

The analysis of these answers was difficult for two reasons: There are first only few participants who specified their requirements and second it *seems* that for the minimum area there are some answers in different dimensions ([*m*] or [*m*<sup>2</sup>]) than asked (cf. Table 16).

The expectation is, that the minimum size or height increases with the classes of decreasing resolutions. The result confirms this approximately, though influenced by the problems mentioned above. E. g. the minimum values for the heights of single objects are 0.1 *m* in the 0 to 0.1 *m* resolution class and 2 *m* in the low resolution class of > 5 *m*.

Comparing the quantitative resolution classes of the **producers** with the *tasks* of their clients in nearly all tasks there is a maximum at the 0.5 *m* to 1 *m* resolution in **planimetry** and 0.2 *m* to 0.5 *m* in **height**.

When producing for the same institution or for clients with tasks in mapping, surveying and planning the **planimetric** data are more often requested in higher resolution classes than in the low resolution classes. For clients with tasks in environmental analysis and public utility tasks the lower resolution data are normally provided. In **height** we have in most tasks a local minimum in the production of data in the resolution scale of 0.5 *m* to 1 *m*.

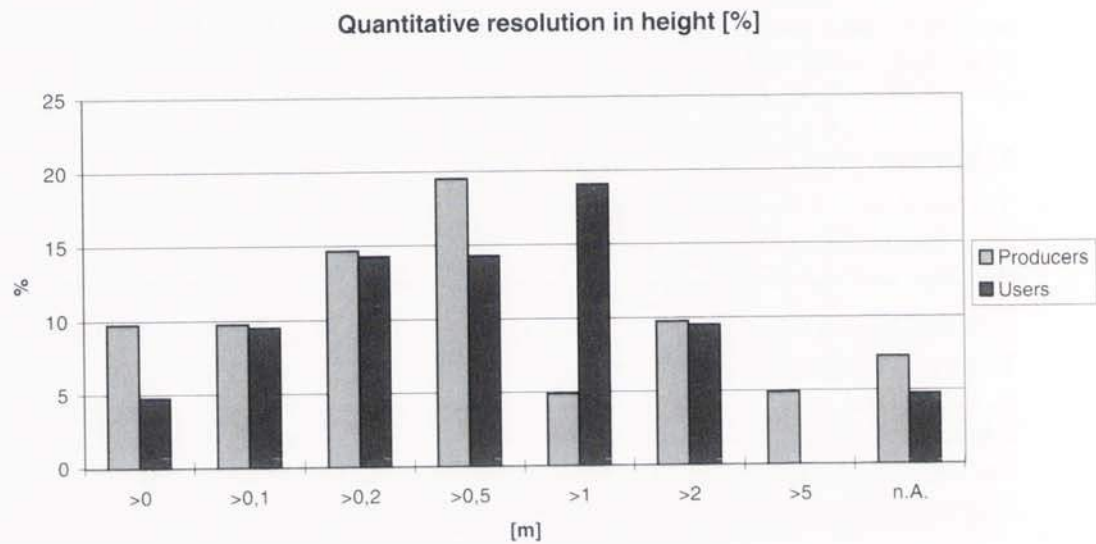
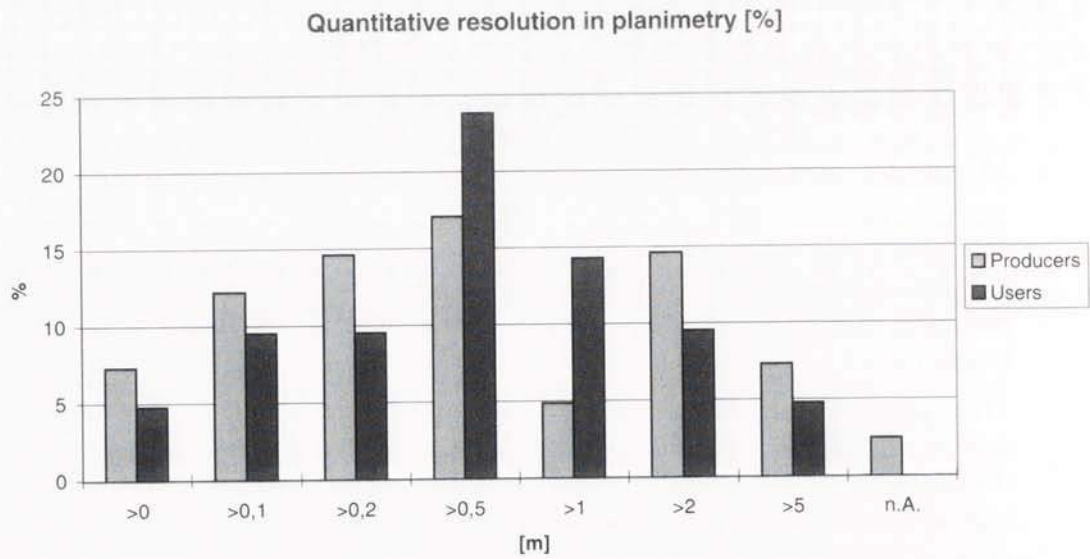


Figure 17: Quantitative resolution of building data in planimetry and height provided by the producers (grey bars) and asked for by the users (dark bars) resp. The values correspond to percentages of all producers and percentages of all users. (n.A.: no answer).

size/height	producers	users
area [m <sup>2</sup> ]	0.1 - 100	0 - 50
height [m]	0.05 - 2.6	0 - 3

Table 16: Comparison of the minimum sizes in area and height a building must have to be acquired by the producers and needed by the users. The values indicate, that these questions were probably misunderstood by some participants as e. g. buildings with a size of 0.1m<sup>2</sup> do not exist.

Comparing the quantitative resolution classes of the **producers** with the *data sources* for the production we find that maps, classical surveying methods and terrestrial range images are more often applied for the high resolution classes, whilst image data and aerial range data are used for all resolution classes. This holds for both planimetry and height.

Comparing the quantitative resolution classes of the **users** with the *tasks* of their suppliers the data are for all tasks are more often provided in the higher resolution scales for both planimetry and height.

Comparing the quantitative resolution classes of the **users** with the class of *input data* there are no significant preferences. For all types of input data the maximum peak lies in the two classes between 0.5 m and 2 m. But in principle all input data could be provided with any resolution.

**Remark:** Concerning the **quantitative** resolution for building data, we can find an average size of details of about 0.5 m - 1 m in planimetry and 0.2 m - 1 m in height which should be acquired for most producers and users. It can be observed that all currently required details by the users are produced by at least one of the producers. Higher degrees of detail are possible. Concerning the minimum size and minimum height of single buildings, there is obviously no common notion.

### 3.5.2 Qualitative Resolution

For describing the qualitative resolution, i. e. what type of objects or object parts the participants have interest in, we asked for objects which are always of interest and for objects which are of interest only depending on their size (cf. Fig. 18).

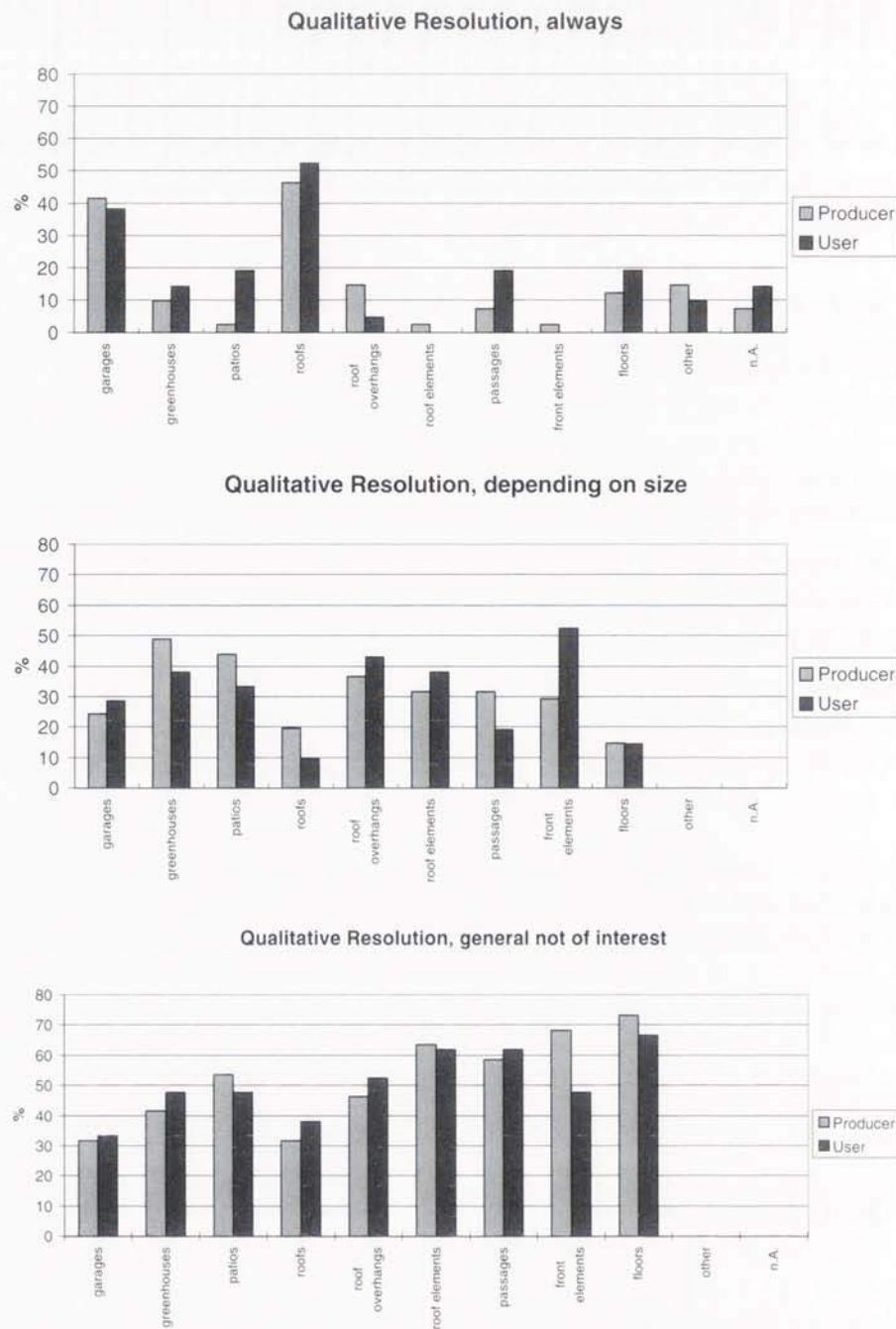


Figure 18: Qualitative resolution of building data provided and needed by the producers (grey bars) and users (dark bars) resp. The heights of the bars reflect percentages of all producers and percentages of all users. (n.A.: no answer).

- The objects which are **always** of interest for the producers and the users fit well. The maximum was found for the building roofs (46% / 52%) and for garages (41% / 38%). The main difference between producers and users was found for roof overhangs and patios where the percentages of those who always produce and of those who always use these data are different (e. g. 15% of the producers always acquire roof overhangs while only 5% of the users always require those data).
- The objects which are of interest for the producers and the users **depending on the size** fit also well. The maximum difference between producers and users was found for front elements (30% of the producers, but 55% of the users).
- Asking for objects being **in general of no interest** for the participants, only less than 35% producers have no interest in garages, roofs and roof elements. That is, except the roof elements, similar to the answers of the users. The object details of lowest interest are the floors, front elements and the passages for the producers and also the floors, the passages and the roof elements for the users.

Other qualitative criteria named by the participants are e. g. stone buildings, car parks, roof lines, gutters, division between houses in blocks. The users further named windows and 3D elements of building front sides.

**Remark:** For the **qualitative** resolution, i. e. the interest in object parts, the views of producers and users match well. There is of course a dependency on the size (scale) which has to be taken into account when representing the results. Depending on the size, detailed roof structures and garages are wanted by 67% of the producers and users, but also roof overhangs or front elements.

### 3.5.3 Accuracy of the data

The answers given by the (few) participants differs significantly (e.g. the best possible, sigma, absolute/relative, dependency on scale, RMSE, not precisely calculated yet). What we could extract from the answers is, that there is no unique way to characterize the requirements on the data accuracy. Further it is of course difficult for the producer to characterize in general the accuracy of the data they provide, it depends not only on the technique but also on the type of data sources (e. g. scale), the quality of the data sources (including the history), etc.

**Remark:** There is no common agreement on the definition of accuracy of data. Each statement should be seen as well in context of scale, precision of input data etc. There is a definite need for further actions on specifying standards on this item.

### 3.5.4 Representation

The most used representation type (cf. Fig. 19, Fig. 15 and Fig. 16) provided by the **producers** is the boundary representation of the buildings (32%). The representation by ground and roof description (simple (27%), qualitative (20%), quantitative (27%)) is used similarly often. Raster data are still produced by 24% (regular grid) and 12% (irregular network). Only 7% produce buildings in volumetric representation.

Similarly, 24% and 14% of the **users** use building data in DEM representation with regular grid and irregular network. Within the vector representation the boundary description and the ground+single height representation is most used with 47% each. The representation by volumes is only used by one participant.

Between 20% and 27% of the **producers** represent the buildings in simple ground+single height, ground+qualitative roof or ground+quantitative roof description, the **users** prefer the simple vector representation (47%), ground+qualitative roof is used by 29% and ground+quantitative roof by 14%.

**Specialists:** Except for irregular DEM and volumes, only a few producers/users deal with only one type of the predefined representation type.

**Remark:** There is no common type of representation for 3D city data in use. We can, however, find vector data representations most often applied. Among those we can find a preference for a 3D boundary representation (24%-32%) and a  $2\frac{1}{2}$ D representation based on ground-plan & single height. This simple  $2\frac{1}{2}$ D representation is in some cases extended by qualitative and quantitative roof descriptions. Volumetric representations are so far rarely applied. Raster representations, which are less used, are mainly based on regular grid.

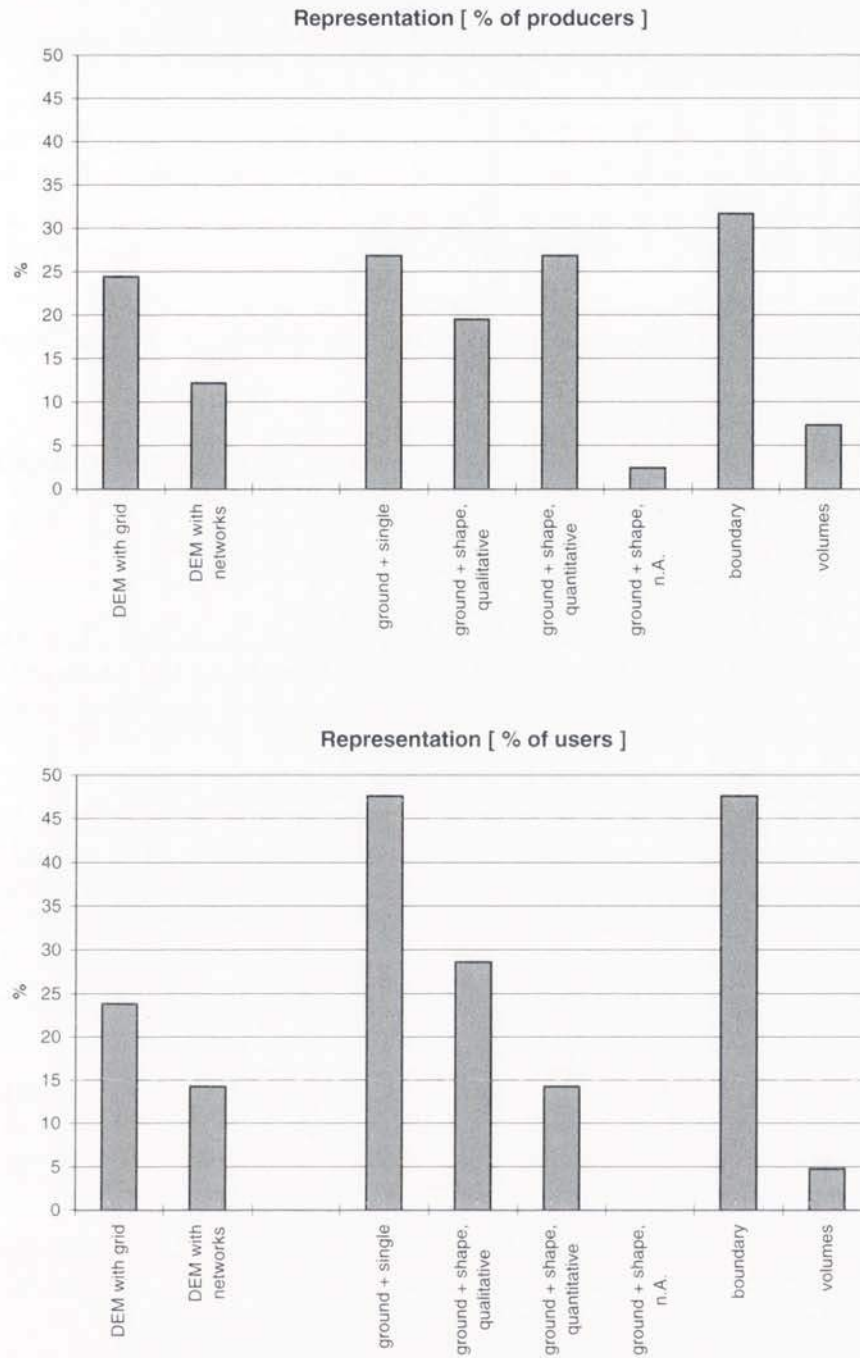


Figure 19: Representation of building data provided and needed by the producers and users resp. For an explanation of the different classes cf. Fig. 15 and Fig. 16. The heights of the bars represent percentages of the producers or the users. (n.A.: no answer).

### 3.6 Requirements for Other City Data

To get an overview of the needs of **other objects** than buildings, we finally also asked the participants to specify what other kind of city data are produced (Questionnaire P-2.6.2, cf. App I, pp. 93, 94) or needed (Questionnaire U-3.6.2, cf. App. I, pp. 100, 101).

In detail we asked for the following object classes:

1. *Vegetation* Data: **trees, parks, others**
2. *Traffic Network* Data: **road nets, train nets, others**
3. *Public Utility* Data: **energy supply, sewerage nets, telecommunication, others**
4. *Others*

In accordance with P-2.6.1 and U-3.6.1 we asked for each object class for the requirements in the quantitative and qualitative resolution, the accuracy and the representation (s. a.). But in contrast, we did not provide predefined answers here.

**Results**, see Fig. 20:

The analysis of P-2.6.2 and U-3.6.2 is summarized in Fig. 20. It shows in the first diagram the object classes produced or used at the moment. The second diagram shows the representation models of the three classes, and the table summarizes the requirements in the quantitative resolution and in the accuracy of the data.

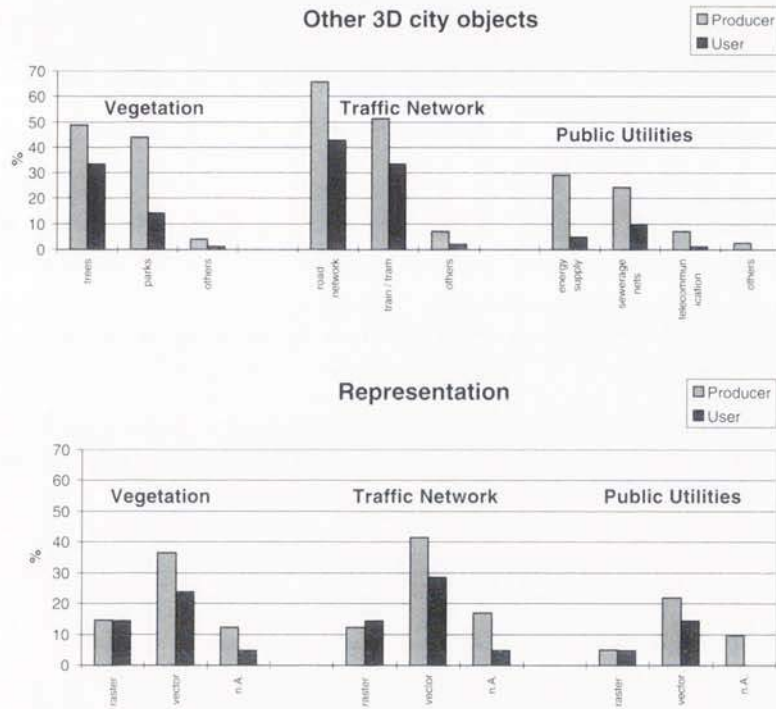
#### 3.6.1 Objects of interest

The answers of the participants concerning the kind of city objects also produced or needed are summarized in the upper diagram of Fig. 20. 65% of the producers acquire road network data, followed by 50% railway data and vegetation data between 40% and 50%.

Comparing the number of answers in percentage of the producers and the users it seems that in all object classes the activities of the producers are higher than the activities of the users<sup>23</sup>. The values differ often significantly with  $> 20\%$ .

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<sup>23</sup>(But please remember the inequality within the users group, where  $\approx 50\%$  are from university.)



<i>Precision &amp; Resolution, geom. Mittel</i>						
	Vegetation		Traffic networks		Public utilities	
	Producer	User	Producer	User	Producer	User
object details, planimetry [m]	0,70	0,59	0,68	0,59	0,30	0,10
object details, height [m]	0,64	0,52	0,31	0,47	0,29	0,10
n.A. [#]	5	3	6	4	3	2
single details, planimetry [m]	0,67	0,59	0,65	0,57	0,26	0,10
single details, height [m]	0,55	0,74	0,46	0,47	0,29	0,10
n.A. [#]	5	2	7	3	2	2
other criteria [#]	8	2	7	2	4	1
n.A. [#]	2	0	3	1	2	0
abs. precision, planimetry [m]	0,53	0,40	0,40	0,20	0,32	0,03
abs. precision, height [m]	0,39	0,22	0,22	0,06	0,22	0,03
n.A. [#]	0	1	0	1	0	1
rel. precision, planimetry [m]	0,40	0,22	0,20	0,15	0,17	0,01
rel. precision, height [m]	0,32	0,22	0,09	0,06	0,10	0,01
n.A. [#]	5	3	5	1	5	2
n.A. [#]	8	2	7	4	3	1

Figure 20: Other city data than buildings, also of interest to the participants. The upper diagram shows the object classes of interest, the lower diagram the representation modes provided and needed by the producers and users. The heights of the bars represent percentages of the producers or the users. The table contains the geometric means ("geom. Mittel") of the quantitative resolution and the accuracy of the data, and the number of participants. (n.A.: no answer).

The following list summarizes the qualitative object criteria named by the participants as being of interest for the acquisition or use:

- **Vegetation:**

Producers: agricultural fields, gardens, forest, bushes, full information for maps in different scales (1:500 - 1:50), green area database, waste deposit, grave yards, stades.

Users: bushes, tree cluster, hedges, deciduous and coniferous trees, shrubs.

- **Traffic Network:**

Producers: foot paths, environment, fences, water, runways, bridges, type of cover, curb-stones, one-ways, width and height restrictions, furniture, roads allowed for motor vehicles, administrative types.

Users: foot paths, bus lines, administration, traffic density, curb-stones, bridges, tunnels, signs.

- **Public Utilities:**

Producers: water, electricity supply pylons, valves

Users: -

- **Other objects:**

Producers only: waterways, e. g. channels, including the sides of waterways and the shoulder of the sides and with a quantitative resolution of 1 m and 0.5 m.

Producers and Users: DEMs and reliefs, including break lines and with a quantitative resolution of 2 m and 5 m.

Obviously, maps or other information sources (beside images) are necessary to provide these city data.

### 3.6.2 Quantitative resolution

- **Vegetation:**

For the producers the objects of interest are less than 5 m in planimetry and height. This holds for both, object details and the maximum single object size which could be ignored as a whole in the acquisition or use. The users requirements are higher, they require objects or object details with about 1 m size.

Other criteria for the quantitative resolution of vegetation data mentioned by the participants are e. g. the area size, collected data in 2D, required information for maps in different scales, or the minimum diameter of the object.

- **Traffic Networks:**

The answers from the producers are mostly about 1 *m* (but in a range of 0 *m* to 10 *m*) for object details and maximum size of objects of no interest. This also holds for the users except for one user, who answered 5 *m*.

Other criteria for the quantitative resolution of traffic network data mentioned by the participants are e. g. the full information for maps depending on different scales, minimal width, public roads, or the complete data for visual impact.

- **Public Utilities:**

The answers from the producers are mostly between 0 *m* and 2 *m* - 3 *m* for object details and maximum size of objects of no interest. Only few users answered. The values are here in general below 1 *m*.

Other criteria for the quantitative resolution of public utility data mentioned by the participants are minimal voltage, main pillars only.

### 3.6.3 Accuracy of the data

Because there are only few and very different answers an evaluation of the answers is difficult. The definition of the relative error seems not clear. We unfortunately pre-defined the unit in [*m*], which may lead to misunderstandings. We therefore neglect the relative errors in the following. There are also few, possibly wrong or misunderstood answers with extremely high sigma values (e. g.  $\sigma = 3\ m, 10\ m, 20\ m$ ). These values are not used for the estimation of the mean values (cf. below).

The results are summarized in Table 17: It is shown that the users need the data with a higher accuracy than the producers provide the data. In general, the majority of the participants answered they need the data with a accuracy of about  $\sigma < 1\ m$ .

In detail, the requirements of the city data with respect to the accuracy in the different object classes are as follows (cf. Table 17):

- **Vegetation:**

The accuracy in planimetry named by 30% of the producers are in the range of 0.1 *m* to 3 *m* and 10 *m*. 20% of the users answered they require the data with an accuracy of 0.5 *m* in planimetry and 0.2 *m* in height, which appears to be highly optimistic.

- **Traffic Networks:**

The accuracy in planimetry named by 40% of the producers are in the range of 0.1 *m* to 3 *m* and 20 *m*. 20% of the users answered they require the data with an accuracy of 0.2 *m* in planimetry and 0.1 *m* in height.

object	participant	range $\sigma_{x,y} [m]$	range $\sigma_z [m]$	mean $\sigma_{x,y} [m]$	mean $\sigma_z [m]$
vegetation	producers	0.1 - 10	$\approx 0.5$	0.5	0.4
	users	0.1 - 1	0.1 - 0.5	0.3	0.3
traffic network	producers	0.1 - 20	0.05 - 0.5	0.3	0.3
	users	0.01 - 3	0.01 - 0.2	0.2	0.1
public utilities	producers	0.05 - 3	0.1 - 0.5	0.3	0.3
	users	0.05	0.05	0.05	0.05

Table 17: Data accuracy required by the producers and users for the different object types. The mean values are calculated neglecting the large values indicated by single persons.

#### • Public Utilities:

The accuracy in planimetry named by 24% of the producers are in the range of 0.05 m to 3 m (sigma). Neglecting the 3 m the mean value is 0.3 m. This is also the mean value for the accuracy in height. 10% of the users answered they require the data with 0.05 m in planimetry and 0.05 m in height.

#### 3.6.4 Representation

As shown in Fig. 20, lower diagram, both producers and users represent the data more in vector than in raster representation (approximately with factor 2). The raster representation is at most over 10% (except for energy, sewerage and telecommunication), and highest for vegetation (possibly needed for land use classification).

**Remark:** The analysis of the answers was difficult due to the lack of predefined answers, the limited number of answers and their high diversity. Highest interest is in traffic network and vegetation data. Concerning the objects of interest we can find object parts of vegetation, traffic networks and public utilities of every type and scale.

Concerning the quantitative resolution we can find for vegetation a preference for size of single objects or details between 1 m to 5 m in planimetry and height. For traffic network data and public utility data there are slightly higher requirements. In all cases most users require better quantitative resolution than provided by most of the producers. The required accuracy of data is again higher by the users and can be described by a  $\sigma$ -value of below 1 m. Concerning the representation we can find a clear preference for vector representation. Raster representations are mostly applied for vegetation data.

## 4 Individual Evaluation of the Results - Example

Up to this point, we gave a summary of the general results of the questionnaires. However, the results contain further information relevant to the individual situation or problems of the producers or the users. We now want to illustrate how the results of the survey may be evaluated for the individual interests of the reader.

We assume the following situation is given: An institution has interest in producing or using a distinct type of data XXX, where XXX stands for either **Buildings**, **Vegetation**, **Traffic Network**, **Public Utility**, **Telecommunication** in 2D,  $2\frac{1}{2}$ D or 3D.

The results allow us to give answers for the following four questions:

1. **Who (else) *would like to use* XXX?**
2. **Who is *already using* XXX?**
3. **Who (else) *would like to produce* XXX?**
4. **Who is *already producing* XXX?**

If there are other institutions with the same interest we can ask in more detail for:

- which **types** of institution they are,
- which **tasks** these institution have, and
- how **important** (relevant) XXX is for these institutions.

The motivations for these questions from the producers and the users viewpoint are for the producers, e. g.:

- **Search of (new) clients** (cf. questions 1,2): Who has interest in the data I (can) provide, to whom can I sell?
- **Exchange of ideas** (cf. questions 3,4): Are there others who want to produce the same type of data? Can I share costs.
- **Exchange of experience** and knowledge, e. g. for research (cf. question 4): Where/ from whom can I get more information on how to produce the data? Initiations of cooperation, etc.

for the users, e. g.:

- **Search of (new) suppliers** (cf. questions 3,4) : Where/from whom can I get/buy the data I want to use?

- **Exchange of ideas** (cf. questions 1,2): Are there others who want to use the same type of data? What do they want? What problems may occur?
- **Exchange of experience** and knowledge, e. g. for research (cf. question 2): Where/from whom can I get more information on how to use the data? Initiations of cooperation, etc.

Table 18 contains in the two columns for two examples the answers to the four questions:

1. **Building data in 3D:**

We choose this example as buildings in 3D are found to be of high interest for both, producers and users, especially for the producers who are already producing such data.

2. **Vegetation Data in 3D:**

We choose this example as vegetation in 3D is presently of interest to the producers and also highly needed by the users.

The values in Table 18 are extracted from the tables shown in App. III, pages 115-120. The columns of *Type* and *Task* of the institutions are independently filled, i. e. the values in one row do not correspond to the same institutions. The values in brackets are the values of indications given by the 41 producers and 21 users. Please remember that it was possible for the participants to select several tasks to classify their institutions.

Interpreting Table 18 we got e. g. the following results:

1. **Buildings in 3D**, cf. Table 18, left column:

- We found new clients for 3D building data in Telecommunication as we have institutions with tasks in telecommunication who would like to use this data (question 1) but no institution with these tasks who already use such data (question 2).
- We may find (new) clients or (new) suppliers for 3D building data in the area of architecture as these institutions have demand for this data (question 3) but no institution with this task already produces such data (question 4).

2. **Vegetation in 3D**, cf. Table 18, right column:

- We found new clients for 3D vegetation data in telecommunication and mapping as we have institutions with tasks in telecommunication and mapping who would like to use this data (question 1) but no institutions with these tasks who already use such data (question 2).

- We may find (new) suppliers or (new) clients for 3D vegetation data in the area of Architecture and Computing Services as these institutions have demand for this data (question 3) but no institutions with these tasks already produce such data (question 4).

In case the reader would like to make a similar analysis for **other classes of city objects**, the values in Table 18 must be adapted using the tables in App. III, pages 115-120.

	Buildings in 3D		Vegetation in 3D	
Question 1:	<i>Type</i>	<i>Task</i>	<i>Type</i>	<i>Task</i>
Who would like to use	3 Firms 3 Admin 2 Univs	Pl(5), Map(4), EnvA(4), Arch(4), Surv(3), SwD(2), TCom(2)	3 Firms - Admin 4 Univs	Pl(3), Map(3), EnvA(3), Arch(3) SwD(2), Tcom(2)
	mean level of relevance: 4.3		mean level of relevance: 3.6	
Question 2:	<i>Type</i>	<i>Task</i>	<i>Type</i>	<i>Task</i>
Who is presently using	4 Firms 1 Admin 5 Univs	Pl(6), EnvA(5), SwD(5), Map(4), Arch(4)	1 Firms 1 Admin - Univs	Pl(2), EnvA(1), SwD(1), Arch(1)
	mean level of relevance: 4.5		mean level of relevance: 4.0	
Question 3:	<i>Type</i>	<i>Task</i>	<i>Type</i>	<i>Task</i>
Who has request to produce	3 Firms 5 Admin 1 Univs	Map(9), Surv(8), PhoS(6), EnvA(4), Pl(3), Arch(2)	1 Firms - Admin 1 Univs	SwD(2), Arch(2), Map(1), Surv(18), ComS(1), EnvA(1), Pl(1)
	mean level of relevance: 4.0		mean level of relevance: 4.5	
Question 4:	<i>Type</i>	<i>Task</i>	<i>Type</i>	<i>Task</i>
Who is presently producing	11 Firms 7 Admin 5 Univs (1 unk.)	Map(19), Surv(16), PhoS(13), EnvA(10), Pl(9), oth(4)	6 Firms 2 Admin 2 Univs	Surv(7), PhoS(6), Map(6), SwD(5), Pl(4), EnvA(4)
	mean level of relevance: 4.5		mean level of relevance: 3.4	
Interpretation:	(e. g.) new clients in Tcom new suppliers or clients from Arch		(e. g.) new clients in Tcom and Map, new suppliers or clients from Arch and ComS	

Table 18: Individual use of the results for 3D Building data and 3D Vegetation data. For the 4 question the extracted results out of Tables in App. III, pp. 115 - 120, are shown. (The columns of Type and Task are independent. The values in brackets are the values of indications given by the 41 producers and 21 users (It was possible for the participants to select several tasks to classify their institutions). The following abbreviations were used: Admin (Administration), Univs (Universities), Map (Mapping), Pl (Planning), PhoS (Photogrammetric Service, SwD (Software Development), ComS (Computer Service), Arch (Architecture), EnvA (Environmental Analysis), PUn (Public Utilities), Tcom (telecommunication), unk. (unknown type of institution).

## 5 Summary and Outlook

The scope of this study was to find out the current state of generating and using 3D-city data. For this purpose a questionnaire was sent out to appr. 200 European institutions. The questionnaire was completed by a total of 55 institutions from 17 European countries (Germany(17), France (7), Austria(6), Netherlands (5), Finland(4), Northern Ireland (2), Slovenia (2), Sweden (2), Belgium, Bulgaria, Denmark, Greece, Italy, Lithuania, Norway, Switzerland, UK, unknown).

The questionnaire contains two parts, one for the producers and one for the users of 3D-city data. As 7 institutions acted as both, producers and users, we have a total of 41 producers and a total of 21 users. In particular we have the following distribution with respect to the type of the institution:

- 18 firms, covering small companies as well as big enterprises.
- 16 administrations and government agencies
- 20 universities
- (1 unknown).

The tasks of the institutions cover a broad range: mapping, surveying, photogrammetric service, environmental analysis, software development, architecture, computing services, telecommunication and research. The wide range of interest of the participants provides a good basis for a representative evaluation of the present situation in 3D-city modeling. The number of participating users from university is high, which is due to the ongoing research efforts in this field. It does not reflect the real market situation. This is taken into account in the analysis.

The results confirm that 3D-city data are needed, are already used and provided to a large extent.

The following detailed results appeared interesting:

1. **All types of 3D-city objects** required by the users are provided by at least some of the producers. But, every second producer has requests to provide other objects or information than he is presently producing, and three out of four users would like to have other city data than already available.

This clearly reveals a deficit in the mutual knowledge of producers and users, especially with respect to the availability of basic 3D-city information.

2. **Objects of interest** (2D,  $2\frac{1}{2}$ D and/or 3D) are
  - buildings (producers: 95%, users: 95%)
  - traffic network (producers: 90%, users: 76%)
  - vegetation (producers: 78%, users: 71%)

There is a definite lack of economical techniques for *producing* 3D-city data. In addition a surprisingly great lack of knowledge of data sources, i.e. practically no access to data, is observed. The lack of knowledge of information sources, as well as the high costs (for buildings and vegetation acquisition) currently hinder broader use. But there is as well a lack of evaluation methods (tools) for 3D city data, which is probably due to the so far limited availability of those types of data.

3. Participants were asked about the **future need** of city data. As presently most acquired and used data is 2D, there is only limited demand except for public utility data. Vegetation data are urgently needed as was mentioned consistently by producers and users.  $2\frac{1}{2}$ D vegetation data are of interest in future for producers from administrations and by users of all types. Firms and universities would like to have 3D vegetation data. 3D buildings and traffic network data are of significant interest and also urgently required in the future. This holds for all, firms, administrations and universities.
4. **Data sources** used by the **producers** mainly are aerial images (76%) followed by map data (54%), classical surveying methods (46%). Aerial images are used in analog or digital form in large to medium image scales, where digital data are used more frequently than analog data. Map data are used in analog and digital form. Aerial (terrestrial) range data are only used by 20% (5%), which still corresponds to more than 1000 km<sup>2</sup> processed data per year. Many producers regard range data as currently too expensive.  
  
A small percentage of the producers (12%) would like to use image data, if these data would be available and less expensive. The demand for range data is even higher (25%), again the availability and the prices seem to be prohibitive to the producer, who also have no evaluation tools at hand.
5. The structure of **building data**, i. e. the degree of detail which is provided by the producers seems to fit the demands. Roof data (appr. 50%) and garages (appr. 40%) are of greatest interest. Some producers obviously can provide more detailed information, which - at least at the moment - is not really required by the users, probably for cost reasons.

Concerning the **quantitative** resolution for building data, we can find an average size of details of about 0.5 m - 1 m in planimetry and 0.2 m - 1 m in height which should be acquired for most producers and users. It can be observed that all currently required details by the users are produced by at least one of the producers. Higher degrees of detail are possible. Concerning the minimum size and minimum height of single buildings, there is obviously no common value.

There is no common type of representation for 3D city data in use. We can, however, find vector data representations most often applied. For buildings, we find a preference for a 3D boundary representation (24%-32%) and a  $2\frac{1}{2}$ D representation based on ground-plan & single height. This simple  $2\frac{1}{2}$  D representation is in some cases extended by qualitative and quantitative roof

descriptions. Volumetric representations are so far rarely applied. Raster representations, which are less used, are mainly based on regular grid, but also on irregular networks.

The lack of having software tools to handle such data is one of the main reasons for not using 3D data.

6. We asked for **requirements for city data other than buildings**.

The analysis of the answers appeared difficult, due to the lack of predefined answers, the limited number of answers and their high diversity. Greatest interest is in traffic network and vegetation data. Concerning the objects of interest we can find object parts of vegetation, traffic networks and public utilities of every type and scale.

Concerning the quantitative resolution we can find for vegetation a preference for size of single objects of details of between 1 m to 5 m in planimetry and height. For traffic network data and public utility data there are slightly higher requirements. In all cases most users require better quantitative resolution, than provided by most of the producers. The required accuracy of data is again higher by the users and can be described by a  $\sigma$ -value of below 1 m. Concerning the representation we can find a clear preference for vector representation. Raster representations are mostly applied for vegetation data.

There were two outliers worth mentioning: Traffic networks were required with a precision of 20 m, public utilities with 3 m, both in planimetry. This clearly indicates that also very coarse data may be useful.

7. We hoped to get information on the **Technical Environment** of the institutions which would be able to explain some of the results in production and use. The questions were not specific enough to fully achieve this goal. However, two results are worth mentioning. The use of workstations and PC: the majority of the participants use workstations (appr. 80%), the use of PC is most common in the group of users (producers: 12%, users: 60%). Most remarkable, 41% of the producers already use Digital Photogrammetric Workstations, which reveals that technology has already fully reached the market.

A high level of digital photogrammetric software and equipment (photogrammetric workstations) on the producers side can be observed. The most used software by the producers are GIS, CAD, Aerial Triangulation, DEM analysis, automatic DEM and orthophoto generation. The most used software by the users are GIS, CAD and DBS. Simulation software is mainly applied by universities.

Of course the study left open some questions which need to be tackled in the future:

- The range of applications obviously is wide. The study restricted to some well known areas. It could not really give a detailed picture of the applications, which need true 3D-data in contrast to  $2\frac{1}{2}$ D data.

- No attempt was made to obtain information about costs, neither for data acquisition, nor for applications. Cost are very much dependent on the local structure of the organizations and the detailed specifications for the data and applications. This would only be possible within a well designed market study, which would be extremely valuable but is – for cost reasons – well beyond this study.
- The problem of maintenance of 3D-data is a general problem of GIS. There do not exist standard techniques for maintenance of 2D-data already, the theory for maintaining data in spatial data bases is by far not solved. The problem is even more complex for 3D-objects.
- Finally, the impact of the upcoming high resolution sensors as well as the new interferometric SAR technique needs to be evaluated. For low resolution requirements ( $> 3$  m) these sensors may provide a highly economical potential.

Phase II of the study is dealing with the comparison of current 3D-acquisition techniques and might stimulate to approach these open problems.

Summarizing, the need for a better communication between producers and users of 3D city data has been clearly confirmed. The second phase of the test will give the chance to strengthen this interaction.

The result of this study of course leads to a number of questions and motivates further actions:

1. The **definition** of  $2\frac{1}{2}$ D and 3D **representation** appears to be - in a positive sense - an academic one as neither producers nor users need to think in this category. However, the conceptual differences and the need for semantically and technically well defined exchange and storage formats will require much more investigation and clarification. With respect to the answers to the questionnaire we therefore expect a certain error rate in the answers when referring to a distinction between  $2\frac{1}{2}$ D and 3D.
2. The **definition of resolution, precision and accuracy**, as well as the structure of specification of 3D data seems to be an unsolved problem. The solution to this quite difficult problem needs to be found soon due to the standardization activities going on in Europe. Here we only identify a great deficiency in theoretical and empirical research.
3. The questionnaire did not ask for information about the production process nor the **production rates**. Therefore the estimated percentages only give a qualitative image of the present situation. A more detailed study and much more in depth study would be necessary to be able to make predictions on market requirements. It should be performed by an institution with long experience in market analysis.

## Acknowledgments

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## References

- Fuchs, C. (1996). Oeepe Study on 3D City Models. In *Proceedings Workshop on 3D City Models*. Institute of Photogrammetry, University Bonn, Bonn, Germany, October 9-11.

## Questionnaire

## Instructions for Completing the Questionnaires

- The questionnaire is divided into three parts which is also indicated by different colors of the sheets:
  - **Blue sheet** (page 85): This part contains general questions about your institution and should be completed by everybody.
  - **Yellow sheets** (pages 86 - 94): This part contains questions for the **producers** of city information. Thus, these pages should be completed by the producers.
  - **Green sheets** (pages 95-101): This part contains questions for the **users** of city information. Thus, these pages should be completed by the users.
- In most cases, completing the questionnaire just requires an indication cross:
  - Lists of ☐ ordered horizontally in rows, e. g. 1.1 (page 85), indicate that you should **only tick one** alternative.
  - Lists of ☐ ordered vertically in columns, e. g. 1.2 (page 85), or tables, e. g. 2.1 (page 86), indicate that you could possibly tick **several** alternatives.
- In case the given alternatives do not hold, please use the category “ **others** ” and give a short specification.
- In case the predefinition of alternative answers was impossible, we ask for comments **in text form**. Mostly, these questions aim at getting background information and will further help the interpretation and analysis of the questionnaires.

## 1 General Information on Institution

### 1.1 *Type of Institution (tick one)*

firm, company  
industry  
☐

government agency  
administration  
☐

university  
research institution  
☐

### 1.2 *Task of institution (possibly tick several)*

- ☐ mapping
- ☐ surveying
- ☐ photogrammetric services
- ☐ planning
- ☐ software development
- ☐ computing services
- ☐ environmental analysis
- ☐ architecture
- ☐ public utilities, e. g. energy supply
- ☐ telecommunication
- ☐ others, please name: .....

### 1.3 *Size of institution (tick one)*

Number of employees:

< 10  
☐

< 30  
☐

< 100  
☐

< 300  
☐

> 300  
☐

## 2 Information on Producers of 3D-city information

### 2.1 Type of 3D-city information produced

**Scope:** This information is to find out a possible correlation between different needs today. It will be compared with the actual and future needs of the users (cf. 3.1). You may weight your answer by classifying the relevance of the objects from 1 (not relevant) to 5 (very relevant).

**Please fill out the following two tables with respect to the dimension :**

2D, if you only acquire planimetric information,

2 1/2 D, if you acquire height information as attribute (e. g. DEM) and

3D, if you acquire the 3D structure of the objects.

The 2D column is meant to get complete information of the acquired type of data.

Please indicate the objects which you acquire <u>at the moment</u>	dimension			relevance 1 (not) - 5 (very)				
	2D	2 1/2 D	3 D	1	2	3	4	5
buildings	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
vegetation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
traffic network (road, railway)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
public utilities (energy, sewerage)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
telecommunication	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please indicate the objects which you <u>do not</u> acquire <u>at the moment</u> , but you <u>are asked to acquire</u>	dimension			relevance 1 (not) - 5 (very)				
	2D	2 1/2 D	3 D	1	2	3	4	5
buildings	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
vegetation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
traffic network (road, railway)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
public utilities (energy, sewerage)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
telecommunication	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please comment on reasons why you do not produce the following objects as 3D-city information:

	Objects				
	please indicate reasons why you <u>do not</u> produce these objects				
	Buildings	Vegetation	Traffic network	Energy / Sewerage	Telecommunication
<b>Reasons:</b>					
no needs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
too expensive, not economical	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
no information sources available	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
no evaluation techniques available	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
others: .....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
others: .....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
others: .....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

## 2.2 Class of Clients

**Scope:** This list is to be correlated with the different information you acquire and reflects the actual needs in terms of users. It will be compared to the suppliers named by the users (cf. 3.2).

Please specify the class of your clients:

- ☐ your own institution
- ☐ mapping
- ☐ surveying
- ☐ photogrammetric services
- ☐ planning
- ☐ software development
- ☐ computing services
- ☐ environmental analysis
- ☐ architecture
- ☐ public utilities, e. g. energy supply
- ☐ telecommunication
- ☐ others, please name: .....

If possible, please give us names and addresses of your clients, if they are not in the enclosed list of those who got the questionnaires. This is to further extend the number of participants.

## 2.3 Technical environment

**Scope:** We will correlate this with the type of data sources (cf. 2.4.) and the description of 3D-city information you acquire (cf. 2.6). This also will give an indication of the actual potential for acquiring data of other types.

Please specify the technical environment you have:

### Hardware

- Photogrammetric Equipment (give number, if appropriate)

- ☐ .... Analytical Plotter(s)
- ☐ .... Digital Photogrammetric System(s)
- ☐ .... Scanner(s)
- ☐ .... others, please name .....

- Computers (give appr. number, if appropriate)

- ☐ .... Workstations
- ☐ .... others, please name .....

- ☐ Other specific hardware (please name) .....

### Software (give name(s), if appropriate)

- ☐ Aerial Triangulation: .....
- ☐ DEM-Analysis/Visualization: .....
- ☐ Automatic DEM-Generation: .....
- ☐ GIS: .....
- ☐ CAD: .....
- ☐ DBS: .....
- ☐ others: .....

## 2.4 Type of data sources

**Scope:** This section is to document the current availability of the different data sources. Only the data sources for acquiring 3D-city information is of interest.  
Please specify the data sources you use:

**Images:** Do you use images as data source

☐ yes

- ☐ aerial images, please specify which scale

- ☐ > 1 : 2 000
- ☐ 1 : 2 000 - 1 : 5 000
- ☐ 1 : 5 000 - 1 : 10 000
- ☐ 1 : 10 000 - 1 : 20 000
- ☐ 1 : 20 000 - 1 : 50 000
- ☐ < 1 : 50 000

## 2.4. Images used as data source (continued)

☐ terrestrial images, please specify which scale

- ☐ ☐ > 1 : 20  
☐ 1 : 20 - 1 : 50  
☐ 1 : 50 - 1 : 100  
☐ 1 : 100 - 1 : 200  
☐ < 1 : 200

☐ analog images

☐ digital images, please specify the image resolution (pixel size):

- ☐ < 10  $\mu m$   
☐ 10  $\mu m$  - 20  $\mu m$   
☐ 20  $\mu m$  - 50  $\mu m$   
☐ 50  $\mu m$  - 100  $\mu m$   
☐ > 100  $\mu m$

☐ color images

☐ B/W images

☐ others, please name .....

Number of processed photos per year for acquiring 2 1/2 or 3D-city information (tick the most left):

- ☐ <10   ☐ < 30   ☐ < 100   ☐ < 300   ☐ > 300

☐ **no**, I do not use images as data source

Indicate **reasons** why you do **not use images** as data source for acquiring 3D-city information

- ☐ no needs  
☐ too expensive, not economical  
☐ not available  
☐ no evaluation techniques available  
☐ others, please name: .....

**Range data:** Do you use range data (e. g. Laser or DEMs) as data source

☐ **yes**

Specify which type and name if appropriate:

- ☐ aerial range data .....  
☐ terrestrial range data .....

Average density of points at the object

- ☐ < 10 cm  
☐ 11 cm - 30 cm  
☐ 31 cm - 100 cm  
☐ 101 cm - 300 cm  
☐ > 300 cm

#### 2.4. Range data used as data source (continued)

Give number of km<sup>2</sup> processed per year (tick the most left):

< 1 km<sup>2</sup>   < 3 km<sup>2</sup>   < 10 km<sup>2</sup>   < 30 km<sup>2</sup>   < 100 km<sup>2</sup>   < 300 km<sup>2</sup>   > 300 km<sup>2</sup>  
☐   ☐   ☐   ☐   ☐   ☐   ☐

☐ **no**

Indicate **reasons** why you do **not use range data** as data source for acquiring 3D-city information

- ☐ no needs
- ☐ too expensive, not economical
- ☐ not available
- ☐ no evaluation techniques available
- ☐ others, please name: .....

**Other data sources**, which you use for acquiring 3D-city information.

- ☐ classical surveying methods
- ☐ maps
  - ☐ analog
  - ☐ digital
    - please name the **map type** you use : .....
    - please name the **map scale** you use : .....
- ☐ other sources, please name: .....

#### 2.5 Type of output data you deliver to your clients

**Scope:** This section is to document the current availability of different 3D-city data in terms of the users.

Please indicate the type of output data you produce:

- ☐ Digital Elevation Models (DEM)
- ☐ Orthoimage Maps
- ☐ Digital Maps
- ☐ CAD-Models
- ☐ Others, relevant in this context of 3D-city data. Please, name: .....

## 2.6 Description of 3D-city information produced

**Scope:** This information is to establish the type of object information produced today. It will be compared with the actually received and needed products named by the users (cf. 3.6). We distinguish between buildings (2.6.1) and other 3D-city objects (2.6.2).

### 2.6.1 Building extraction

If you acquire buildings as 3D-city information please answer the following questions:

- **Quantitative Resolution:** Describe the resolution, i. e. the degree of generalization you aim at in terms of the size of details. We want to distinguish planimetry and height. Object details are acquired, if they are in size (tick the most right):

in planimetry: > 0 m   > 0.1 m   > 0.2 m   > 0.5 m   > 1 m   > 2 m   > 5 m  
☐   ☐   ☐   ☐   ☐   ☐   ☐

in height: > 0 m   > 0.1 m   > 0.2 m   > 0.5 cm   > 1 m   > 2 m   > 5 m  
☐   ☐   ☐   ☐   ☐   ☐   ☐

minimum size (area in [m<sup>2</sup>]) of single buildings: .....

minimum height (in [m]) of single buildings: .....

- **Qualitative Resolution:** Describe the resolution, i. e. the degree of generalization you aim at in term of the type of buildings, building parts or architectonic details. Details are acquired if they are:

	always	depending on size
<input type="radio"/> garages	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> greenhouses, bower, etc.	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> patios	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> roofs	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> roof overhangs	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> roof elements, e. g. chimneys	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> passages	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> front elements , e. g. balconies	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> floors	<input type="checkbox"/>	<input type="checkbox"/>

Other specific criteria for generalization, if available:.....

### 2.6.1 Building Extraction (continued)

- **Precision.** Please specify the precision of the buildings you acquire:

**in planimetry**, i. e. the precision of absolute and/or relative  $X/Y$  - coordinates of the buildings (e. g. as maximum relative error, maximum standard deviation) in [m]:  
please specify or comment:

**in height**, i. e. the precision of absolute and/or relative building heights (e. g. as maximum relative error, maximum standard deviation) in [m]:  
please specify or comment:

- **Representation.** Which representation do you use to describe the 3D shape of buildings?

☐ **Raster Representation**

- ☐ DEM with regular grid
- ☐ DEM with triangular irregular networks

☐ **Vector Representation**

- ☐ ground plan of building + single height per building unit (neglecting the roof shape)
- ☐ ground plan of building + shape description of roof
  - ☐ qualitative roof description (just type of roof shape, e. g. flat, peaked)
  - ☐ quantitative roof description (e. g. heights of gable and eaves, direction of gables)
- ☐ complete boundary representation (allowing attributes for vertical walls)
- ☐ complete representation by volumes, e. g. CSG
- ☐ others: .....

## 2.6.2 Other 3D-city objects

If you acquire other 3D-city objects than buildings please complete the following table (pages 10,11):

Objects			
please indicate the <i>objects</i> you acquire and complete the corresponding columns			
<input type="radio"/> Vegetation	<input type="radio"/> Infrastructure networks		<input type="radio"/> Other
<input type="radio"/> trees <input type="radio"/> parks <input type="radio"/> others: .....	<input type="radio"/> traffic network <input type="radio"/> road network <input type="radio"/> train / tram <input type="radio"/> others: .....	<input type="radio"/> public utilities <input type="radio"/> energy supply <input type="radio"/> sewerage nets <input type="radio"/> telecommunication <input type="radio"/> others	
Quantitative Resolution			
specify minimum size of <i>details</i> and minimum size of <i>single objects</i> you acquire (cf. 2.6.1)			
minimum size of • object details in – planimetry: .....[m] – height: .....[m] • of single objects in – planimetry: .....[m] – height: .....[m] • other criteria:	minimum size of • object details in – planimetry: .....[m] – height: .....[m] • of single objects in – planimetry: .....[m] – height: .....[m] • other criteria:	minimum size of • object details in – planimetry: .....[m] – height: .....[m] • of single objects in – planimetry: .....[m] – height: .....[m] • other criteria:	minimum size of • object details in – planimetry: .....[m] – height: .....[m] • of single objects in – planimetry: .....[m] – height: .....[m] • other criteria:
Qualitative Resolution			
indicate and specify <i>object types, details</i> and <i>features</i> you acquire (cf. 2.6.1)			
<input type="radio"/> type name: ..... name: ..... <input type="radio"/> details (e.g. tree trunks, tree tops) name: ..... name: ..... other criteria:	<input type="radio"/> type name: ..... name: ..... <input type="radio"/> details (e. g. bridges, tunnels, slots, signs) name: ..... name: ..... other criteria:	<input type="radio"/> type name: ..... name: ..... <input type="radio"/> details name: ..... name: ..... other criteria:	<input type="radio"/> type name: ..... name: ..... <input type="radio"/> details name: ..... name: ..... other criteria:

Table continued			
please complete the columns corresponding to the objects you indicated on page 10 as objects <b>you acquire</b>			
Vegetation	Infrastructure networks		Other
<p align="center"><b>Precision</b></p> <p align="center">specify the absolute and/or relative <b>precision</b> of the objects <b>you acquire</b> (cf. Precision in 2.6.1)</p>			
<ul style="list-style-type: none"> <li>• absolute precision               <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> <li>• relative precision               <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• absolute precision               <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> <li>• relative precision               <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• absolute precision               <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> <li>• relative precision               <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• absolute precision               <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> <li>• relative precision               <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> </ul>
<p align="center"><b>Representation</b></p> <p align="center">specify the <b>representation type</b> of the objects <b>you acquire</b> (cf. Representation in 2.6.1)</p>			
<input type="radio"/> raster specify:	<input type="radio"/> raster specify:	<input type="radio"/> raster specify:	<input type="radio"/> raster specify:
<input type="radio"/> vector specify:	<input type="radio"/> vector specify:	<input type="radio"/> vector specify:	<input type="radio"/> vector specify:

### 3 Information on Users of 3D-City Data

#### 3.1 Type of 3D-City information used

**Scope:** This information is to find out a possible correlation between different needs today. It will be compared with the actual and future tasks named by the producers (cf. 2.1). You may weight your answer by classifying the relevance of the objects from 1 (not relevant) to 5 (very relevant).

Please fill out the following two tables with respect to the *dimension* :

2D, if you only use planimetric information,

2 1/2 D, if you use height information as attribute (e. g. DEM) and

3D, if you use the 3D structure of the objects.

The 2D column is meant to get complete information of the used type of data.

Please indicate the objects which you use <u>at the moment</u>	dimension			relevance 1 (not) - 5 (very)				
	2D	2 1/2 D	3 D	1	2	3	4	5
buildings	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
vegetation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
traffic network (road, railway)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
public utilities (energy, sewerage)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
telecommunication	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please indicate the objects which you <u>do not use at the moment</u> , but you <u>would like to use</u>	dimension			relevance 1 (not) - 5 (very)				
	2D	2 1/2 D	3 D	1	2	3	4	5
buildings	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
vegetation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
traffic network (road, railway)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
public utilities (energy, sewerage)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
telecommunication	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
others:.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please comment on reasons why you do not use the following objects as 3D-city information:

	Objects				
	please indicate reasons why you <u>do not</u> use these objects				
	Buildings	Vegetation	Traffic network	Energy / Sewerage	Telecommunication
<b>Reasons:</b>					
no needs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
too expensive, not economical	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
no information sources available	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
no evaluation techniques available	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
others: .....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
others: .....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
others: .....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

### 3.2 Class of Suppliers of 3D - City Information

**Scope:** This list is to be correlated with the different information you use and reflects the actual tasks in terms of the producers. It will be compared to the clients named by the producers (cf. 2.2).

Please specify the class of your suppliers:

- ☐ your own institution
- ☐ mapping
- ☐ surveying
- ☐ photogrammetric services
- ☐ planning
- ☐ software development
- ☐ computing services
- ☐ environmental analysis
- ☐ architecture
- ☐ public utilities, e. g. energy supply
- ☐ telecommunication
- ☐ others, please name: .....

If possible, please give us names and addresses of your suppliers, if they are not in the enclosed list of those who got the questionnaires. This is to further extend the number of participants.

### 3.3 Technical Environment

**Scope:** We will correlate this with the type of input data (cf. 3.4) and the description of 3D-city information you use (cf. 3.6). This also will give an indication of the actual potential for using data of other types.

Please specify the technical environment you have:

**Hardware**

- Computers (give appr. number, if appropriate)

- ☐ .... Workstations
- ☐ .... others, please name .....

- Specialized hardware, periphery

- ☐ Stereo display
- ☐ Large format plotter
- ☐ others, please name: .....

**Software** (give name(s), if appropriate)

- ☐ DEM-Analysis/Visualization: .....
- ☐ GIS: .....
- ☐ CAD: .....
- ☐ DBS: .....
- ☐ Simulation-Software, possibly within a GIS. Please give name of package, if appropriate.
  - ☐ Wind simulation, climatological simulation: .....
  - ☐ Noxious emission: .....
  - ☐ Noise pollution, sound expansion: .....
  - ☐ Electromagnetic field strength simulation: .....
  - ☐ Lighting: .....
- ☐ others, please name: .....

### 3.4 Type of input data you use

**Scope:** This section is to document the current availability of the different 3D-city data.  
Please specify the data sources you use:

- ☐ Digital Elevation Models (DEM)
- ☐ Orthoimage Maps
- ☐ Digital Maps
- ☐ CAD-Models
- ☐ Others, relevant in this context of 3D-city data. Please, name: .....

### 3.5 Type of output data

Please comment the **purpose** or task of using city information and, if appropriate, specify the **type of result** you produce (you may also send brochures or reports):

### 3.6 Description of 3D-city information used

**Scope:** This information is to establish the type of object information used today. It will be compared with the actually acquired objects named by the producers (cf. 2.6). We distinguish between buildings (3.6.1) and other 3D-city objects (3.6.2).

#### 3.6.1 Buildings

If you use buildings as 3D-city information please answer the following questions:

- **Quantitative Resolution.** Describe the resolution, i. e. the degree of generalization of the objects **in terms of the size** of objects or details. We want to distinguish planimetry and height. You **need** object details if they are in size (tick the most right)

in planimetry: > 0 m   > 0.1 m   > 0.2 m   > 0.5 m   > 1 m   > 2 m   > 5 m  
☐   ☐   ☐   ☐   ☐   ☐   ☐

in height: > 0 m   > 0.1 m   > 0.2 m   > 0.5 m   > 1 m   > 2 m   > 5 m  
☐   ☐   ☐   ☐   ☐   ☐   ☐

minimum size (area in [m<sup>2</sup>]) of single buildings: .....

minimum height (in [m]) of single buildings: .....

### 3.6.1 Buildings (continued)

- **Qualitative Resolution:** Describe the resolution, i. e. the degree of generalization in terms of the type of buildings, building parts or architectonic details. **Details of interest** are:

	always	depending on size
<input type="radio"/> garages	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> greenhouses, bower, etc.	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> patios	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> roofs	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> roof overhangs	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> roof elements, e. g. chimneys	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> passages	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> front elements, e. g. balconies	<input type="checkbox"/>	<input type="checkbox"/>
<input type="radio"/> floors	<input type="checkbox"/>	<input type="checkbox"/>

Other specific criteria for generalization, if available:.....

- **Precision.** Please specify the required precision of the buildings:  
**in planimetry**, i. e. the required precision of absolute and/or relative  $X/Y$  - coordinates of the buildings (e. g. as maximum relative error, maximum standard deviation) in [m]:  
 please specify or comment:  
**in height**, i. e. the required precision of absolute and/or relative building heights (e. g. as maximum relative error, maximum standard deviation) in [m]:  
 please specify or comment:

- **Representation.** Which representation do you use to describe the 3D shape of buildings?

☐ **Raster Representation**

- ☐ DEM with regular grid
- ☐ DEM with triangular irregular networks

☐ **Vector Representation**

- ☐ ground plan of building + single height per building unit (neglecting the roof shape)
- ☐ ground plan of building + shape description of roof
  - ☐ qualitative roof description (just type of roof shape, e. g. flat, peaked)
  - ☐ quantitative roof description (e. g. heights of gable and eaves, direction of gables)
- ☐ complete boundary representation (allowing attributes for vertical walls)
- ☐ complete representation by volumes, e. g. by CSG
- ☐ others: .....

### 3.6.2 Other 3D-city objects

If you use other 3D-city objects than buildings please complete the following table:

Objects			
please indicate the <i>objects</i> you use and complete the corresponding columns			
<input type="radio"/> <b>Vegetation</b>  <input type="radio"/> trees <input type="radio"/> parks <input type="radio"/> others: .....	<input type="radio"/> <b>Infrastructure networks</b>  <input type="radio"/> <b>traffic network</b> <input type="radio"/> road network <input type="radio"/> train / tram <input type="radio"/> others: .....	<input type="radio"/> <b>public utilities</b> <input type="radio"/> energy supply <input type="radio"/> sewerage nets <input type="radio"/> telecommunication <input type="radio"/> others	<input type="radio"/> <b>Other</b>
Quantitative Resolution			
specify <b>minimum size</b> of <i>details</i> and minimum size of <i>single objects</i> you need (cf. 3.6.1)			
<b>minimum size of</b> • object details in – planimetry: .....[m] – height: .....[m] • of single objects in – planimetry: .....[m] – height: .....[m] • other criteria:	<b>minimum size of</b> • object details in – planimetry: .....[m] – height: .....[m] • of single objects in – planimetry: .....[m] – height: .....[m] • other criteria:	<b>minimum size of</b> • object details in – planimetry: .....[m] – height: .....[m] • of single objects in – planimetry: .....[m] – height: .....[m] • other criteria:	<b>minimum size of</b> • object details in – planimetry: .....[m] – height: .....[m] • of single objects in – planimetry: .....[m] – height: .....[m] • other criteria:
Qualitative Resolution			
indicate and specify <i>object types, details</i> and <i>features</i> you use (cf. 3.6.1)			
<input type="radio"/> <b>type</b> name: ..... name: ..... <input type="radio"/> <b>details</b> (e.g. tree trunks, tree tops) name: ..... name: ..... <b>other criteria:</b>	<input type="radio"/> <b>type</b> name: ..... name: ..... <input type="radio"/> <b>details</b> (e. g. bridges, tunnels, slots, signs) name: ..... name: ..... <b>other criteria:</b>	<input type="radio"/> <b>type</b> name: ..... name: ..... <input type="radio"/> <b>details</b> name: ..... name: ..... <b>other criteria:</b>	<input type="radio"/> <b>type</b> name: ..... name: ..... <input type="radio"/> <b>details</b> name: ..... name: ..... <b>other criteria:</b>

Table continued

please complete the columns corresponding to the objects you indicated on the page before as objects **you use**

Vegetation	Infrastructure networks	Other
<p align="center"><b>Precision</b></p> <p align="center">specify the <b>required</b> absolute and/or relative <b>precision</b> of the objects <b>you use</b> (cf. Precision in 3.6.1)</p>		
<ul style="list-style-type: none"> <li>• absolute precision                             <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> <li>• relative precision                             <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• absolute precision                             <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> <li>• relative precision                             <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• absolute precision                             <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> <li>• relative precision                             <ul style="list-style-type: none"> <li>– planimetry: .....[m]</li> <li>– height: .....[m]</li> </ul> </li> </ul>
<p align="center"><b>Representation</b></p> <p align="center">specify the <b>representation type</b> of the objects <b>you use</b> (cf. Representation in 3.6.1)</p>		
<input type="radio"/> raster specify:	<input type="radio"/> raster specify:	<input type="radio"/> raster specify:
<input type="radio"/> vector specify:	<input type="radio"/> vector specify:	<input type="radio"/> vector specify:



## Description of the Test Data

## Description of Test Data – Phase I

### Data sources

#### A) Images:

Images of the test field OEDEKOVEN has been chosen to acquire raster and vector data for the OEEPE test on 3D-city models – phase 1. The image scale of the B/W aerial imagery is 1:12000, the focal length is 153 mm. A stereo pair had been digitized with a pixel size of 12.5 m in the image.

**Note:** *The digital images have been kindly provided by the Landesvermessungsamt Nordrhein-Westfalen, Germany, and are allowed to be only used for the OEEPE test for scientific, non commercial purposes (letter from January 30, 1996, Akz 22-2904.7/E).*

Three areas of different size have been selected (cf. Fig. 1):

Area a: 500 m × 500 m

Area b: 1000 m × 1000 m

Area c: 1400 m × 1700 m

For each area three types of data have been prepared: a digital surface model (raster data), vector data and a 3D-visualization.

**Note:** *All prepared data sets are allowed to be only used for the OEEPE test for scientific, non commercial purposes.*

#### B) Laser Scan Data:

Laser scan data from the test field BONN has been chosen to provide another type of raster data for the OEEPE test on 3D-city models – phase 1. The area of the size 1000 m × 1000m does not overlap with the test field OEDEKOVEN.

**Note:** *The laser scan data have been kindly provided by the Stadtvermessungsamt Bonn, Germany, and are allowed to be only used for the OEEPE test for scientific, non commercial purposes (DHM der Bundesstadt Bonn mit Genehmigung der Kataster- und Vermessungsamtes der Bundesstadt Bonn, Genehmigungs Nr. 202/96 from February 13, 1996).*

### Description of 2½D- and 3D data sets

#### 1. 2½D data sets (raster data):

##### (a) Digital surface model from image data:

From the digital images of OEDEKOVEN digital surface models with a raster width of 1m has been derived with MATCH-T (INPHO GmbH, Stuttgart). This raster data have been transformed to raster widths of 2 m, 5 m and 10 m. The data are provided as raster images in TIFF format with 8 Bit gray values. The heights are coded as gray values (cf. Fig. 2).

An overview of the areas and a detailed file description is provided in the data set (readme.dsm).

(b) Digital surface model from laser scan data:

An area of 1000 x 1000 m has been chosen from the laser scan flight BONN (TopScan GmbH, Stuttgart). The resolution on the ground is 1 m. Raster width of 2 m, 5 m and 10 m had been derived from the 1 m resolution data set. The data have been post-processed by the Institute of Photogrammetry Bonn (ipb) and transformed to an raster image in TIFF format with 8Bit gray values. The heights are coded as gray values (cf. Fig. 3).

A detailed file description is provided in the data set (readme.lsm).

2. **3D data sets (vector data):**

The buildings in the test field OEDEKOVEN have been extracted by a one-eye stereo system at the Institute of Photogrammetry Bonn (ipb)<sup>1</sup>. The modeling is based on Constructive Solid Geometry (CSG) and various automated and supporting tools. Single 3D primitives are combined by boolean operations (union, intersection, difference) to complex building descriptions. The emphasis has been put on the acquisition of detailed roof and building structures. The result are volumetric models of the buildings.

The vector data is provided as ground plan and one representative height per building (gutter height) in ASCII DXF File Format ('Drawing Interchange File', AUTOCAD) and in Intergraph DGN Format. A complete 3D boundary description in DXF/DGN formats is not yet available.

A detailed file description is provided in the data set (readme.vec).

3. **Visualization:**

A boundary representation of the acquired CSG models is given in the Virtual Reality Modeling Language (VRML). The ground height between buildings has been provided by triangulation of building ground heights (cf. Fig. 4).

A detailed file description is provided in the data set (readme.vis).

VRML is a scene description language that standardizes how three-dimensional environments are represented on the World Wide Web (WWW). VRML files get parsed and then displayed. There are (partly freely) down-loadable versions of products available for UNIX and PC. Some allow you just to browse in 3D, while others allow for various levels of 3D creation and VRML authoring. A list of VRML sites and VRML browsers is given in the file description (readme.vis). The enclosed VRML files have been tested on Webspaces 1.0 from SGI (Silicon graphics International), on Virtual Web for DEC-Alpha, for SUN-OS 4.1.3 and for SGI IRIX 5.3. After you have installed and configured your VRML application, you can load the VRML file the same way you access a HTML file.

<sup>1</sup> cf. Roman Englert, Eberhard Gülch: "One-Eye Stereo System for the Acquisition of Complex 3D Building Descriptions", paper submitted to GIS Journal 4/96.

### How to access the data?

The data is accessible via anonymous ftp to the ftp server of the Institute of Photogrammetry, University of Bonn, or is contained on the requested storage media (DAT-tape, CD-ROM).

Content of directory /pub/oeepe on the ftp server, resp. of the storage media (DAT, CD-ROM):

dsm (directory)	Digital surface model from images in TIFF format
ldsm (directory)	Digital surface model from laser scan data in TIFF format
vector (directory)	Vector data in DXF format (Ground plan + 1 height)
visual (directory)	Visualization of 3D boundary representation in VRML format
readme (file)	General Information and file descriptions
oeepetar.gz	Compressed (gzip) tar file of the complete
directory 'oeepe'	
oeepetar.Z	Compressed (Unix) tar file of the complete directory 'oeepe'

#### 1. Data access via ftp:

To access the data you use the following commands:

```
ftp ftp.ipb.uni-bonn.de
```

```
login: anonymous passwd: your e-mail address
```

```
cd /pub/oeepe
```

```
bin to set the binary transfer mode.
```

To retrieve data you can either use:

```
get oeepetar.gz
```

To transfer the whole content of the directory or to retrieve single files you may use e.g.:

```
get readme .
```

After finishing the transfer of data you logout with

```
bye
```

#### 2. Data access via storage media:

To access the data you simply copy single files (cf. above), or a compressed TAR file of the whole data set (oeepetar.gz, oeepetar.Z) with your standard procedures.

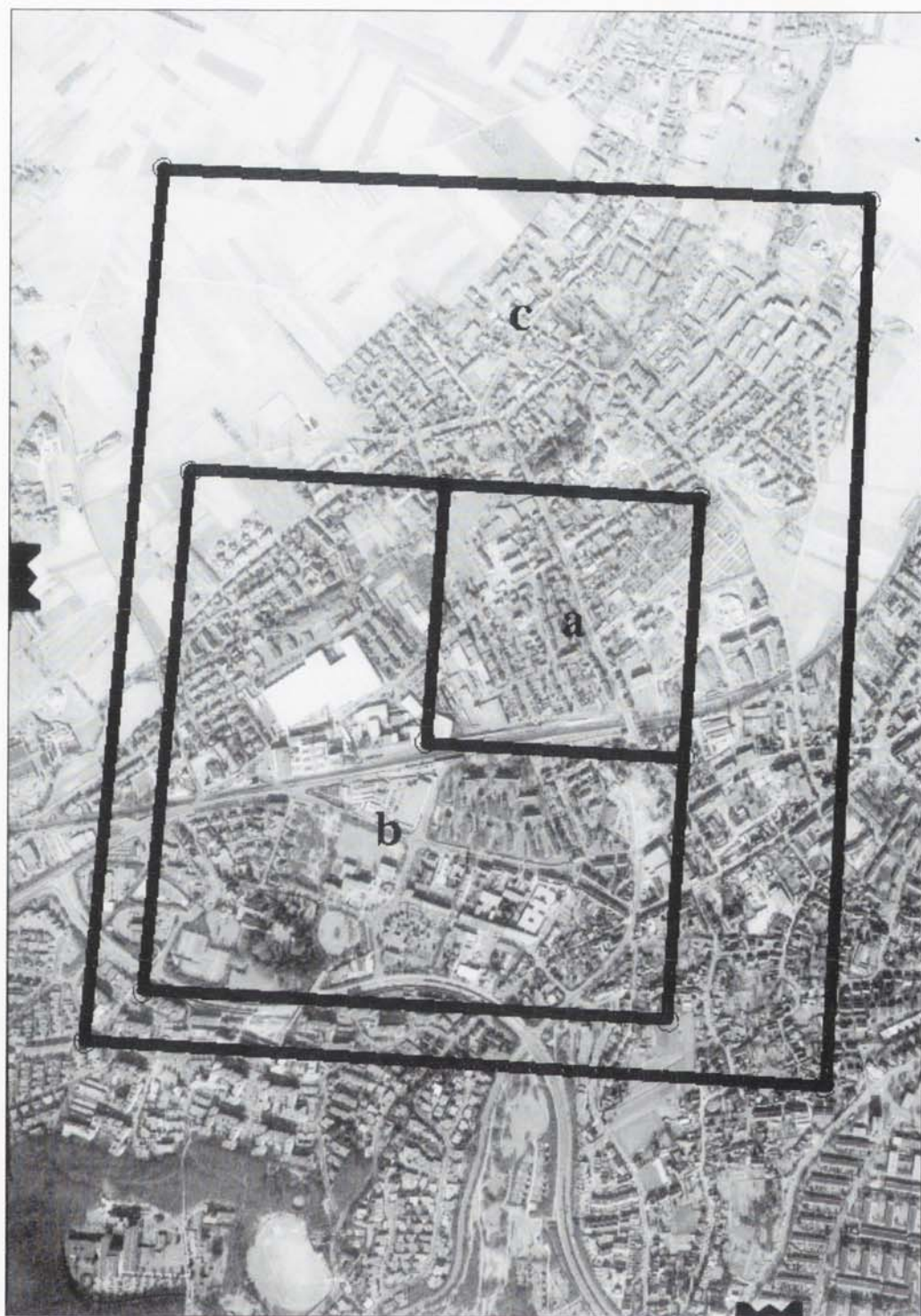


Figure 1: Overview on the selected areas of the test field OEDEKOVEN prepared for phase I. **a**: small area (500 m x 500 m), **b**: medium area (1000 m x 1000 m), **c**: large (1400 m x 1700 m). The digital images have been kindly provided by the Landesvermessungsamt Nordrhein-Westfalen, Germany, and are allowed to be only used for the OEEPE test (letter from January 30, 1996, Akz 22-2904.7/E).



Figure 2: Visualization of the digital surface model of the test field OEDEKOVEN. The surface model has been derived with MATCH-T from digital images, cf. 1.(a) in the description of the data sets. Gray values represent heights. The digital images have been kindly provided by the Landesvermessungsamt Nordrhein-Westfalen, Germany. The data are allowed to be only used for the OEEPE test.



Figure 3: Visualization of the digital surface model of the test field BONN derived from laser range data (TopScan). The data have been kindly provided by the Stadtvermessungsamt Bonn, Germany, and are allowed to be only used for the OEEPE test (Genehmigungs-Nr. 202/96 from February 13, 1996). The data have been post-processed at the ipb. Gray values represent heights, cf. 1.(b) in the description of the data sets.

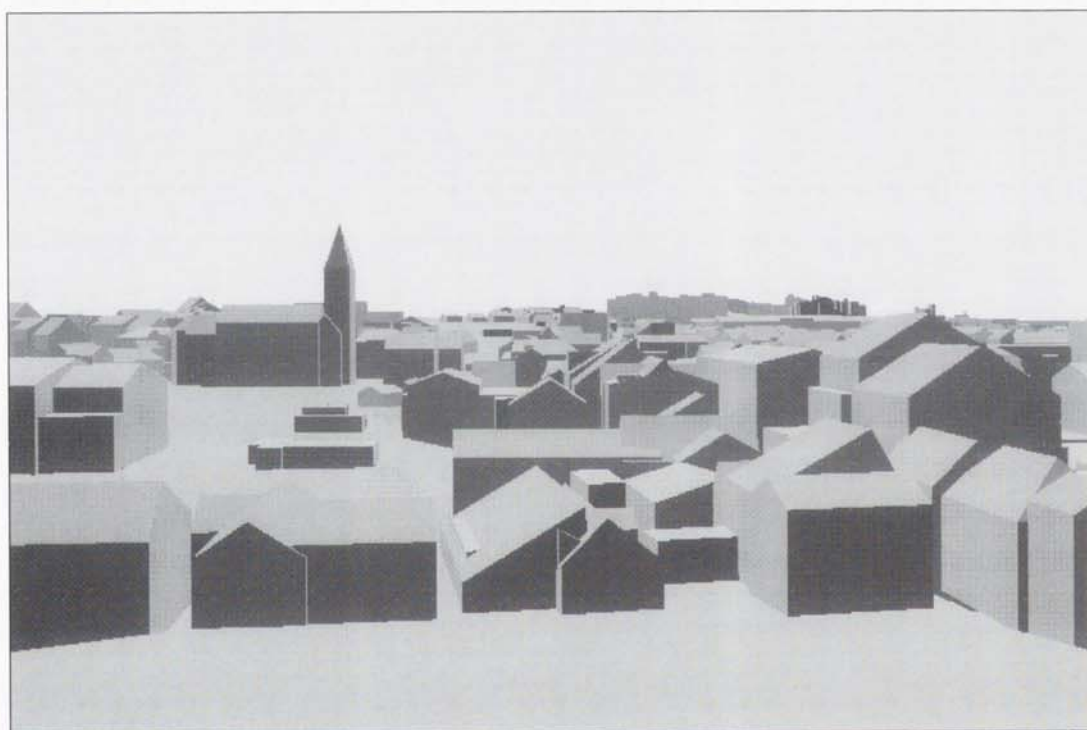
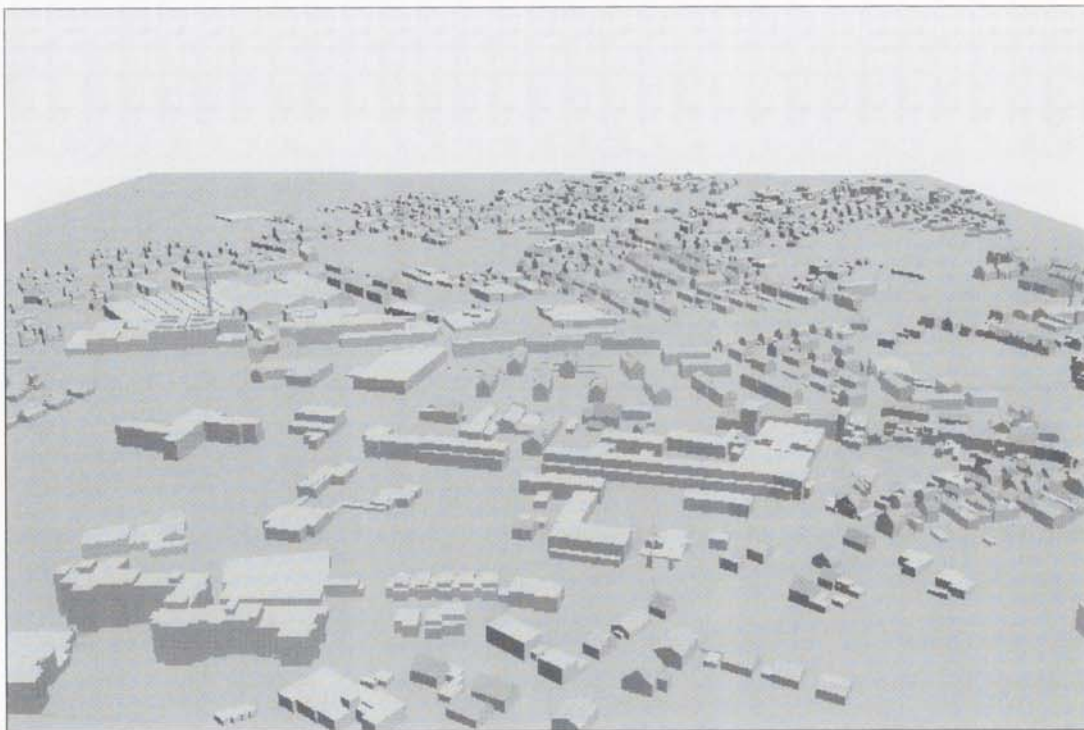


Figure 4: VRML visualization of the acquired vector dat of the test field OEDEKOVEN from two different viewpoints. The buildings have been extracted by a one-eye stereo system at the ipb, cf. 2. and 3. in the description of the data sets. The data are allowed to be only used for the OEEPE test.

## Results for Individual Evaluation

Reasons for not producing these objects [%]						
	overall					total
	no need	too exp.	no infos	no tools	other	
buildings	10	40	15	5	30	100
vegetation	32	28	24	0	16	100
traffic network	30	25	25	15	5	100
public utilities	33	19	17	11	19	100
telecommunication	39	18	16	11	16	100

Reasons for not producing these objects [%] / Type of Institutions					
	firm, company, industry				
	no need	too exp.	no infos	no tools	other
buildings	5	5	5	0	5
vegetation	4	8	4	0	0
traffic network	15	5	5	5	0
public utilities	17	6	6	3	0
telecommunication	21	5	8	3	0
	government agency, administration				
	no need	too exp.	no infos	no tools	other
buildings	5	35	10	5	20
vegetation	20	16	12	0	12
traffic network	5	15	15	10	5
public utilities	0	11	3	6	14
telecommunication	5	11	0	5	13
	university, research institution				
	no need	too exp.	no infos	no tools	other
buildings	0	0	0	0	5
vegetation	8	4	8	0	4
traffic network	5	0	5	0	0
public utilities	14	0	8	3	6
telecommunication	11	0	8	3	3

**Table 1: Reasons for not producing city data:**

1. *in general* (in % of all producers) (cf. Questionnaire Q2.1, 3. Table)

With respect to *Type of institution* (cf. Questionnaire Q1.1):

2. for Firms (in % of producers from Firm)

3. for Government Agencies (in % of producers from Gov. Ag.)

4. for Universities (in % of producers from Univ.)

Abbreviations: too expensive (too exp.), no access to data or lack of information (no infos), no evaluation methods (no tools), other reasons (other)

Reasons for not producing these objects [%]						
	overall					total
	no need	too exp.	no infos	no tools	other	
buildings	6	31	44	13	6	100
vegetation	6	22	44	11	17	100
traffic network	23	15	38	15	8	100
public utilities	50	7	29	14	0	100
telecommunication	46	0	31	23	0	100

Reasons for not using these objects [%] / Type of Institutions					
	firm, company, industry				
	no need	too exp.	no infos	no tools	other
buildings	0	13	6	0	0
vegetation	6	11	11	0	6
traffic network	15	0	8	0	0
public utilities	21	0	7	0	0
telecommunication	15	0	8	0	0
	government agency, administration				
	no need	too exp.	no infos	no tools	other
buildings	0	6	13	6	6
vegetation	0	0	11	6	6
traffic network	8	8	8	8	0
public utilities	21	0	0	7	0
telecommunication	15	0	8	15	0
	university, research institution				
	no need	too exp.	no infos	no tools	other
buildings	6	13	25	6	0
vegetation	0	11	22	6	6
traffic network	0	8	23	8	8
public utilities	7	7	21	7	0
telecommunication	15	0	15	8	0

**Table 2: Reasons for not using city data:**

1. *in general* (in % of all users) (cf. Questionnaire Q3.1, 3. Table)

With respect to *Type of institution* (cf. Questionnaire Q1.1):

2. for Firms (in % of users from Firm)

3. for Government Agencies (in % of users from Gov. Ag.)

4. for Universities (in % of users from Univ.)

Abbreviations: too expensive (too exp.), no access to data or lack of information (no infos), no evaluation methods (no tools), other reasons (other)

Mean Degrees of Relevance (range: 1–5)								
41 producers, 21 users								
Objects acquired								
	2D	#	2.5D	#	3D	#	total	#
buildings	4,59	18	4,87	15	4,52	24	4,63	57
vegetation	3,93	16	3,86	14	3,44	10	3,78	40
traffic network	4,00	20	4,46	13	4,85	13	4,37	46
public utilities	3,50	12	4,22	9	3,20	5	3,69	26
telecommunication	4,25	4	3,75	4	4,00	6	4,00	14
others	4,67	6	5,00	6	4,33	9	4,62	21
Objects not acquired at present								
	2D	#	2.5D	#	3D	#	total	#
buildings	5,00	1	4,50	2	4,00	9	4,17	12
vegetation	3,00	3	3,00	4	4,50	2	3,33	9
traffic network	4,00	2	4,00	2	3,80	6	3,88	10
public utilities	3,67	3	3,67	6	3,00	5	3,43	14
telecommunication	3,00	4	3,60	5	3,75	4	3,46	13
others	0,00	0	3,00	1	3,00	3	3,00	4
Objects used								
	2D	#	2.5D	#	3D	#	total	#
buildings	3,89	9	4,50	8	4,50	10	4,30	27
vegetation	3,50	10	3,67	6	4,00	2	3,61	18
traffic network	4,08	12	4,50	2	3,00	7	3,76	21
public utilities	4,33	6	5,00	2	3,50	2	4,30	10
telecommunication	4,67	3	3,50	2	4,00	2	4,14	7
others	3,80	5	5,00	3	4,50	4	4,33	12
Objects not used at present								
	2D	#	2.5D	#	3D	#	total	#
buildings	0,00	0	4,00	2	4,29	8	4,23	10
vegetation	2,00	1	4,33	4	3,57	7	3,69	12
traffic network	0,00	0	3,67	3	4,50	2	4,00	5
public utilities	3,67	3	3,00	3	0,00	0	3,33	6
telecommunication	2,67	3	3,33	3	0,00	0	3,00	6
others	0,00	0	0,00	0	5,00	1	5,00	1

**Table 3: Objects of interest** for the participating institutions: *Mean degrees of relevance* for the institutions [1(low) – 5(high)] and *Number of answers #* (from 41 producers and 21 users):

1. already in production (cf. Quest. Q2.1, 1. Table)
2. with request for production (future) (cf. Quest. Q2.1, 2. Table)
3. already in use (cf. Quest. Q3.1, 1. Table)
4. would like to use (future) (cf. Quest. Q3.1, 2. Table)

Objects acquired at present / Type of Institution				
	3D			
	firms	gov.	uni.	n.A
buildings	11	7	5	1
vegetation	6	2	2	0
traffic network	9	2	2	0
public utilities	5	0	0	0
telecommunication	4	1	1	0
others	5	2	2	0
Objects not acquired at present / Type of Institution				
	3D			
	firms	gov.	uni.	n.A
buildings	3	5	1	0
vegetation	1	0	1	0
traffic network	2	2	2	0
public utilities	2	2	1	0
telecommunication	1	2	1	0
others	1	0	2	0
Objects used at present / Type of Institution				
	3D			
	firms	gov.	uni.	n.A
buildings	4	1	5	0
vegetation	1	1	0	0
traffic network	1	3	3	0
public utilities	1	0	1	0
telecommunication	1	0	1	0
others	1	2	1	0
Objects not used at present / Type of Institution				
	3D			
	firms	gov.	uni.	n.A
buildings	3	3	2	0
vegetation	3	0	4	0
traffic network	0	0	2	0
public utilities	0	0	0	0
telecommunication	0	0	0	0
others	1	0	0	0

**Table 4: 3D-Objects of interest** in present or future with respect to the *Type of Institution* (Number of answers from 41 producers and 21 users):

1. already in production (cf. Quest. Q1.1, Q2.1, 1. Table)
2. with request for production (future) (cf. Q1.1, Q2.1, 2. Table)
3. already in use (cf. Q1, Q3.1, 1. Table)
4. would like to use (future) (cf. Q1.1, Q3.1, 2. Table)

Objects acquired at present / Task of Institution									3D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	19	16	13	9	7	4	10	4	4	4	5	1
vegetation	6	7	6	4	5	2	4	0	1	1	2	0
traffic network	9	10	8	6	5	2	5	2	2	1	3	0
public utilities	3	3	3	3	5	2	3	0	1	1	1	0
telecommunication	5	5	4	2	3	2	3	0	1	2	1	0
others	7	7	5	5	4	4	4	1	3	3	4	0

Objects not acquired at present / Task of Institution									3D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	9	8	6	3	2	1	4	2	1	1	1	0
vegetation	1	1	0	1	2	1	1	2	0	0	0	0
traffic network	5	3	1	3	2	1	3	3	1	0	0	0
public utilities	4	4	2	1	0	0	1	1	1	0	1	0
telecommunication	4	2	2	1	0	0	2	1	2	0	0	0
others	1	3	0	1	1	1	1	1	0	0	0	0

Objects used at present / Task of Institution									3D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	4	1	0	6	5	1	5	4	0	0	4	0
vegetation	0	0	0	2	1	0	1	1	0	0	0	0
traffic network	4	2	2	3	2	0	5	1	0	2	1	0
public utilities	0	0	0	1	2	0	1	0	0	0	1	0
telecommunication	0	0	0	0	1	0	0	0	0	1	1	0
others	1	0	0	2	0	0	1	2	0	0	1	0

Objects not used at present / Task of Institution									3D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	4	3	1	5	2	1	4	4	1	2	0	0
vegetation	3	1	0	3	2	1	3	3	0	2	3	0
traffic network	0	0	0	2	0	0	1	1	0	0	1	0
public utilities	0	0	0	0	0	0	0	0	0	0	0	0
telecommunication	0	0	0	0	0	0	0	0	0	0	0	0
others	0	0	0	0	0	0	0	0	0	0	1	0

**Table 5: 3D-Objects of interest** with respect to the *Task of institution* (number of answers from 41 producers and 21 users):

1. already *in production* (cf. Quest. Q1.2, Q2.1, 1. Table)
2. with *request* for production (future) (cf. Q1.2, Q2.1, 2. Table)
3. already *in use* (cf. Q1.2, Q3.1, 1. Table)
4. *would like* to use (future) (cf. Q1.2, Q3.1, 2. Table)

Objects acquired at present / Type of Institution				
	2.5D			
	firms	gov.	uni.	n.A
buildings	6	3	6	0
vegetation	5	4	5	0
traffic network	3	4	6	0
public utilities	2	5	2	0
telecommunication	2	2	0	0
others	0	6	0	0
Objects not acquired at present / Type of Institution				
	2.5D			
	firms	gov.	uni.	n.A
buildings	0	2	0	0
vegetation	0	3	1	0
traffic network	0	1	1	0
public utilities	1	4	1	0
telecommunication	1	3	1	0
others	0	0	1	0
Objects used at present / Type of Institution				
	2.5D			
	firms	gov.	uni.	n.A
buildings	2	2	4	0
vegetation	1	1	4	0
traffic network	0	0	2	0
public utilities	0	1	1	0
telecommunication	0	1	1	0
others	0	0	3	0
Objects not used at present / Type of Institution				
	2.5D			
	firms	gov.	uni.	n.A
buildings	0	0	2	0
vegetation	1	1	2	0
traffic network	1	1	1	0
public utilities	1	0	2	0
telecommunication	1	1	1	0
others	0	0	0	0

**Table 6: 2.5D-Objects of interest** with respect to the *Type of Institution* in present or future (number of answers from 41 producers and 21 users):

1. *already in production* (cf. Quest. Q1.1, Q2.1, 1. Table)
2. *with request for production (future)* (cf. Q1.1, Q2.1, 2. Table)
3. *already in use* (cf. Q1.1, Q3.1, 1. Table)
4. *would like to use (future)* (cf. Q1.1, Q3.1, 2. Table)

Objects acquired at present / Task of Institution									2.5D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	10	9	8	3	7	4	4	1	2	2	7	0
vegetation	10	9	8	2	5	3	4	1	2	3	5	0
traffic network	9	7	7	2	4	2	3	0	2	2	4	0
public utilities	8	6	6	2	2	1	2	0	3	1	1	0
telecommunication	4	3	3	1	1	1	2	0	0	1	0	0
others	6	6	6	0	0	1	0	0	0	0	0	0
Objects not acquired at present / Task of Institution									2.5D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	2	1	0	1	0	0	1	0	1	0	0	0
vegetation	4	2	2	0	0	0	2	0	0	1	0	0
traffic network	2	1	1	0	1	0	1	0	0	0	1	0
public utilities	6	4	1	2	1	1	4	2	2	0	0	0
telecommunication	5	4	1	2	1	1	5	2	2	1	0	0
others	0	0	0	0	1	0	1	0	0	0	1	0
Objects used at present / Task of Institution									2.5D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	4	3	2	3	2	1	5	3	1	4	1	0
vegetation	4	2	1	3	3	1	3	0	1	3	2	0
traffic network	1	1	0	2	1	1	1	0	1	1	1	0
public utilities	2	2	0	2	1	1	2	0	2	1	0	0
telecommunication	2	2	1	1	1	1	2	0	1	2	0	0
others	3	3	0	3	3	3	3	0	3	3	0	0
Objects not used at present / Task of Institution									2.5D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	1	1	1	1	1	0	2	0	0	0	0	0
vegetation	3	0	0	1	0	0	2	2	0	0	2	0
traffic network	2	3	1	2	2	1	3	1	1	0	0	0
public utilities	2	1	0	2	1	1	3	2	0	0	0	0
telecommunication	3	2	0	2	1	1	3	1	1	0	0	0
others	0	0	0	0	0	0	0	0	0	0	0	0

**Table 7: 2.5D-Objects of interest** with respect to the *Task of Institution* in present or future (number of answers from 41 producers and 21 users):

1. already *in production* (cf. Quest. Q1.2, Q2.1, 1. Table)
2. with *request* for production (future) (cf. Q1.2, Q2.1, 2. Table)
3. already *in use* (cf. Q1.2, Q3.1, 1. Table)
4. *would like* to use (future) (cf. Q1.2, Q3.1, 2. Table)

Objects acquired at present / Type of Institution				
	2D			
	firms	gov.	uni.	n.A
buildings	6	8	4	0
vegetation	6	6	3	1
traffic network	6	9	4	1
public utilities	6	4	1	1
telecommunication	2	2	0	0
others	1	5	0	0
Objects not acquired at present / Type of Institution				
	2D			
	firms	gov.	uni.	n.A
buildings	1	0	0	0
vegetation	1	2	0	0
traffic network	1	1	0	0
public utilities	0	3	0	0
telecommunication	2	2	0	0
others	0	0	0	0
Objects used at present / Type of Institution				
	2D			
	firms	gov.	uni.	n.A
buildings	1	4	4	0
vegetation	4	2	4	0
traffic network	5	4	3	0
public utilities	3	1	2	0
telecommunication	2	0	1	0
others	0	1	4	0
Objects not used at present / Type of Institution				
	2D			
	firms	gov.	uni.	n.A
buildings	0	0	0	0
vegetation	0	1	0	0
traffic network	0	0	0	0
public utilities	0	2	1	0
telecommunication	0	3	0	0
others	0	0	0	0

**Table 8: 2D-Objects** of interest with respect to the *Type of Institution* in present or future (number of answers from 41 producers and 21 users):

1. already *in production* (cf. Quest. Q1.1, Q2.1, 1. Table)
2. with *request* for production (future) (cf. Q1.1, Q2.1, 2. Table)
3. already *in use* (cf. Q1.1, Q3.1, 1. Table)
4. *would like* to use (future) (cf. Q1.1, Q3.1, 2. Table)

Objects acquired at present / Task of Institution									2D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	15	14	10	4	5	4	4	4	4	1	5	0
vegetation	15	13	11	5	2	2	4	2	4	1	5	1
traffic network	18	15	11	6	5	5	8	4	5	2	4	1
public utilities	11	10	7	5	3	2	5	3	3	1	3	1
telecommunication	4	4	2	2	1	1	2	3	1	0	0	0
others	6	5	2	2	1	2	5	4	4	1	1	0

Objects not acquired at present / Task of Institution									2D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	1	1	1	1	0	0	0	1	0	0	0	0
vegetation	2	3	2	2	1	1	1	2	1	0	0	0
traffic network	2	2	2	1	0	0	1	1	0	1	0	0
public utilities	2	3	2	1	1	2	1	1	1	0	0	0
telecommunication	3	4	3	3	1	2	1	2	1	0	1	0
others	0	0	0	0	0	0	0	0	0	0	0	0

Objects used at present / Task of Institution									2D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	5	3	0	7	4	2	6	4	3	2	2	0
vegetation	4	3	0	7	4	2	6	5	2	2	3	0
traffic network	6	4	1	9	6	3	7	6	2	3	1	0
public utilities	3	3	0	6	4	2	5	3	2	1	0	0
telecommunication	3	2	0	2	2	2	2	1	1	2	0	0
others	4	3	0	4	3	3	4	2	3	3	1	0

Objects not used at present / Task of Institution									2D			
	Mp	Sv	Ph	PI	SW	CS	EA	Ar	PU	Tc	O	nA
buildings	0	0	0	0	0	0	0	0	0	0	0	0
vegetation	0	1	0	1	1	1	1	1	1	0	0	0
traffic network	0	0	0	0	0	0	0	0	0	0	0	0
public utilities	2	1	0	3	2	1	2	2	1	0	0	0
telecommunication	1	1	0	3	1	1	1	3	1	0	0	0
others	0	0	0	0	0	0	0	0	0	0	0	0

**Table 9: 2D-Objects** of interest with respect to the *Task of Institution* in present or future (number of answers from 41 producers and 21 users):

1. *already in production* (cf. Quest. Q1.2, Q2.1, 1. Table)
2. *with request for production (future)* (cf. Q1.2, Q2.1, 2. Table)
3. *already in use* (cf. Q1.2, Q3.1, 1. Table)
4. *would like to use (future)* (cf. Q1.2, Q3.1, 2. Table)

## Workshop 3D-City Models

Bonn, 9–11 October 1996

### Program

## **Wednesday, 9. October 1996**

### *10.00 Opening*

#### **OEEPE-Study on 3D-City Models**

C. Fuchs, Universität Bonn

### *11.00 Laserscanner*

#### **Applications of the ALTM for 3D-Data Acquisition**

P. Frieß, TOPSCAN

#### **Imaging Distance Measurements by Pulsed Laser**

U. Lohr, TOPOSys

#### **Combined Use of Laser Scanner 3D-Geometry and Reflectance Data to Identify Surface Objects**

C. Hug, Universität Stuttgart

### *14.00 Software Demo*

### *16.30 Data Acquisition for Telecommunication*

#### **Requirements of 3D-City Structure Data from the View Point of a Radio Network Service**

E. Siebe, MANNESMANN MOBILFUNK

#### **Urban Building Models for Telecommunication,**

E. Ehrhardt, PHOENICS

#### **3D-Models for Telecommunication – Methods and Experiences**

A. Loffet, EUROSENSE/EUROSENSE BELFOTOP

## **Thursday, 10. October 1996**

### *8.30 3D-Data for Urban Planning*

#### **3D-City and Environment CAD Modeling with Engineering Applications**

J. Sarkkila, TERRA SOLID, Helsinki

#### **GIS-Datasets for Urban Planning in Vienna**

E. Kranjec, GRINTEC, Graz

#### **Semiautomated Production Line for the Transformation of a 2½D Model into a 3D City Model**

A. Halmer, Magistrat der Stadt Wien

### *10.30 3D-Building Models*

#### **Photogrammetric 3D-Data for Immission Measurements**

L. Arentz, City of Köln

**Incorporation of Buildings into the ATKIS DLM 25/2**

W. Müller, Landesvermessungsamt Brandenburg

**A 3D-Model of Ravensburg using Photogrammetric Techniques**

A. Dietrich, Ingenieurbüro Dietrich

*13.30 Software Demo*

*16.00 Visualization*

**The Impact of Texture on 3D-City Models**

M. Gruber, TU Graz

**Geographic Reality for Mastering Information Complexity**

M.-P. Hébert, Matra CAP Systèmes

**Photogrammetric Methods for Generating High Resolution Data Bases for Simulation and Virtual Reality**

J.-P. Dichter, EVANS & SUTHERLAND

*18.00 Boat Trip on the Rhine*

**Friday, 11. October 1996**

*8.30 Digital Photogrammetry*

**Semiautomatic Building Extraction**

E. Gülch, Universität Bonn

**3D-Reconstruction of Buildings and Visualization of City Models**

O. Henricsson, ETH Zürich

**Urban Scene Interpretation using Aerial Images and Maps**

M. Roux, ENST, Paris

*10.30 Architectural Applications*

**REMUS: Simulation of Architectural and Urban Morphology**

J. Zoller, GAMS AU

**Complex 3D Animations of Architecture and Landscapes**

P. Uhlich, DIGITAL AFFAIRS COMPUTERGRAPHIX

**Virtual Reality and Architectural Planning**

C. Boytscheff, Universität Stuttgart

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# Performance of tie point extraction in automatic aerial triangulation

with 22 Figures, 9 Tables and 3 Appendices

*Report by Christian Heipke and Konrad Eder*

Lehrstuhl für Photogrammetrie und Fernerkundung  
Technische Universität München



# Performance of tie point extraction in automatic aerial triangulation

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Technische Universität München, D-80290 München

## Abstract

The European Organisation for Experimental Photogrammetric Research (OEEPE) and the International Society for Photogrammetry and Remote Sensing (ISPRS) have carried out a test on the performance of tie point extraction in automatic aerial triangulation (AAT). The aims of the test were to investigate the geometrical block stability, the accuracy of the tie points and the derived orientation parameters, and the limitations of existing commercial and experimental software systems. In order to separate the essentially new aspect of digital processing, namely automation, from conventional issues of aerial triangulation, control information was not assessed, and the test blocks to be processed had an arbitrary block datum.

The Chair for Photogrammetry and Remote Sensing, Technische Universität München acted as pilot centre for the test. In early 1997 various small blocks of different scene content were distributed to interested participants. Their task was to generate tie points in an automatic way. The results of 21 participants, including all major software vendors of AAT and users of their systems, have been analysed and are presented in this report. Given a large number of tie points per image has been extracted, the blocks were found to be mostly stable. Under good conditions (open, flat terrain) an accuracy for the tie points of up to 2.2 mm corresponding to 0.11 pixel could be reached, while under less favourable conditions, the result was 4–9 mm or 0.2–0.3 pixel. These figures were found to be very similar for the different systems. In mountainous and forested areas, some systems failed to produce acceptable results. Reliable self control is a feature missing in all systems to date. Also, it seems that considerable experience is required to properly run the systems.

## 1 Introduction

Automatic aerial triangulation (AAT) has been an increasingly interesting topic of research and development in digital photogrammetry over the last couple of years (see Schenk 1997 for an excellent review of the subject). The two tasks of measuring the image coordinates of tie points and of computing the orientation parameters, which were well separated in analytical photogrammetry, are more and more being merged into a single process, carried out in a hierarchical fashion using image pyramids. In future there will most probably be an option to also include the generation of digital terrain models (DTM) into this process. At the same time a shift of focus concerning the

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results of aerial triangulation can be observed. While in earlier times point densification was the primary goal, currently the orientation parameters themselves are of growing importance. There are two reasons for this shift of focus: First, the automatically determined tie points are not really useful for point densification, since in general they do not fulfil the requirements set out in the point selection phase of analytical aerial triangulation. Second, the orientation parameters themselves are increasingly used directly for subsequent tasks such as orthoprojection or vector data capture.

Today, a number of AAT software systems with different degree of automation are commercially available, either as stand-alone packages or as part of a Digital Photogrammetric Workstation, and are being introduced into practice (*de Venecia et al. 1996; Ackermann, Krzystek 1997; Tang et al. 1997*). Recently, users have started to report on their experience with these systems (e.g. *Kersten, O'Sullivan 1996; Hartfield 1997; Kersten, Häring 1997; Kersten et al. 1998; Köhler 1998*). However, at present a comprehensive comparison between the systems and also with analytical aerial triangulation, does not exist. At the same time a number of questions remain open, from the theoretical side (multi image matching vs. matching only two images at a time, area based vs. feature based matching, the influence of local image texture etc.) as well as from the practical side (what is the proper pixel size to use, how many tie points should be available per image, which degree of automation can be reached and what does it depend on, what is the effect of image compression, how to implement an efficient procedure for quality control etc.).

In this situation the European Organisation for Experimental Photogrammetric Research (OEEPE) and the International Society for Photogrammetry and Remote Sensing (ISPRS) launched a common test on the performance of tie point extraction in automatic aerial triangulation (*Heipke, Eder 1996*). "Tie point extraction" is meant to include the selection, transfer and image coordinate measurement of block tie points. The test is primarily aimed at the commercial software development and the user community of AAT systems. The results are intended to serve as a guide for assessing the capabilities of available systems and to give some hints towards improving them.

It may be asked, why a test about the indirect determination of the image orientation parameters by means of aerial triangulation should be conducted in a time when these parameters are more and more being measured directly using GPS and INS (e.g. *Skaloud et al. 1996; Skaloud, Schwarz 1998*). Ultimately, such indirect methods might become obsolete, but it seems safe to predict that they will remain to be used for some time to come (see also the results of the OEEPE test on GPS, *Ackermann 1996*).

This report contains the final results of the test. Preliminary results were published in *Heipke et al. (1998)*. The next chapter briefly outlines the test goals, the used data sets and the test organisation. Chapter 3 contains a list of the test participants and shortly discusses some features of the used software systems. The analysis procedure is described in chapter 4. The test results along with discussions are presented in chapter 5. The report closes with a number of conclusions and open issues.

## 2 The OEEPE-ISPRS Test

### 2.1 Test goals

In preliminary discussions with a number of potential test participants, a significant interest was expressed in assessing and comparing available AAT algorithms and strategies in terms of the achievable accuracy of the conjugate tie points as well as for the orientation parameters, and in terms of the software limitations. An operational AAT test including a large number of images and questions related to ground control, while being a vital issue in everyday practice, was generally considered to be less important. Also problems related to the development status of individual AAT programs (user interface, program stability, computing time etc.) did not catch much attention.

Throughout the test, tie point extraction was considered to be a totally **autonomous** process, to be carried out without any user interaction. In particular, any interaction during the tie point generation process, as well as manual editing or completion of the automatically obtained results in order to improve the measurement precision, to eliminate blunders and/or to introduce new measurements in areas where the automatic process failed to determine tie points, was not allowed within the test. Only automatic blunder detection and elimination within a robust adjustment was permitted. In this way the essentially new aspect of digital imagery, namely automation, could be investigated separately from the issues which basically remain constant in the transition from analytical to digital photogrammetry (control information, block configuration, accuracy propagation, etc.). The aims of the test were to investigate

- the geometrical stability of the resulting block,
- the accuracy of the image coordinates of the tie points, and
- the limitations of existing commercial and experimental software systems.

### 2.2 Test data sets

Guidelines for the selection of the test data were

- the need for a representative test data set covering different standard applications in photogrammetry,
- small blocks/strips resulting in manageable data volumes,
- a fair chance for success for existing AAT systems,
- use of photogrammetric images and scanners only.

The first point inspired the use of different scene contents, topography, cameras, scales, film material, and overlap configurations. As far as image scales are concerned, preference was given to larger scales, because in these cases, potential matching problems due to occlusions and relief displacement are more pronounced. The second point led to the selection of blocks with 3x2 and 3x3 images, strips with 3 images and pixel sizes of 20-30  $\mu\text{m}$  (although for some data sets higher resolution images were available). While operational problems cannot be detected with such small blocks, the geometrical block stability and the accuracy of the tie points can be assessed. Taking

Project name	Echallens	Montserrat	OSU	Kapellen	München
Scene content	open, partly forest	forest, partly built-up	built-up, partly trees	settlement, partly open	city centre
Scene topography	flat	hilly	flat, buildings	flat	buildings
Image scale	1:5.000	1:15.000	1:4.000	1:4.000	1:2.000
Camera	Wild RC 10	Zeiss RMK TOP	Wild RC 10	Zeiss RMK A	Zeiss RMK A
Focal length [mm]	150	150	150	150	300
Flight datum	September 1982	May 1995	September 1995	April 1992	May 1975
Film material	black and white	black and white	FIR	black and white	colour
Number of images	3 x 3	3 x 3	3 x 3	2 x 3	3
Overlap	l = 60 %, q = 30 %	l = 60 %, q = 30 %	l = 60 %, q = 60 %	l = 60 %, q = 60 %	l = 60 %
Scanner used	LH DSW 200	Zeiss PSI	LH DSW 200	Wehrli RM1	Zeiss PSI
Pixel size for test	20 mm	30 mm	25 mm	24 mm	30 mm
Scanned material	negative, original	negative, original	positive, original	negative, original	positive, original
Scanned channel	pan	pan	red (= infrared)	pan	red
Scan datum	January 1996	November 1996	October 1995	June 1996	December 1996
Source	EPFL, Lausanne	ICC, Barcelona	The Ohio State University / TU München	Hannover University	Technische Universität (TU) München

Table 1: Description of the test data sets

the third point into account imagery with different scale within the block, with large rotations and non-topographic imagery was excluded. As for the last point, only first generation film products were scanned and all employed scanners are especially designed for photogrammetric applications.

According to these guidelines four blocks and two strips were selected as test data sets. Upon receipt of the results from the participants it became clear that one example was only processed by very few participants. Therefore, the results obtained were not considered to be representative for the test, and that data set was consequently excluded from further analysis. Table 1 shows some general information about the remaining five data sets. The individual images are depicted in figures 1 to 5. In the following the different test data sets are described in more detail.

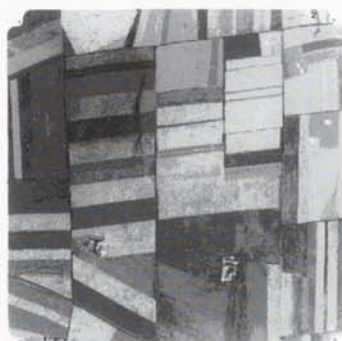
- **Echallens, Figure 1:** This scene near Lausanne, Switzerland, is rather flat and shows mainly open terrain. The black and white images are rich in texture, the overlap configuration corresponds to the standard values of aerial photogrammetry. As the imagery was used in earlier tests on aerial triangulation (Kölbl 1983), a number of signalised points are visible. For these points accurate object space coordinates were available. The negatives were scanned directly. Computations with this block can be considered as a sort of base line test for an AAT system.
- **Montserrat, Figure 2:** The scene is partly covered with forest, is rather mountainous in the northern (upper) part and includes the city of Montserrat in Catalunya, Spain, in the southern (lower) part of the block. The block is the only one of medium image scale. The black and white imagery was selected from a standard flight of the Institut Cartografic de Catalunya (ICC), Barcelona. The negatives were scanned and were converted to positives during scanning.

Echallens 1 : 5.000 l = 60 % q = 30 %

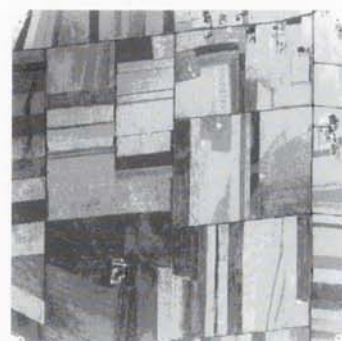
Strip 1 Flight direction → Image coordinate system  $\begin{matrix} y \\ x \end{matrix}$



Image No. 806



807

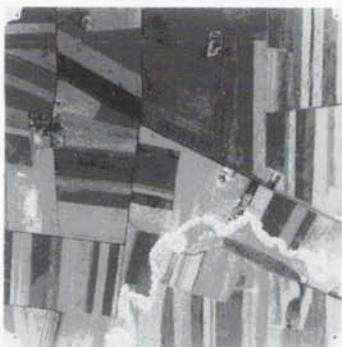


808

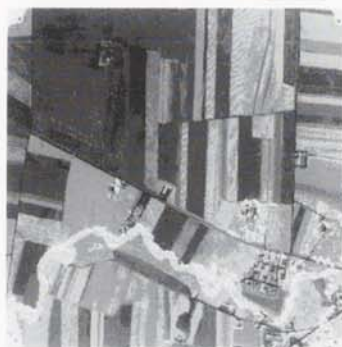
Strip 2 Flight direction → Image coordinate system  $\begin{matrix} y \\ x \end{matrix}$



Image No. 824



825



826

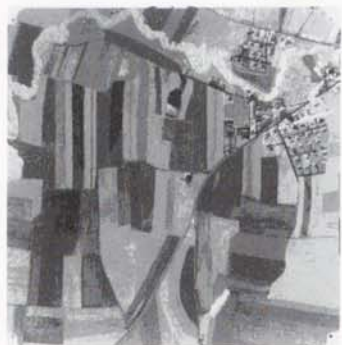
Strip 3 Flight direction → Image coordinate system  $\begin{matrix} y \\ x \end{matrix}$



Image No. 842



843



844

Figure 1: Imagery for test data set Echallens

Montserrat 1 : 15.000  $l = 60 \%$   $q = 30 \%$

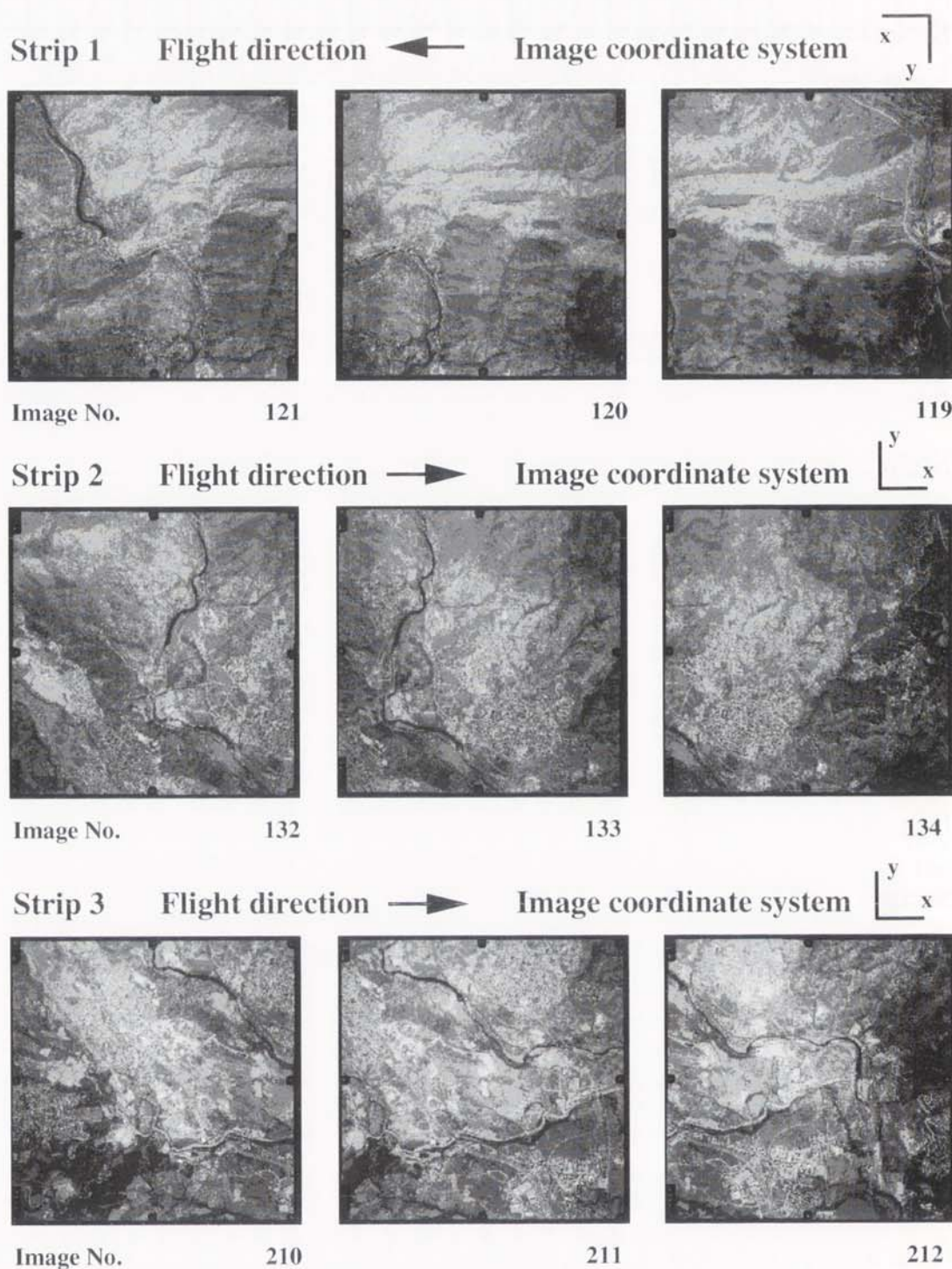


Figure 2: Imagery for test data set Montserrat

OSU

1 : 4.000

l = 60 %

q = 60 %

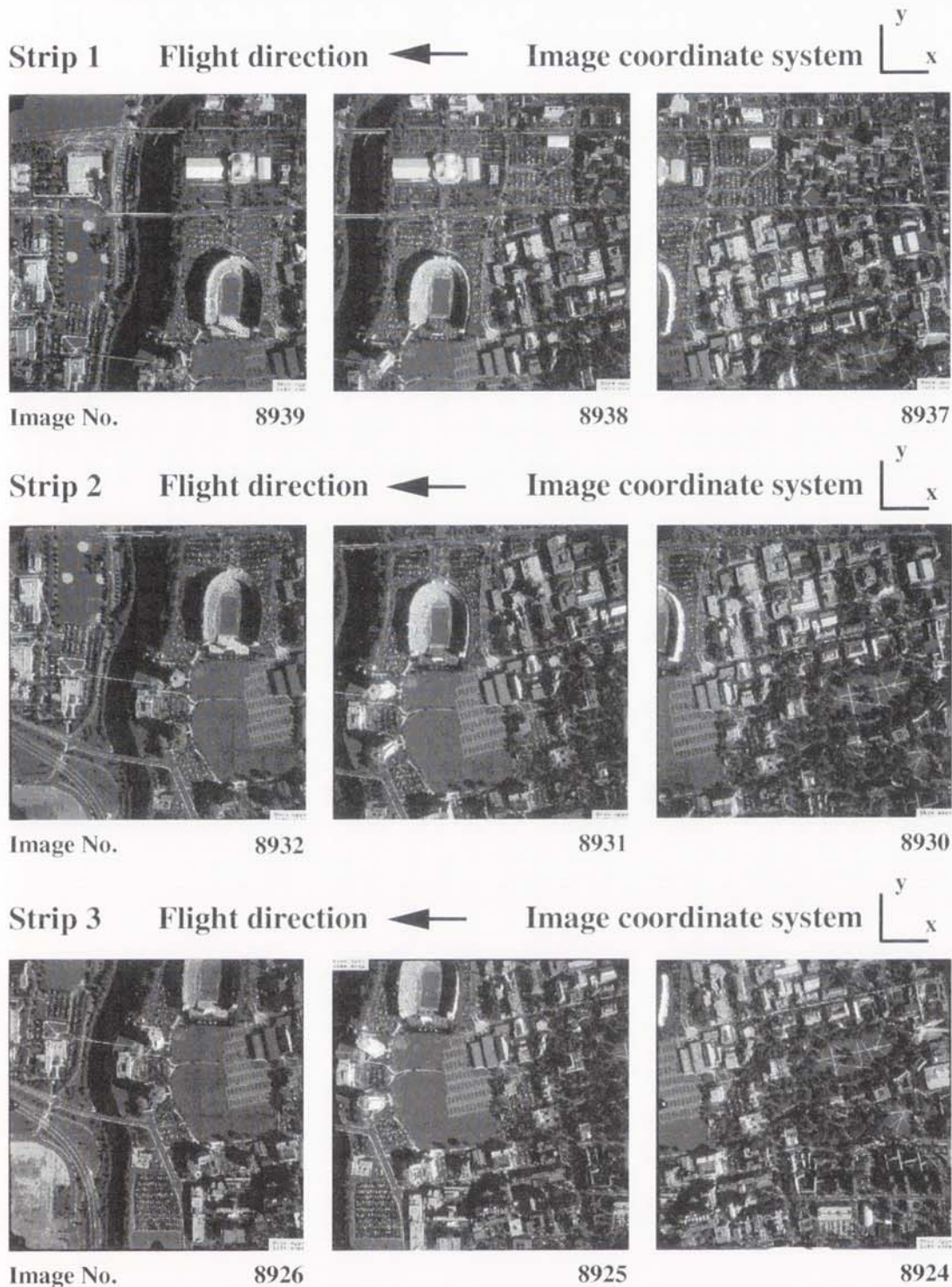


Figure 3: Imagery for test data set OSU

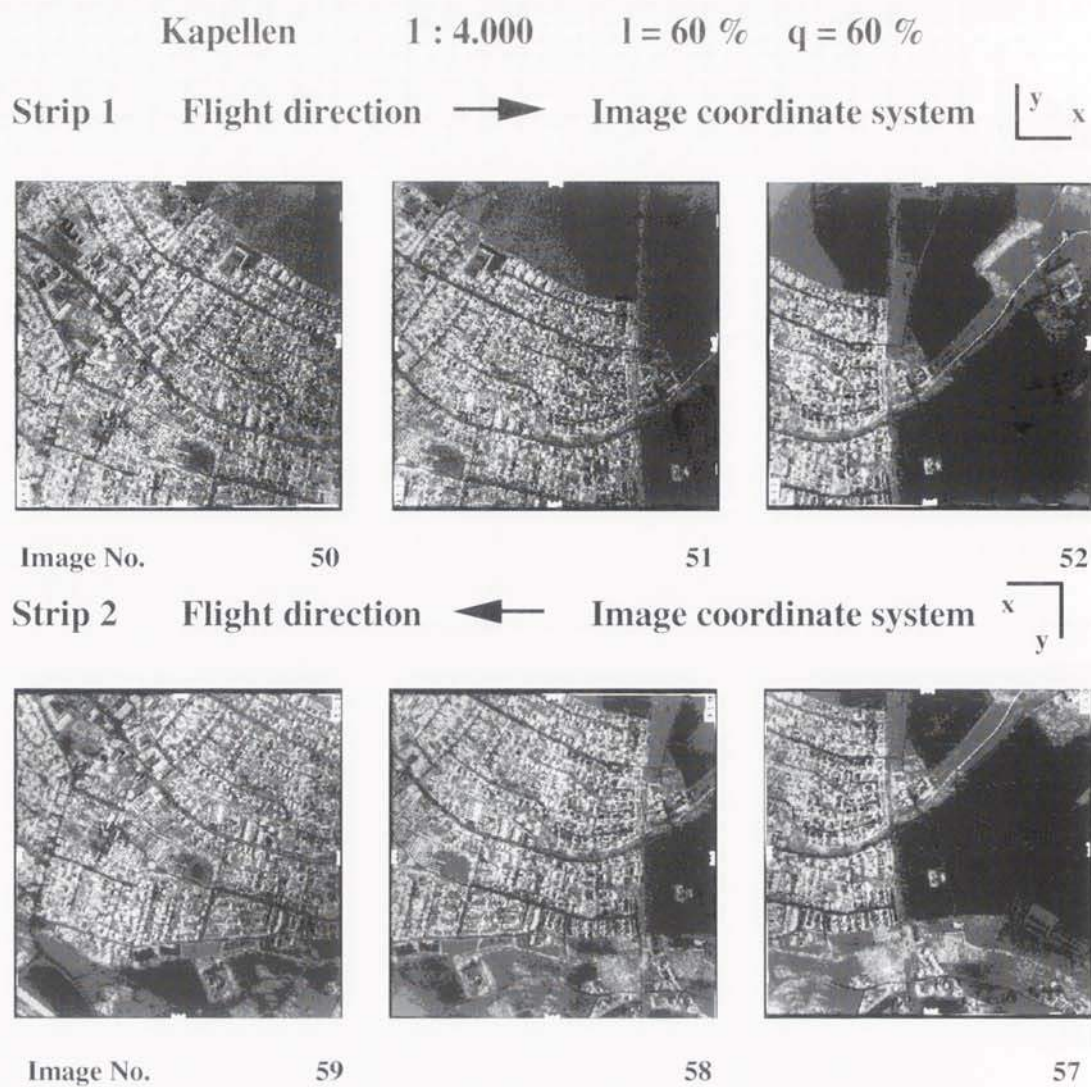


Figure 4: Imagery for test data set Kapellen

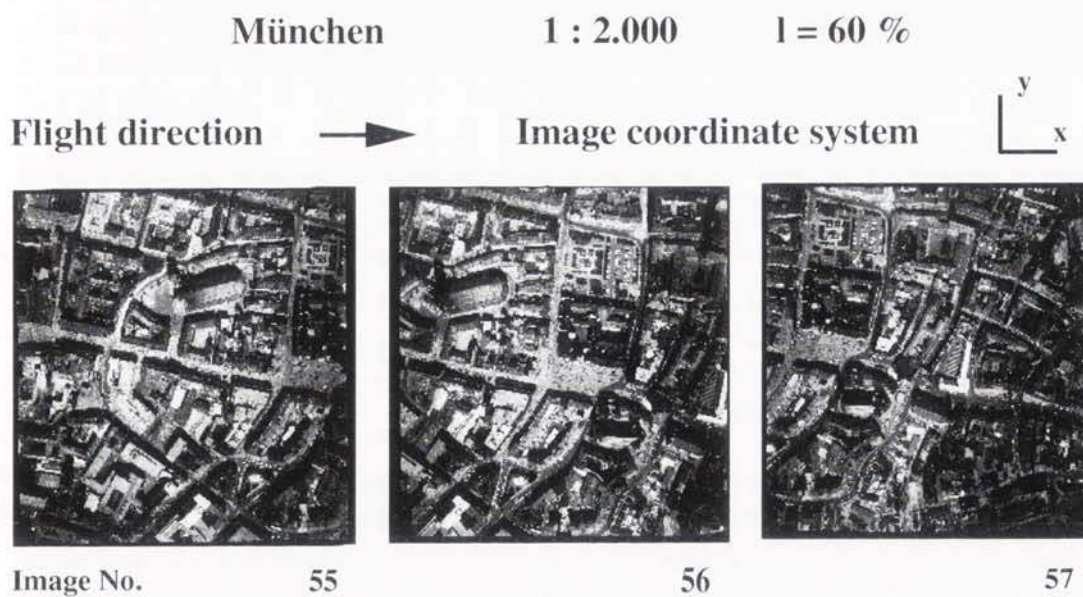


Figure 5: Imagery for test data set München

- **OSU, Figure 3:** This scene shows part of the campus of The Ohio State University, Columbus, USA. It is predominantly flat, the depicted buildings are rather large, and mostly separated by a fair distance. In the central part of the block where all 9 images overlap, a number of tennis courts can be seen. This is significant, since these courts can cause problems to matching algorithms because of the highly repetitive texture. The photo flight was carried out in early September, while the tree still had leaves. The film material is false colour infrared, and thus the image quality is not as high as for a panchromatic film. The red channel, corresponding to the infrared scene reflection was selected for the test.
- **Kapellen, Figure 4:** The imagery was taken near a coal mining area in Germany which is rather flat. Most of the scene contains residential houses with some open spaces. Again, the black and white negatives have been scanned directly. In most parts there is rich texture, however, on the right part of the two strips, rather dark and homogeneous areas exist, and the overall image quality is not very good.
- **München, Figure 5:** This strip of large scale colour images depicts the city centre of Munich, Germany, a densely built-up area. The large building visible in the images 55, and 56 is the famous Frauenkirche. The red channel was selected for the test. The images were taken more than 20 years ago, however, scanning was carried out recently. For these images no image coordinates of the fiducial marks were available in the camera calibration protocol.

### 2.3 Test organisation

The test was set up as a multi site comparative test. The Lehrstuhl für Photogrammetrie und Fernerkundung, Technische Universität München, acted as pilot centre which selected, prepared and distributed the test data, and subsequently collected and analysed the results.

The test participants received a detailed description of the test (Heipke, Eder 1996), the digital imagery together with information on the camera calibration, initial values for the exterior orientation parameters accurate to about 50 m for the projection centre and 2 degrees for the three attitude angles, and an average terrain height for each project. The exact information which was distributed per data set is presented in tables A1.1 to A1.5 in the appendix. Pixel coordinates for the fiducial marks were not provided, because these measurements cannot be introduced into most available AAT systems, but rather have to be taken once the images are loaded. It should be noted that due to this fact slightly different values for the transformation of tie point coordinates from pixel to image coordinate system occur in the test. In preliminary investigations effects resulting from these differences were found to be in the order of 1–2  $\mu\text{m}$ . Ground control points (GCP) were not generally distributed, but 7 GCP coordinates per project were available upon special request, because some AAT program systems need GCP as input. Due to the minimum number of 7 distributed GCP coordinates it could be ensured that the GCP would only define the block datum, but have no influence on the tie point extraction itself.

The test participants were then asked to automatically extract as many tie points from the images as they thought appropriate using their experimental or commercial software. If possible a common set of free parameters for the individual programs was

full name and abbreviation of participant		software and version no.	Echallens	Kapellen	Monterrat	München	OSU
LH Systems, San Diego	LHS	HATS, 3.2.1.1	X	X	X	X	
Bundesamt für Kartographie und Geodäsie, Frankfurt/M.	BKG	HATS, 3.1.1.2	X	X	X	X	
Institute for Photogrammetry, EPFL Lausanne	EPFL	HATS, 3.1.3k	X		X		X
National Land Survey of Finland, Helsinki	NLS-SF	HATS, 3.2.1.2			X		
National Land Survey of Sweden, Gävle	NLS-SWE	HATS, 4.0.8	X	X	X		X
School of Geomatics, UNSW, Sydney	UNSW	HATS, 3.2.1	X		X	X	X
Swissphoto, Regensdorf	SWPH	HATS, 3.2.1.2 *	X	X	X	X	X
Inpho GmbH, Stuttgart	Inpho	Match AT, 2.1.0	X	X	X	X	X
Intergraph, Huntsville	I-graph	Match AT, 2.1.1	X	X	X	X	X
Compagnia Generale Ripreseaeree, Parma	CGR	Match AT, 2.1.1			X	X	X
Hansa Luftbild, Münster	HL	Match AT, 2.1.1			X		
Photogrammetrie GmbH, München	Ph GmbH	Match AT, 2.1.1			X	X	
Carl Zeiss, Oberkochen	CZ	Phodis AT, 2.0.1	X	X	X	X	X
Bayerisches Landesvermessungsamt, München	B-LVA	Phodis AT, 2.0.0	X	X	X	X	X
General Command of Mapping, Ankara	GCM	Phodis AT, 2.0.0		X	X	X	X
Landesvermessung + Geobasisdaten, Hannover	LGN	Phodis AT, 2.0.0	X		X		
Finnish Geodetic Institute, Masala	FGI	research system	X		X		
Institute of Photogrammetry and Eng. Surveys, Hannover	IPI	research system		X		X	X
Chair for Photogram. & Rem. Sensing, TU München	TUM	research system	X	X	X	X	X
Dip. Ing. e Idraul. Amb. e del Rilev., Politec. di Milano	DIAR	research system	X		X	X	X
Chair of Ph & RS, Olsztyn Univ. of Agricul. a. Techn.	OUAT	research system			X		

Table 2: List of test participants (\* SWPH combined HATS with customised software)

to be used. The resulting image coordinates of the conjugate points were subsequently to be communicated back to the pilot centre together with a report detailing the hard- and software and the algorithm used, the workflow adopted, necessary human interaction before and after the actual matching process, computational times, and a general assessment of the obtained results and problems encountered. Figure 6 shows the test scheme as far as the participants' activities are concerned.

### 3 Test Participants and Software Systems

After announcing the test 39 interested groups requested the test data. 21 of them (more than 50 %) actually participated in the test, processed at least some of the test images, and sent back the results. Among those 21 groups four major commercial photogrammetric software providers of AAT (Carl Zeiss, Inpho, Intergraph, LH Systems) were present, together with five national or regional mapping organisations, four private companies and three research institutes employing commercial products. In addition five research institutes who had developed their own AAT software took part in the test.

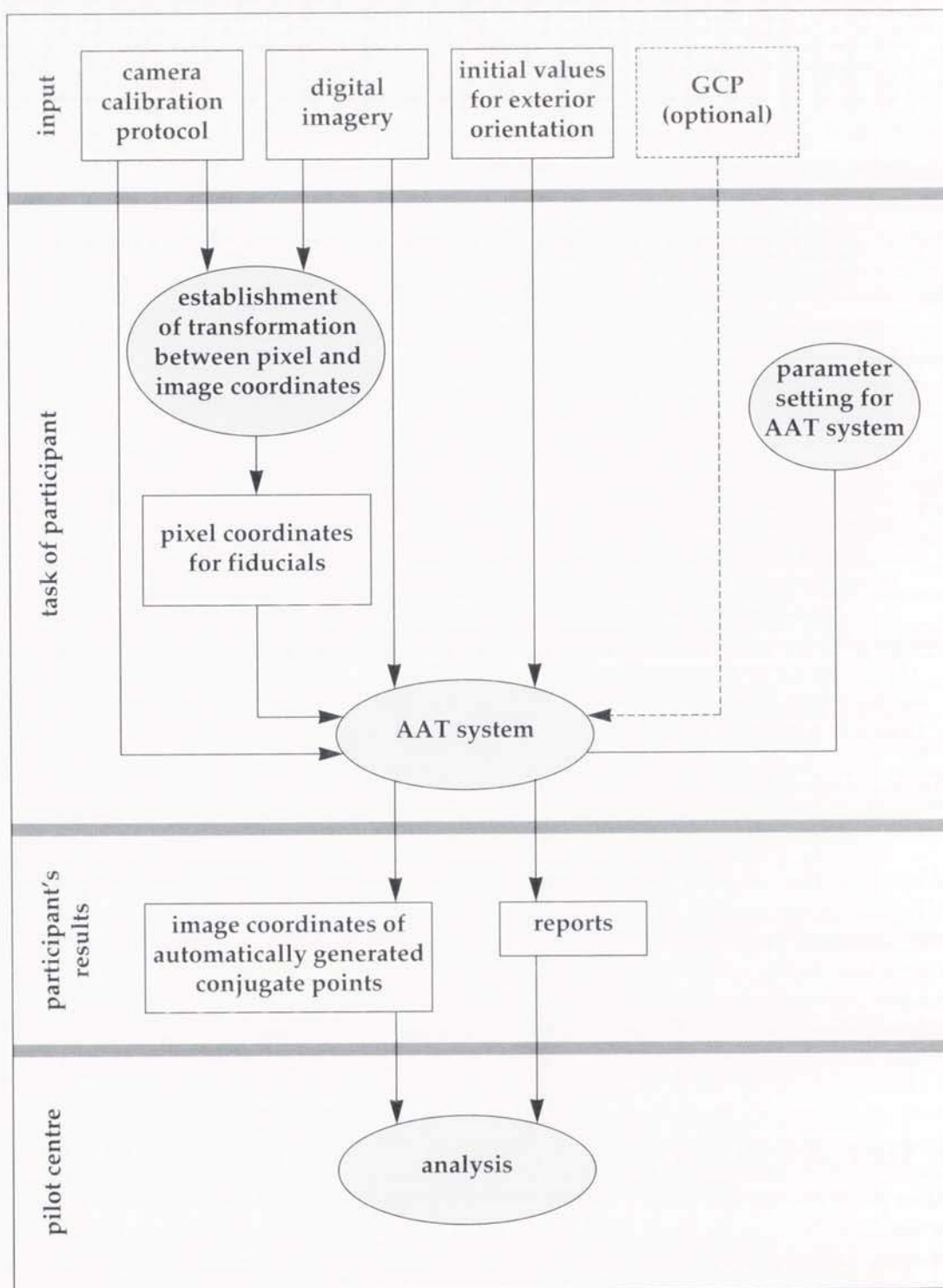


Figure 6: Test data flow, participant's tasks

	matching entities	matching method for accuracy refinement	no. of images during matching refinement	image pyramids	DTM as input (optional)	use of von Gruber positions	automatic blunder elimination	integration of block adjustment programme	need for ground control points	autonomous system design	parameter file
HATS	points	subpixel cross correlation	2	X	-	X	-	(X)	-	(X)	X
HATS*	points	subpixel cross correlation	2	X	-	X	X	(X)	-	X	X
Match AT	points	least squares matching	all overlapping	X	X	(X)	X	X	X	X	X
Phodis AT	points	least squares matching	2	X	-	-	-	-	-	X	-
FGI	points	least squares matching	2	X	-	X	(X)	(X)	X	X	X
IPI	points, structures	least squares matching	2	X	-	-	-	-	-	X	X
TUM	points	-	2	X	-	-	X	X	-	X	X
DIAR	points	least squares matching	2	X	-	-	-	-	-	X	X
OUAT	points	cross correlation	2	X	-	-	X	-	-	X	X

Table 3: Comparison of the different systems used in the test  
(HATS\* is a customisation of HATS developed and used exclusively by SWPH)

Table 2 gives an overview of the participants, the employed software, and the processed test data sets. Four groups can be distinguished, namely users of the commercial systems HATS from LH Systems (*de Venecia et al. 1996*; 7 users), Match AT from Inpho (*Ackermann, Krzystek 1997*; 5 users), and Phodis AT from Carl Zeiss (*Tang et al. 1997*; 4 users), and the five participants having developed their own software (FGI – *Honkavaara, Hoghoen 1996*; IPI – *Wang 1996*; TUM – *Brand, Heipke 1998*; DIAR – *Forlani et al. 1998*; OUAT – *Paszotta 1998*). Table 2 is organised accordingly. Altogether more than 80 sets of image coordinates were processed in the test. Some of the received results contained obvious gross errors. After consultation with the participants these results were deleted. They are not shown in table 2.

Neither the commercial products nor the developments of the research institutes will be presented in detail in this report. However, some aspects shall be mentioned and have been collected in table 3. Further information is available in the given references. The participant SWPH has customized HATS for his own purposes. The resulting system while still being a HATS system has some unique features and was therefore entered in a separate row in table 3 called HATS\*.

The first column of table 3 contains the names of the software systems. The next three columns deal with the **matching methods** employed. As can be seen all but the IPI

development use a feature based matching scheme with points as matching entities. In most cases points are selected using the Förstner-Operator (Förstner 1991). IPI's solution also uses relational descriptions of structures extracted from the imagery. Matching refinement in order to increase the geometric accuracy is mostly based on least squares matching which is known to be the most accurate method. However, HATS and HATS\* use subpixel cross correlation, OUAT uses simple cross correlation, and in the version for the test no refinement procedure is integrated into the TUM development. During matching refinement only Inpho uses all available overlapping images simultaneously. All other systems rely on matching image pairs and generating multi ray tuples in a separate step. It should be noted that the exact matching algorithms are not always published in the literature.

In order to solve the problem of obtaining **initial values** for the unknown orientation parameters all approaches are implemented in a hierarchical fashion based on image pyramids. As an option Match AT can also use an existing DTM as input which is claimed to be helpful especially in mountainous terrain. HATS, HATS\* and FGI search for conjugate points only in predefined areas. Often areas around the "von Gruber positions" are used. Match AT also starts in these areas, but they are automatically shifted away from the initial position if no adequate matching results are obtained. Therefore, the X in the appropriate position in table 3 appears in brackets. On the other hand Phodis AT, and the TUM, IPI and DIAR approaches try to match points in the whole images, at least in the upper pyramid levels. Some participants (e.g. DIAR) have found that their system is very sensitive to the quality of the initial values of exterior orientation and have therefore changed the provided values manually prior to running their AAT software.

In some systems a sophisticated automatic **blunder elimination** scheme is integrated. For instance, in the TUM development every step of the algorithm is immediately followed by a verification step. Such a design allows for the early detection and elimination of blunders. While HATS comes with interactive blunder elimination, HATS\* is tuned to automatic elimination of gross errors.

For the FGI system blunder detection is performed during a robust bundle adjustment loosely coupled with the matching software (thus the brackets in table 3). Match AT and TUM compute **integrated robust bundle adjustments** at each level of the pyramid in order to improve the initial values for the unknowns from one pyramid level to the next and to eliminate additional blunders. For this step Match AT and FGI need a minimum number of 3 ground control points. HATS and HATS\* include a bundle adjustment with a somewhat reduced functionality.

Also the **degree of automation** is different for the different systems. Some systems are designed as autonomous systems without any operator control (such as Match AT and Phodis AT), other approaches (such as HATS) are more flexible and usually call upon the operator in order to manually measure additional points or eliminate blunders. It should be noted that this possibility was not to be used by the test participants (see section 2.1). As evidenced by SWPH HATS can also be tuned into a fully autonomous system.

Finally, most systems have a list of free parameters, sometimes collected in a **parameter file**, which can be used to tune the results. The effect of these parameters, however, is

not always clearly documented. While most participants used a standard parameter set for all test images, some did optimise the values in order to achieve better results.

Given these numerous differences in the approaches it is impossible within this test to link a certain result to a particular design feature. What makes the situation more complicated is the fact that different participants used different versions of the same software (see table 2). Nevertheless, as will be seen the obtained results show some distinct trends.

## 4 Analysis Procedure

As mentioned above, point densification was the major application of aerial triangulation in the early days. Usually, nine tie points were measured per image. In order to check the results, one (very tedious) way consisted in revisiting and checking each observation. AAT systems, on the other hand, often deliver a few hundred, and sometimes more than 1000 tie points per image. Therefore, revisiting and checking each observation was considered impossible within the test. Therefore, alternative ways of evaluating the results based on the orientation parameters themselves had to be developed.

### 4.1 Interactive reference measurements

First of all, classical aerial triangulations were performed at the pilot centre in order to create a base for checking the results of the participants. For each data set image coordinates of a large number of check points were measured interactively in the images, and a bundle adjustment using the programme package CLIC which was developed at the pilot centre over the last 15 years was computed. Subsequently an S-transformation (Baarda 1973) was carried out in order to determine the internal accuracy of the computed object space coordinates of the check points. This internal accuracy is not influenced by control information. In four of the five projects the measurements were carried out using the digital images, in two cases (Montserrat and München) with images of better resolution (half the pixel size as compared to the one distributed in the test) were used. Analogue images were used for the reference measurements of the OSU data set, because in this way the check points could be better identified. For Echallens all the signalised points (see section 2.2) were used as ground control points. Because of the high number of available ground control points additional self calibration parameters according to Ebner (Ebner 1976) could be determined with high statistical significance. For the other test sites the datum was fixed using 7 orientation parameters as constant values. Self calibration did not yield significant additional parameters, because the control information was too weak. In order to ensure that no errors are present in the reference data all interactive measurements were carried out twice. The results are summarised in table 4.

Among other values, table 4 contains the quality of the interior orientation of the digital images in terms of the standard deviation  $\sigma_{o,int}$  of one fiducial measurement after an affine transformation between pixel and image coordinates. This value is interesting,

Project name	Echallens	Montserrat	OSU	Kapellen	München
image scale	1:5.000	1:15.000	1:4.000	1:4.000	1:2.000
av. flying height	850 m	2350 m	600 m	600 m	650 m
pixel size for ref. meas.	20 $\mu\text{m}$	15 $\mu\text{m}$	(analogue)	24 $\mu\text{m}$	15 $\mu\text{m}$
no. of fiducials	4	8	4	4	4
$\sigma_{o,int}$	4.8 $\mu\text{m}/0.24\text{pel}$	7.3 $\mu\text{m}/0.48\text{pel}$	(13.6 $\mu\text{m}/0.54\text{pel}$ )	8.5 $\mu\text{m}/0.35\text{pel}$	3.4 $\mu\text{m}/0.23\text{pel}$
av. no. of tiepts. p. image	41	65	27	55	58
bundle adjustment	$\sigma_{o,ref}$	3.2 $\mu\text{m}/0.16\text{pel}$	3.4 $\mu\text{m}/0.23\text{pel}$	6.1 $\mu\text{m}/0.25\text{pel}$	4.9 $\mu\text{m}/0.33\text{pel}$
	$\sigma_X$	2.4 cm	5.2 cm	2.7 cm	1.1 cm
	$\sigma_Y$	2.6 cm	5.4 cm	2.2 cm	2.2 cm
	$\sigma_Z$	4.9 cm	10.3 cm	4.3 cm	3.8 cm

Table 4: Results of interactive reference measurements

because it contains possible film deformations and deformations due to geometric scanner errors. The results for Echallens and München can be considered excellent, those for Kapellen and Montserrat still agree with the expectations. A value for  $\sigma_{o,int}$  was also determined for the digital OSU images and amounted to approximately 13.6  $\mu\text{m}$  or 0.54 pixel. This value is rather large and is an indication for problems with the geometry of the digital images. Since this effect was not observed in the film images of OSU it must be assumed that the used scanner was not sufficiently well calibrated (see also further discussion in chapter 5).

The accuracy of the reference measurements in image space is summarised in the standard deviation  $\sigma_{o,ref}$ . These figures fulfil the expectations. The best results were reached for Echallens (0.16 pixel or 3.2  $\mu\text{m}$ ). For Kapellen and Montserrat the results (0.25 and 0.23 pixels or 6.1 and 3.4  $\mu\text{m}$ , respectively) reflect the attainable accuracy for interactive measurements with digital images using natural tie points. The same holds for the OSU result obtained from the analogue FIR images. The value for München is somewhat larger (0.33 pixels or 4.9  $\mu\text{m}$ ), probably due to the limited accuracy of the fiducial mark coordinates.

The internal accuracy of the check points in object space is given by the theoretical standard deviations  $\sigma_X$ ,  $\sigma_Y$ , and  $\sigma_Z$  after the S-transformation. The S-transformation was carried out, because the theoretical standard deviations before the S-transformation are influenced by the control information as mentioned above. Just as for the results of the participants this influence needs to be eliminated in order to be able to investigate the quality of the automatic tie point extraction. The obtained values agree with the general experience and thus prove the quality of the reference measurements.

#### 4.2 Robust bundle adjustment

The actual analysis procedure consisted of two different steps. In the first step for each received set of image coordinates a robust bundle adjustment was carried out, again using the programme package CLIC. In this package blunder detection and elimination is performed similar to the suggestions by Klein, Förstner (1984). Within the

adjustment smaller and smaller weights are iteratively assigned to observations showing large residuals. In this way these observations have less influence onto the results. It should be noted that in each blunder detection scheme a number of implicit or explicit assumptions must be made. Usually, an estimate for the accuracy of the observations without the blunders needs to be available. This is also the case for CLIC. In these experiments the image coordinates not representing blunders were assumed to be uncorrelated and of an accuracy of  $\sigma_{o,a \text{ priori}} = 1/3$  of a pixel.  $1/3$  of a pixel is a rather conservative estimate of the accuracy generally attributed to matching of two images. However, in the case of multiple overlapping images this value seems to be rather appropriate and was therefore selected. In section 5.3 the influence of  $\sigma_{o,a \text{ priori}}$  onto the results for selected cases is further investigated.

The block datum was fixed by introducing the minimum of seven orientation parameters (six parameters of one image and one base line) as constant values. Thus, it could be ensured that the resulting block would not be influenced by ground control information. Rather, the potential of the purely automatic tie point extraction could be assessed. Alternatively, a free network adjustment could have been performed in order to reach the same effect, but the current version of CLIC cannot handle the large number of tie points delivered by the participants in the free adjustment mode. In the case of Echallens the additional self calibration parameters determined in the reference measurements (see above) were applied as constant values.

During the bundle adjustment runs various results were collected in a log file:

- the average number of tie points per image,
- the number and percentage of detected blunders.
- the number of multi ray points.

Also a number of plots was generated for every run:

- plots showing the distribution of the tie points in the image, before and after the robust bundle adjustment,
- plots showing the distribution of the points eliminated during the robust adjustment,
- plots showing the distribution of only those tie points which connect strips,
- plots showing the distribution of the tie points in object space.

The log file information and the plots were used in order to obtain a first impression of the quality of the received sets of conjugate points.

Additional results of the robust bundle adjustment consisted of

- the adjusted exterior orientation parameters for each image, and
- the standard deviation so of the image coordinates.

Besides, object space coordinates of all the tie points were computed, however, they were not analysed further, because the orientation parameters were considered as the primary results of AAT within this test (see also comments in the introduction).

The work flow of this first analysis step is depicted in figure 7. Originally it was also planned to analyse the covariance matrix  $\Sigma$  for the orientation parameters based on

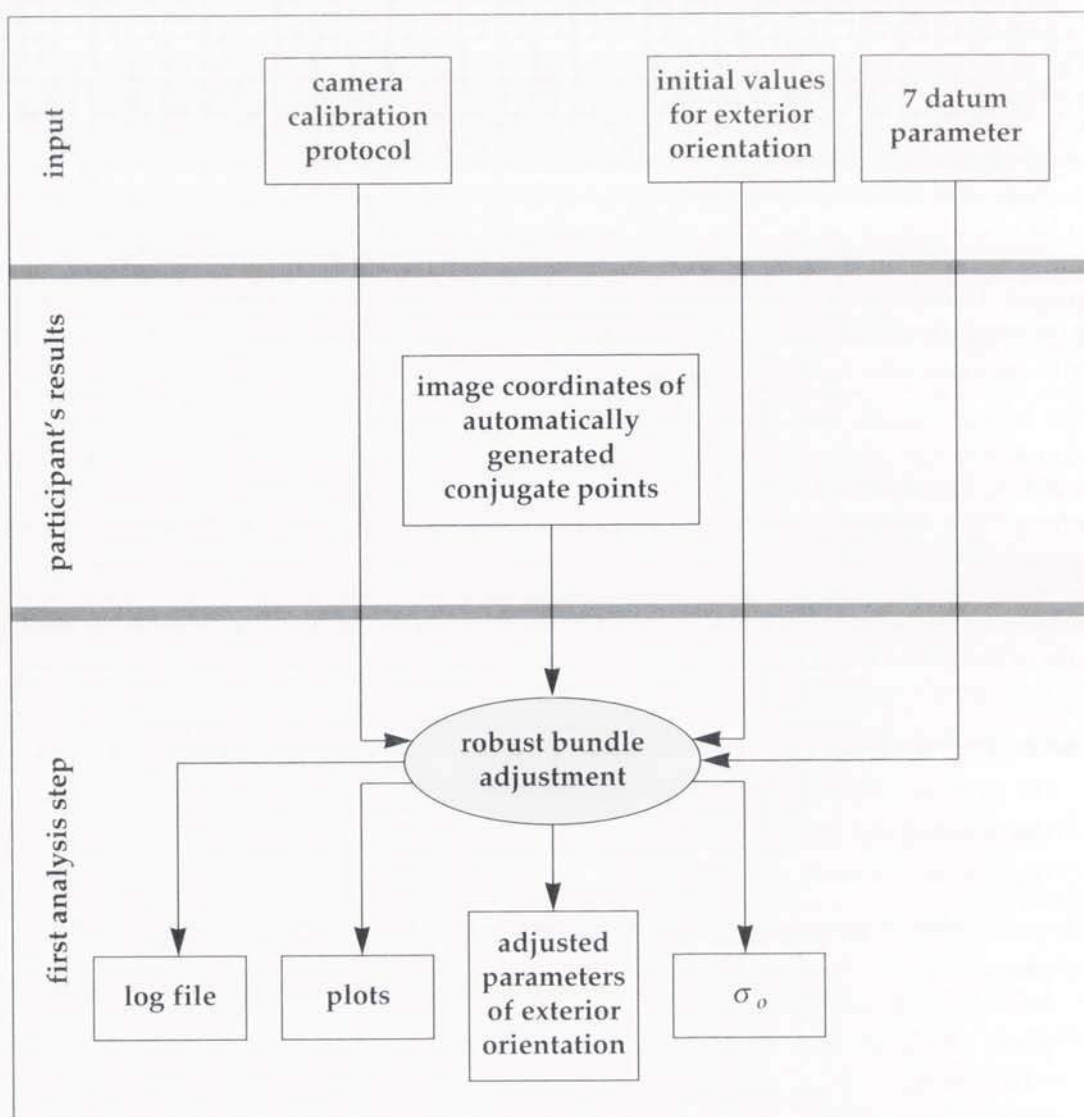


Figure 7: Data flow of robust bundle adjustment

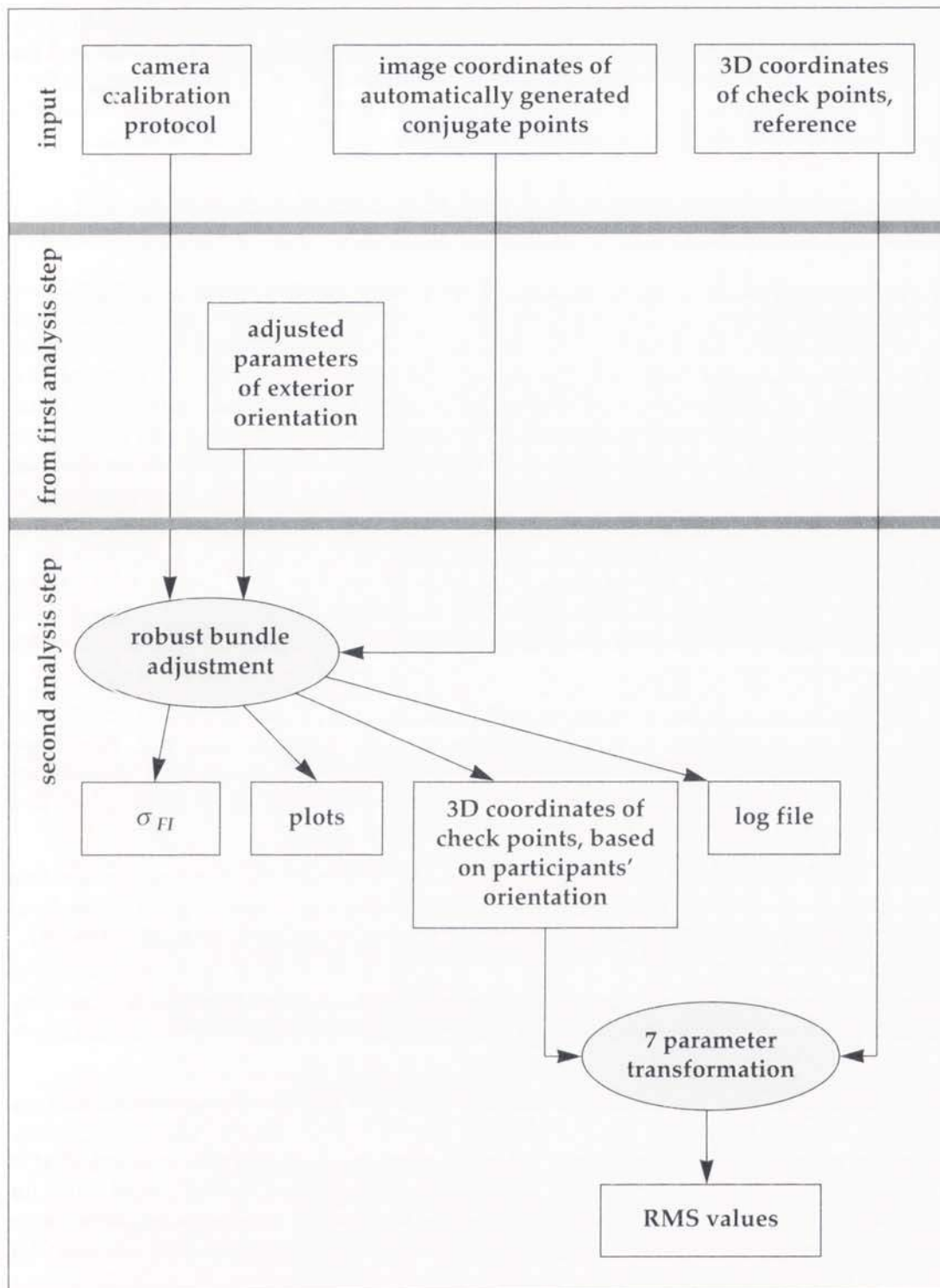


Figure 8: Data of independent accuracy investigation

criterion matrices (Baarda 1973; Förstner 1995) in order to obtain more insight into the geometric block stability. Due to the overwhelming number of test participants and the resulting work load in the analysis phase this investigation had to be dropped. It thus remains a challenge to quantify the accuracy of the exterior orientation in view of the large correlations between the different parameters.

#### 4.3 Independent accuracy check

A second analysis step was carried out for each set of image coordinates in order to independently assess the accuracy of the obtained orientation parameters (see figure 8). Using the interactively measured image coordinates of the check points from the reference measurements, and the exterior orientation parameters from the participants obtained in the robust adjustment of the first analysis step as constant values, over-determined least squares forward intersections were computed (including the additional self calibration parameters for Echallens). Rather than developing a separate software for forward intersection CLIC was again used, and all orientation parameters were introduced as constant values. Among other things, this computation results in a value for the accuracy of the image coordinates termed  $\sigma_{FI}$  for "forward intersection".  $\sigma_{FI}$  can be considered as a measure of quality for the orientation parameters determined from the results of the participants. Besides the numerical value for  $\sigma_{FI}$  plots showing the individual residuals of the least squares forward intersection across the whole block were also generated.

In interpreting  $\sigma_{FI}$  it must be kept in mind that since  $\sigma_{FI}$  is based on the interactive reference measurements, and  $\sigma_{o,ref}$  represents the optimal accuracy for these measurements in the least squares sense,  $\sigma_{o,ref}$  is a lower bound for  $\sigma_{FI}$ . When interpreting  $\sigma_{FI}$ ,  $\sigma_{o,ref}$ , and so (the latter from the robust bundle adjustment of the first analysis step) two different cases can be distinguished:

- $\sigma_{o,ref}$  and  $\sigma_{FI}$  are of the same magnitude. In this case the exterior orientation parameters computed from the results of the participants coincide with those from the interactive measurements.  $\sigma_o$  can be larger, in the order of, or smaller than  $\sigma_{FI}$ .
- $\sigma_{FI}$  is considerably larger than  $\sigma_{o,ref}$ . In this case deformations in the blocks of the participants are present, regardless of the value of  $\sigma_o$ . A small value for  $\sigma_o$  (possibly smaller than  $\sigma_{o,ref}$ ) can indicate that the distribution of the tie points is not adequate and thus the images and / or strips are not appropriately connected.

These arguments assume that the transformations from pixel to image coordinates are identical for the results of the participants and the interactively measured image coordinates. As mentioned in chapter 2 this assumption could not be strictly fulfilled in this test, because not all of the tested systems are able to import pixel coordinates for the fiducial marks. In preliminary studies it was shown that the remaining effects do not significantly influence the interpretation of  $\sigma_{FI}$ . They can, however, account for differences in the order of 1–2  $\mu\text{m}$ .

Besides this comparison in image space also an object space comparison was carried out. In the ideal case one would have compared the object space coordinates ( $X_{FI}$ ,  $Y_{FI}$ ,  $Z_{FI}$ ) of the check points determined in the least squares forward intersection

to independently acquired ground coordinates, e.g. GPS coordinates. In the absence of such independently determined values, an alternative way was chosen: the  $(X_{FI}, Y_{FI}, Z_{FI})$  were compared to the object space coordinates  $(X_{ref}, Y_{ref}, Z_{ref})$  of the reference measurements. In order to eliminate possible influences stemming from different datum definitions one data set was transformed onto the other using a spatial 7-parameter transformation (3 translations, 3 rotations, 1 scale factor). Subsequently the root mean square differences between the coordinates were determined. These values are termed RMS(X), RMS(Y), and RMS(Z), respectively.

Obviously, the two data sets  $(X_{FI}, Y_{FI}, Z_{FI})$  and  $(X_{ref}, Y_{ref}, Z_{ref})$  are correlated with each other, since the image coordinates used to compute them are identical, and only the orientation parameters are different. For the interpretation of the results, one can again distinguish two cases:

- the RMS values are smaller or in the same range as the theoretical standard deviations  $\sigma_X$ ,  $\sigma_Y$ , and  $\sigma_Z$ . In this case the results of the participants are considered to be correct.
- The RMS values are significantly larger than the theoretical standard deviations  $\sigma_X$ ,  $\sigma_Y$ , and  $\sigma_Z$ . This means that the results of the participants yielded a strongly deformed block.

Neither  $\sigma_{FI}$  nor the RMS values fully describe the accuracy of the AAT performed by the participants. The reason is twofold: first, any effects connected to ground control were deliberately excluded from the analysis, and second the reference measurements and the test results were obtained from the same images and thus no independent reference measurements of adequate accuracy (one order of magnitude better than the test results, say) were available. Rather,  $\sigma_{FI}$  and the RMS values must be compared to  $\sigma_{0,ref}$ ,  $\sigma_X$ ,  $\sigma_Y$ , and  $\sigma_Z$ . As will be seen erroneous results can quickly be detected in this way. In the remaining cases  $\sigma_{FI}$  and the RMS values serve as upper bounds for the reached accuracy.

It should also be noted that the suggested quality measures constitute average measures for the complete block. As such they are not useful in detecting local block deformations. Within the test these local effects are investigated using the mentioned  $\sigma_{FI}$  plots.

## 5 Results and Discussion

### 5.1 Blunder elimination, multi ray points, and point distribution

In this section the geometric stability of the blocks is assessed using tables and plots showing the average number and the distribution of tie points in image space, the number, percentage and distribution of eliminated blunders, the distribution of the points connecting strips, and the number and distribution of the multi ray points in object space. Since Echallens represents a kind of base line data set for the test, the corresponding results are presented first, see table 5 for the numerical values. Concentrating on this table a number of observations can be made:

Participant	System	av. no. of correct tie pts. per image	elim. blunders		no. of multi ray points in object					
			no	%	total	2 ray pts.	3 ray pts.	4 ray pts.	5 ray pts.	6 ray pts.
LHS	HATS	59	86	14	195	99	63	21	5	7
BKG		14	24	16	48	31	6	7	2	2
EPFL		25	65	22	88	57	16	11	2	2
NLS-SWE		26	15	6	93	63	17	6	4	3
UNSW		12	6	5	41	22	9	8	1	1
SWPH	HATS*	73	0	0	235	128	55	33	4	15
Inpho	Match AT	182	0	0	496	180	123	115	11	67
I-graph		98	0	0	327	194	70	44	0	19
CZ	Phodis AT	250	179	7	906	538	318	35	10	5
B-LVA		245	208	9	895	549	293	42	6	5
LGN		275	234	9	988	555	381	41	7	4
FGI	research systems	379	0	0	1433	1097	175	133	6	22
TUM		468	46	1	1591	839	534	163	43	12
DIIAR		115	200	16	479	404	70	4	1	0

Table 5: Results for the test data set Echallens, blunder elimination and multi ray points

- The average number of correct tie points per image (this is the number of tie points after blunder elimination) and the total number of multi-ray points in object space differ considerably between the participants and systems. Some of the participants using HATS, e.g. BKG and UNSW, delivered rather few points. On the other hand the Phodis AT users and two research systems (TUM and FGI) extracted between 245 and 468 points per image and between 895 and 1591 object points.
- It can be seen (and comes at no surprise) that within AAT a robust adjustment is absolutely necessary. In the systems which do not include an internal blunder elimination scheme up to 22 % of the measurements were eliminated. The actual number of detected blunders differs according to the number of extracted tie points.
- A closer look at the number of rays per object point reveals that Match AT and the TUM and FGI systems obtained a large number of multi ray points. Although HATS can apparently be tuned in the same way (see the SWPH result), the HATS participants with only a small number of tie points seem to lack multi-ray points. The same is true for the DIIAR system.
- Expressed in relative figures for some participants, LHS obtained 51 % 2 ray points (99 out of 195) and 6 % 5 + 6 ray points (5+7 out of 195), the figures for Inpho are 36 % and 16 %, and those for CZ 59 % and 3 %. When interpreting these percentages one has to keep in mind that given the nominal overlap configuration of  $l=60\%$  and  $q=30\%$ , about 67 % of the block is depicted in two images, 12 % in three, 17 % in four and 4 % in six images. Thus the focus on a large relative number of multi ray points seems to work best for Match AT.

Next, a few of the generated plots shall be presented and discussed. In the figures 9 to 11 the tie point distribution in image space without blunders, the tie points connecting

0EEPE-IPSPRS Test, Performance of tie point extraction in AAT, tie point distribution in image space  
 Part.: LH-Systems, San Diego  
 Project: Echallens, tie points without blunders

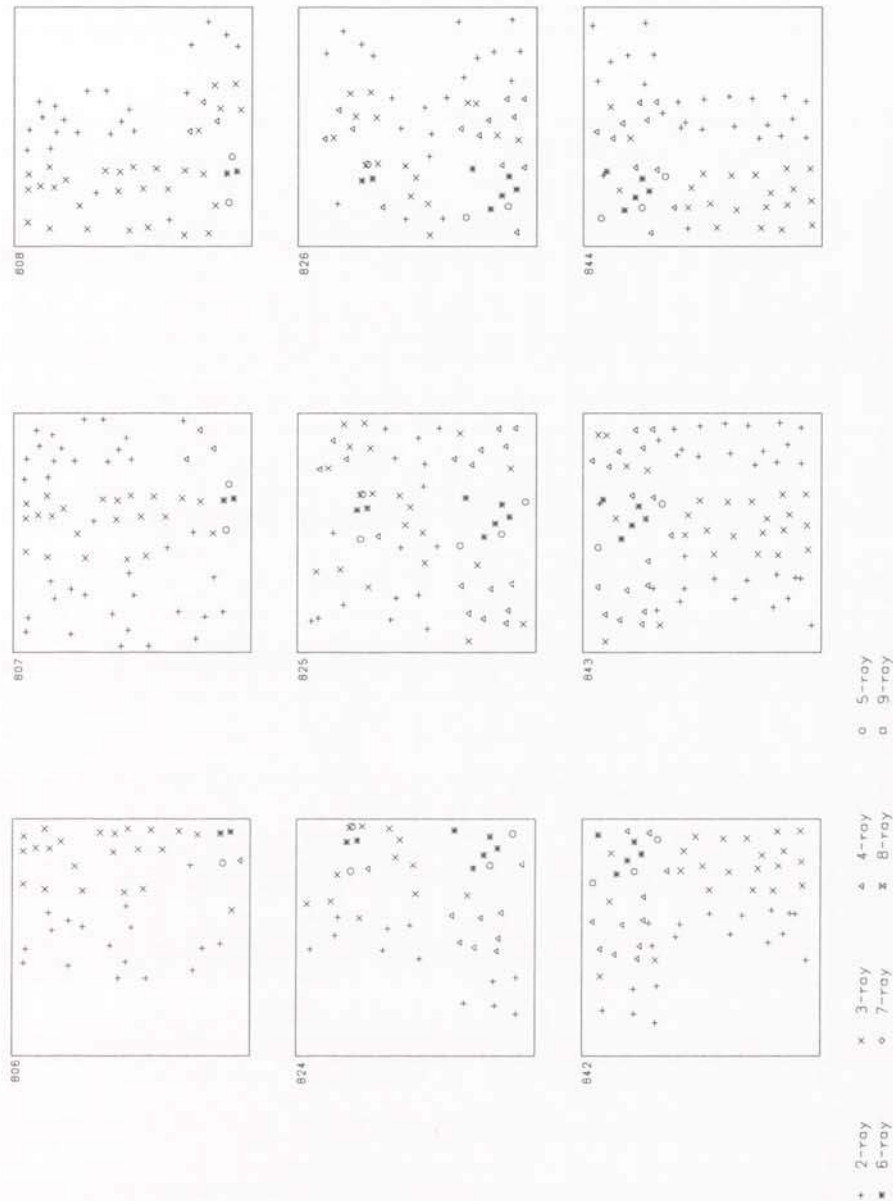


Figure 9: Results for Echallens / LHS, tie points without blunders

OEEPE-ISPRS Test, Performance of tie point extraction in AAT, tie point distribution in image space  
 Part.: LH-Systems, San Diego  
 Project: Echallens, tie points connecting strips (after rob. adj.)

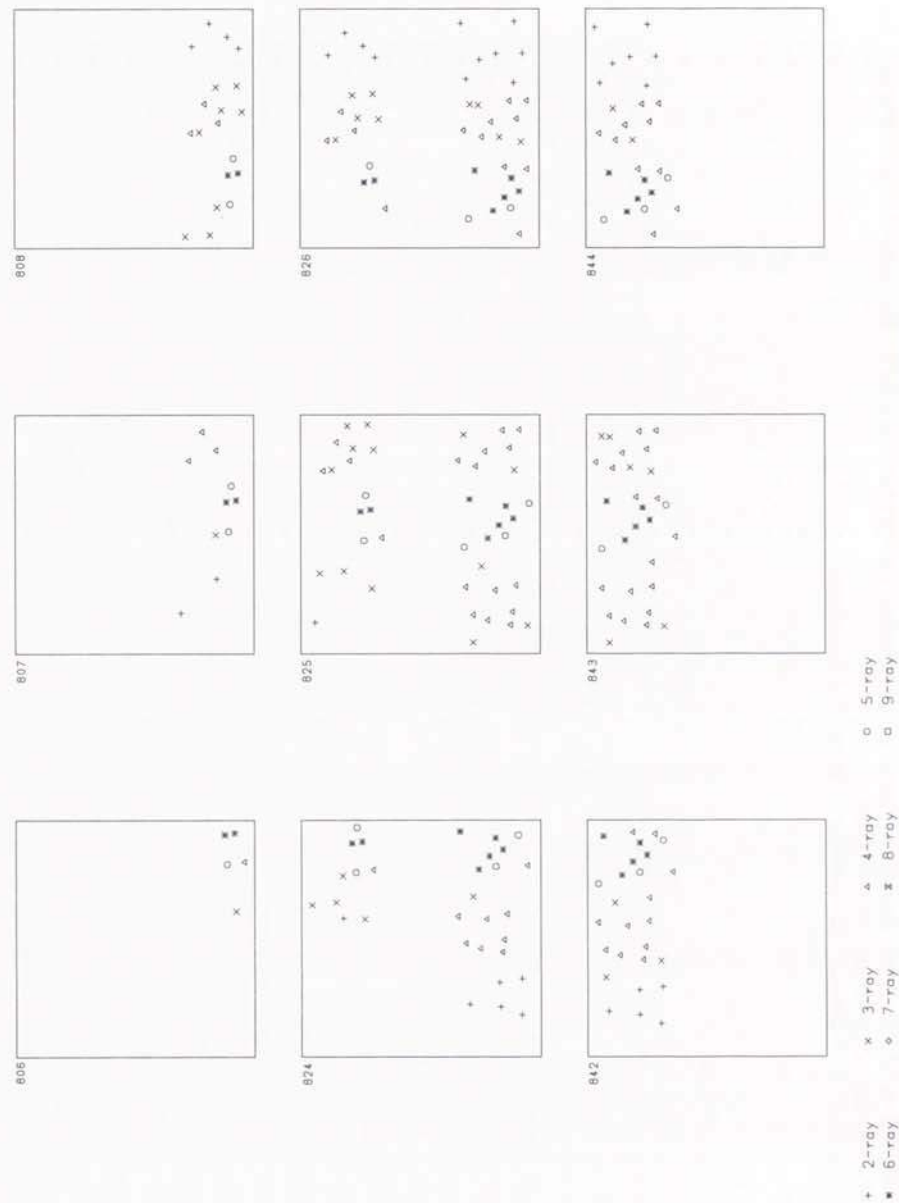


Figure 10: Results for Echallens / LHS, tie points connecting strips

*OEEPE-ISPRS Test, Performance of tie point extraction in AAT*  
*Part.: LH-Systems, San Diego*  
*Project: Echallens, Point distribution in object space (after rob. adj.)*

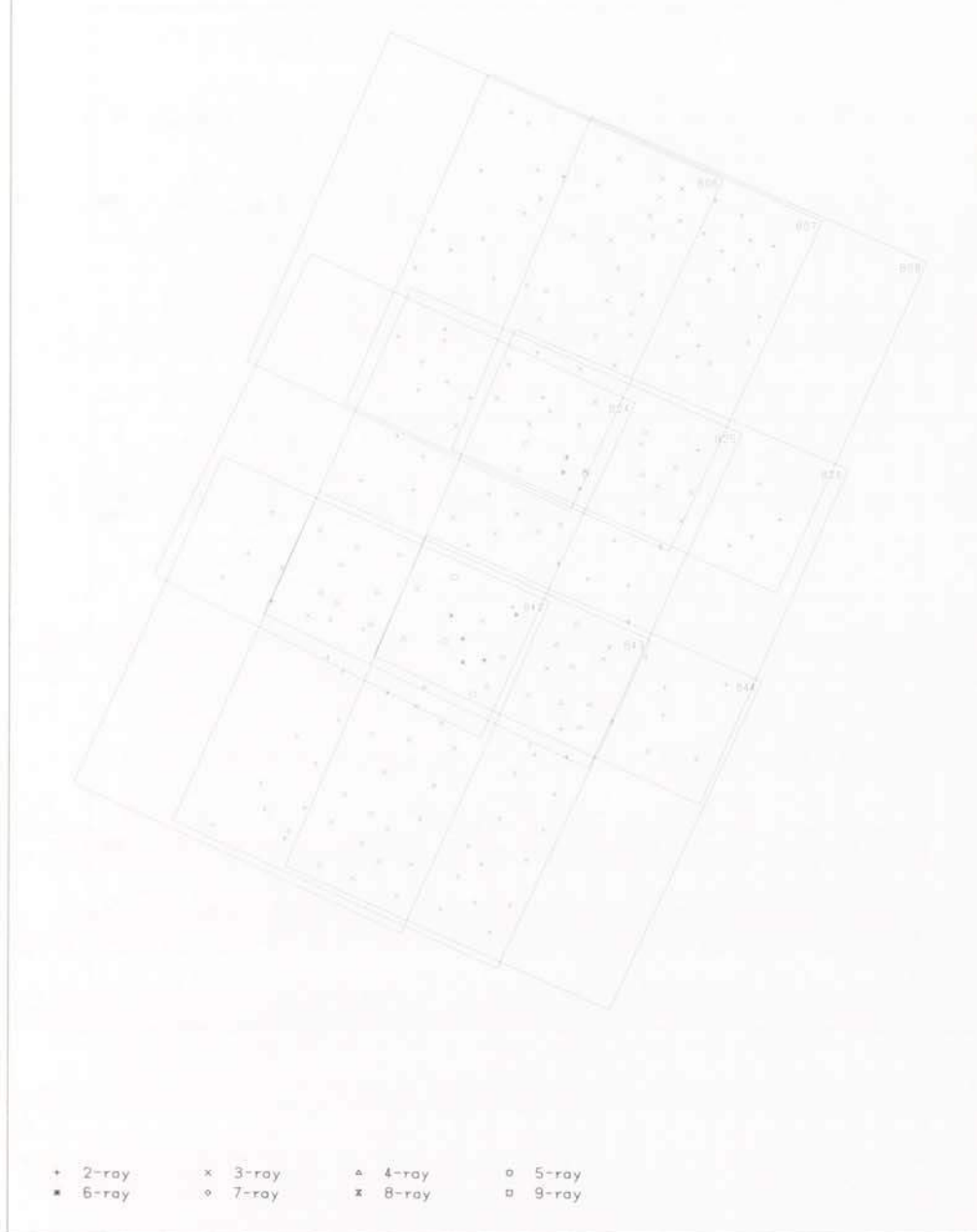


Figure 11: Results for Echallens / LHS, point distribution in object space

*OEEPE-ISPRS Test, Performance of tie point extraction in AAT, tie point distribution in image space*  
*Part.: Inpho, Stuttgart*  
*Project: Echallens, tie points without blunders*

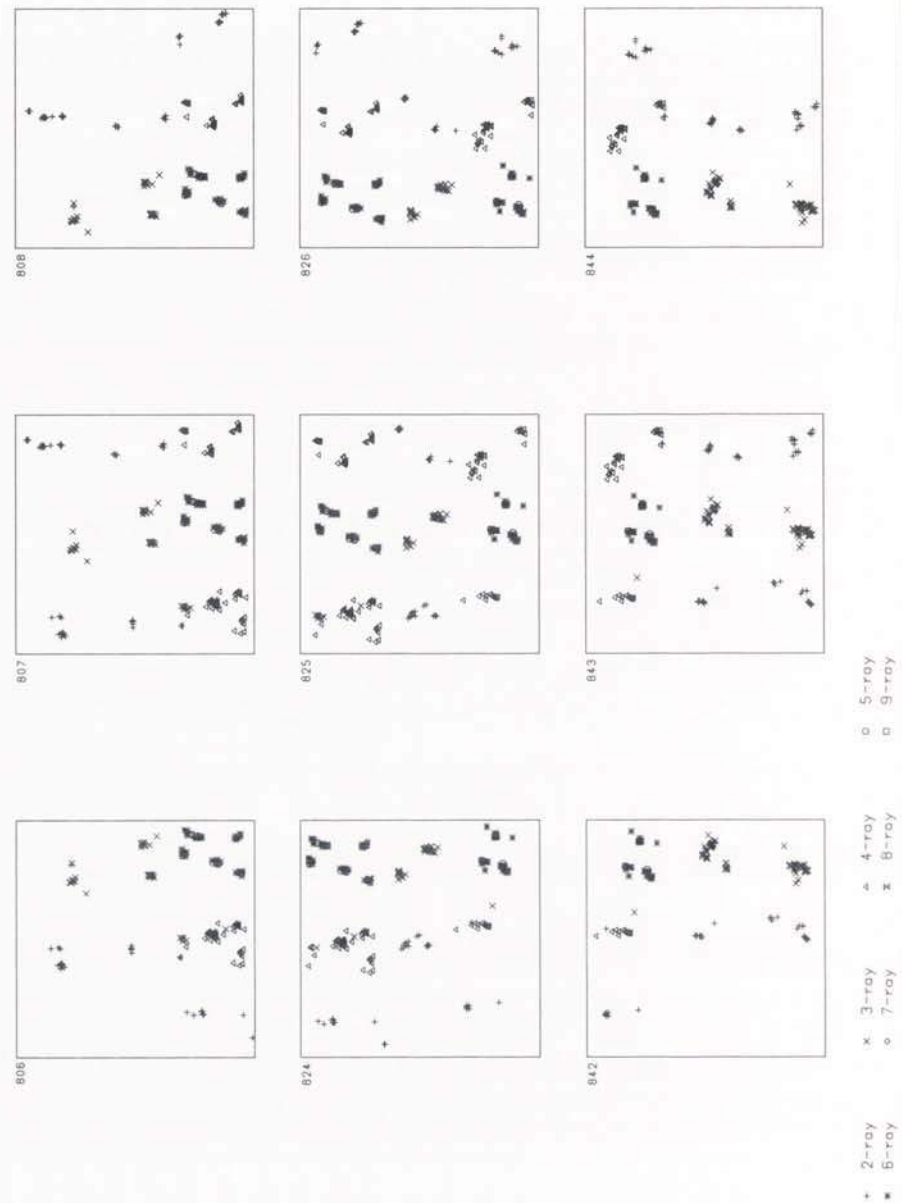


Figure 12: Results for Echallens / Inpho, tie points without blunders

*OEEPE-IPRS Test, Performance of tie point extraction in AAT, tie point distribution in image space  
 Part.: Inpho, Stuttgart  
 Project: Echallens, tie points connecting strips (after rob. adj.)*

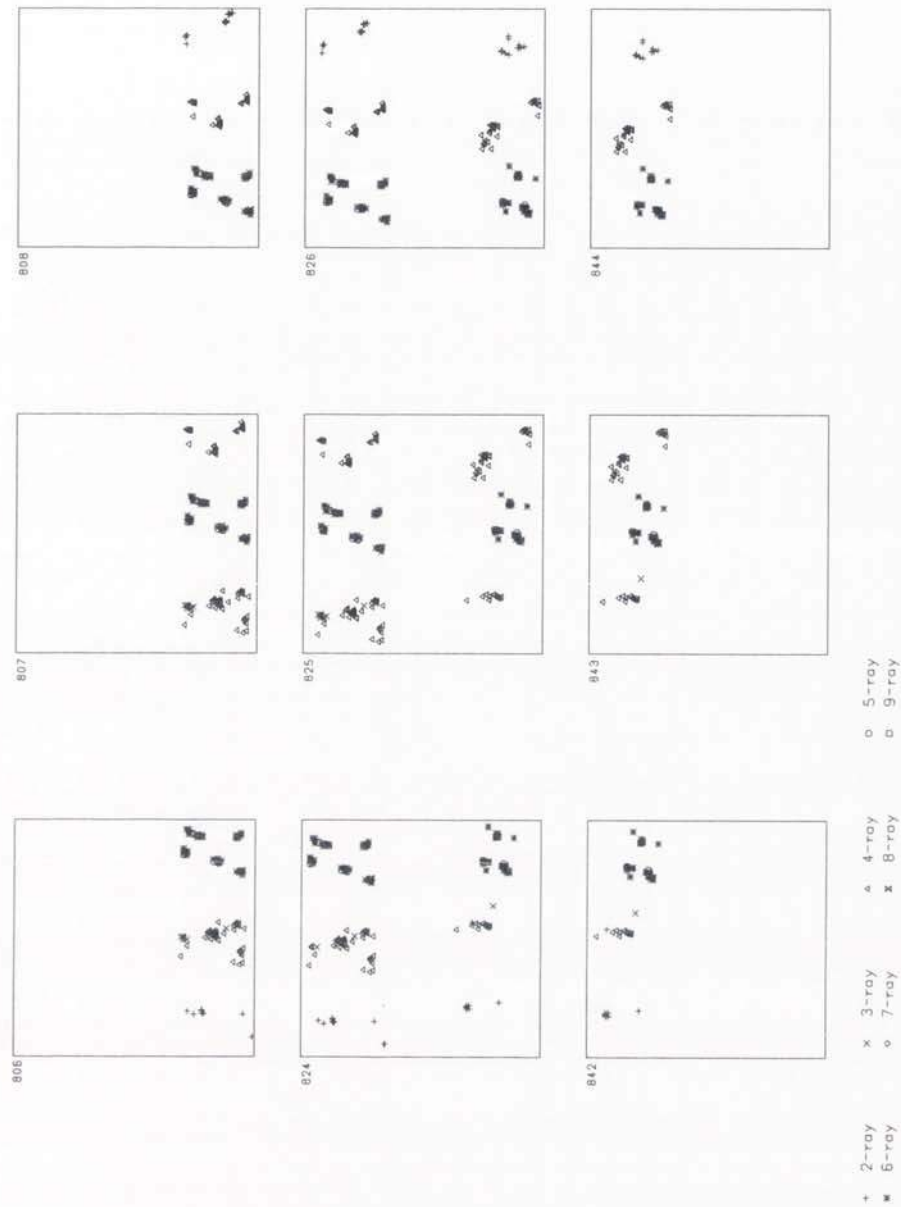


Figure 13: Results for Echallens / Inpho, tie points connecting strips

0EEPE-ISPERS Test, Performance of tie point extraction in AAT  
 Part.: Inpho, Stuttgart  
 Project: Echallens, Point distribution in object space (after rob. adj.)



Figure 14: Results for Echallens / Inpho, point distribution in object space

0EEPE-IPRS Test, Performance of tie point extraction in AAT, tie point distribution in image space  
 Part.: Carl Zeiss, Oberkochen  
 Project: Echallens, tie points without blunders

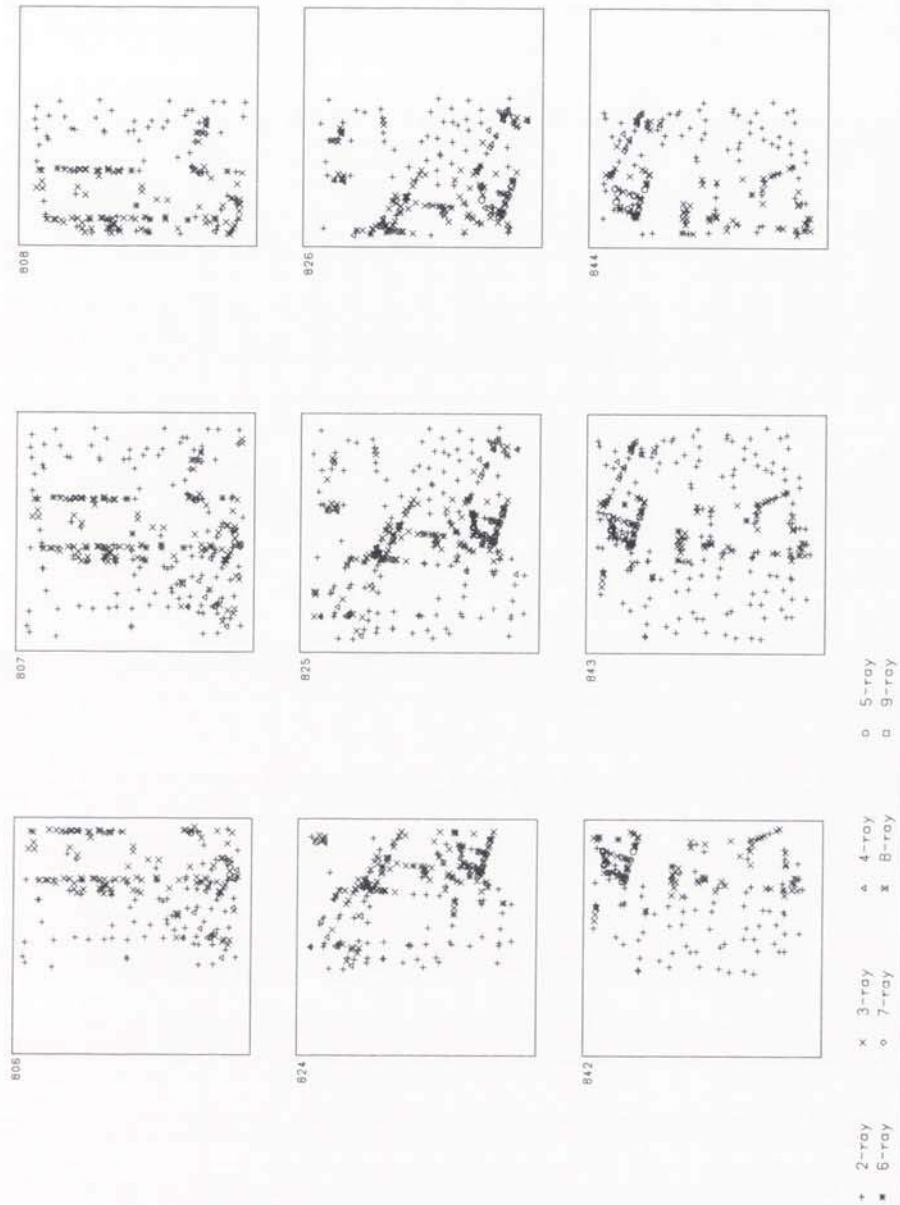


Figure 15: Results for Echallens / CZ, tie points without blunders

*OEEPE-ISPERS Test, Performance of tie point extraction in AAT, tie point distribution in image space  
 Part.: Carl Zeiss, Oberkochen  
 Project: Echallens, tie points connecting strips (after rob. adj.)*

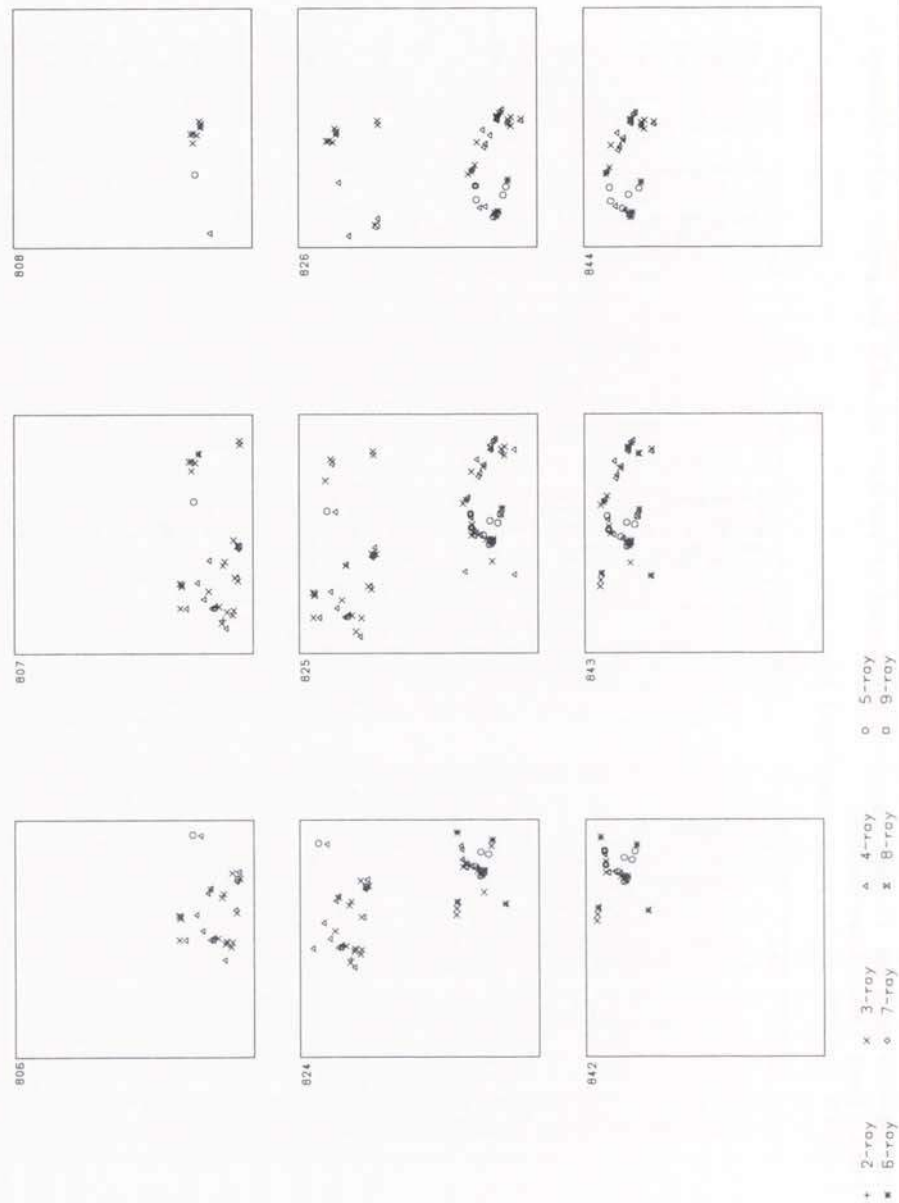


Figure 16: Results for Echallens / CZ, tie points connecting strips

*OEEPE-ISPRS Test, Performance of tie point extraction in AAT  
 Part.: Carl Zeiss, Oberkochen  
 Project: Echallens, Point distribution in object space (after rob. adj.)*



Figure 17: Results for Echallens / CZ, point distribution in object space

strips and the tie point distribution in object space is depicted for the LHS results. Different symbols represent the number of rays per point as explained in the lower left of the plots. Figures 12 to 14 show the same information for the Inpho results, and figures 15 to 17 for CZ. These figures very clearly convey the general philosophy of the different approaches: HATS determines a moderate number of conjugate points well distributed across the images. To some extent HATS emulates the results of interactive measurements. Match AT generates considerably more conjugate points and focuses on the areas of multiple overlap areas. Due to the point clusters generated individual points are hard to distinguish. Phodis AT creates a very large number of conjugate points and thus the plots lose some of their clarity, at least in the given resolution. Nevertheless it can be seen that the major part consists of 2 ray and 3 ray points. These plots were generated for all participants and all data sets at the pilot centre in order to quickly obtain an overview of the quality of the delivered results.

The results for the other data sets generally confirm these findings. The corresponding tables can be found in the appendix (tables A2.1 to A2.5). One additional observation, however, will be discussed here: the percentage of eliminated blunders in the OSU data set is considerably larger than in the others. For Phodis AT it reaches 31% and for DIAR 45%. Even in the systems with blunder elimination some additional gross errors needed to be eliminated. Also, with the exception of Match AT and the TUM system the number of extracted 7 to 9 ray points is very small. 8 out of the 13 participants who processed the data set obtained a maximum of only 2 (!) such points. One reason is certainly the fact that the centre of the block where all 9 images overlap depicts a large number of tennis courts, see figure 18 for an enlargement of this area. Most matching schemes have major difficulties with this type of repetitive texture, because usually matching is performed as a local operation. The plots showing the distribution of the eliminated blunders (as an example the CZ result is shown in figure 19) confirm the hypothesis that most blunders are indeed to be found in the tennis court area.

## 5.2 Accuracy analysis

Again, the results for Echallens are presented first. In table 6 the values  $\sigma_o$  from the robust bundle adjustment (both in pixels and in  $\mu\text{m}$ ),  $\sigma_{FI}$  (in  $\mu\text{m}$ ) and the RMS values in object space (in cm) can be found. A look at the individual figures reveals some interesting findings:

- The standard deviation  $\sigma_o$  of the tie point coordinates generally lies between 0.15 and 0.20 pixels or 3 and 4  $\mu\text{m}$ . This result has been obtained although the expectation for the accuracy of the image coordinates as expressed in  $\sigma_{o, \text{a priori}}$  were set to only 1/3 pixel (see section 4.2). The TUM and the DIAR systems yielded larger values for  $\sigma_o$ , 0.33 and 0.28 pixel, respectively. For TUM this result was to be foreseen, since the version used for the test relies uniquely on feature based matching without a matching refinement stage (see again table 3).
- For many participants the independent check using  $\sigma_{FI}$  confirms this block accuracy, and  $\sigma_{FI}$  is slightly larger than  $\sigma_o$ . This slight increase does not come as a surprise, since as mentioned earlier  $\sigma_{FI}$  must be larger than  $\sigma_{o, \text{ref}}$ , and the latter

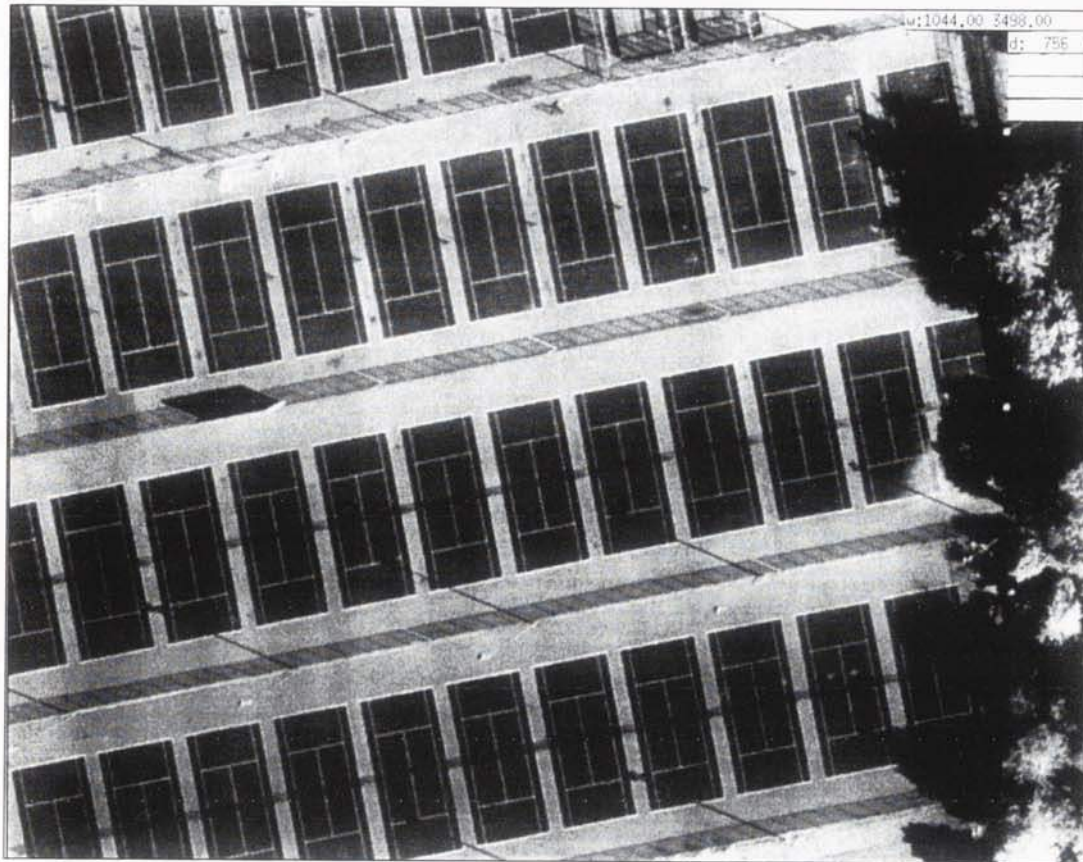


Figure 18: Enlargement for central OSU image, tennis courts

*OEEPE-ISPRS Test, Performance of tie point extraction in AAT, tie point distribution in image space  
 Part.: Carl Zeiss, Oberkochen  
 Project: OSU, tie points eliminated by robust bundle adjustment*

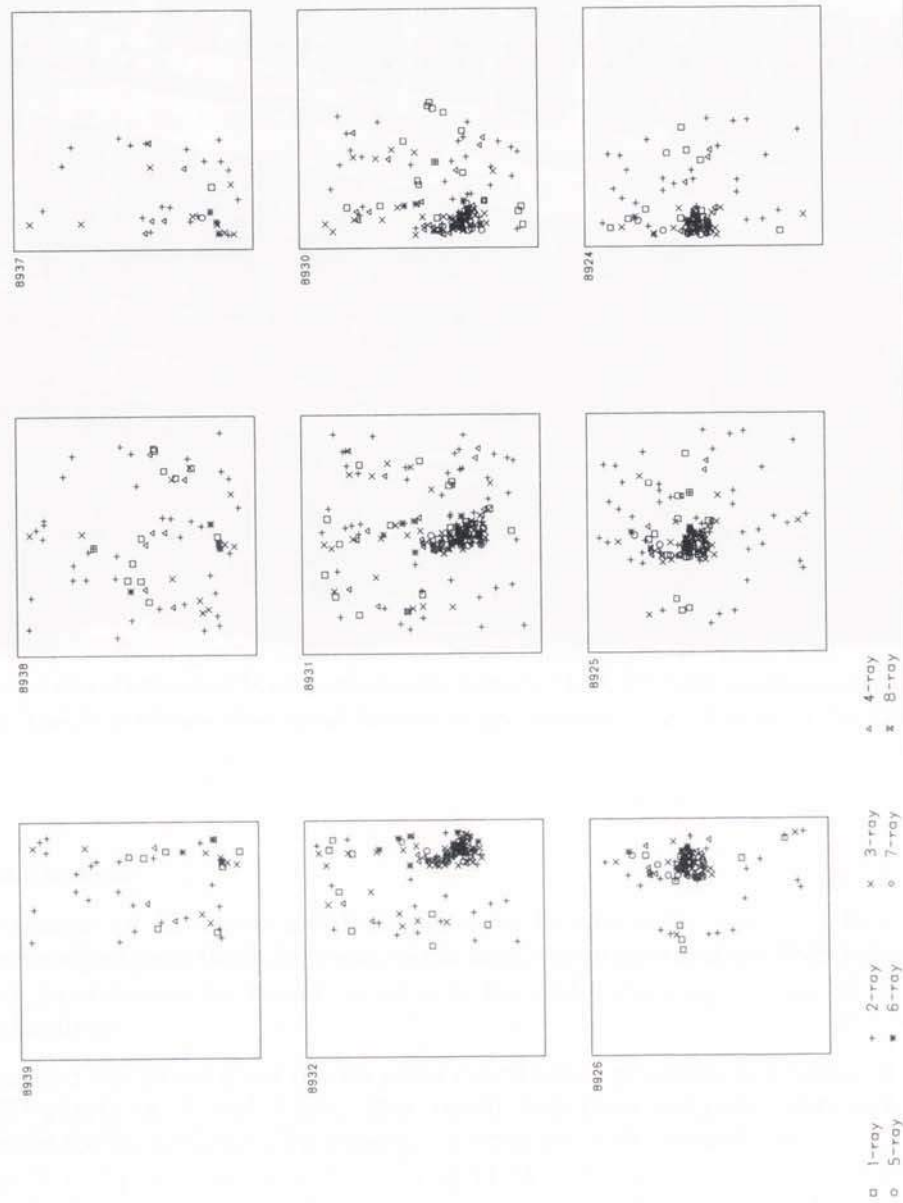


Figure 19: Results for OSU / CZ, points eliminated during robust adjustment

Participant	System	$\sigma_o$		$\sigma_{FI}$	RMS values		
		[pel]	[ $\mu m$ ]	[ $\mu m$ ]	X [cm]	Y [cm]	Z [cm]
LHS	HATS	0.21	4.2	4.5	3.1	3.6	9.5
BKG		0.14	2.7	8.1	8.7	6.1	22.8
EPFL		0.18	3.6	4.8	3.3	3.9	12.0
NLS-SWE		0.18	3.5	6.0	3.0	5.0	8.7
UNSW		0.15	3.0	5.5	4.2	6.9	5.5
SWPH	HATS*	0.17	3.4	3.6	2.2	2.6	4.0
Inpho	Match AT	0.17	3.3	3.7	2.5	2.4	4.7
I-graph		0.18	3.6	4.5	3.0	3.4	16.8
CZ	Phodis AT	0.20	4.0	4.5	4.0	4.2	11.3
B-LVA		0.18	3.5	4.4	4.3	4.7	6.9
LGN		0.17	3.4	4.4	4.5	4.8	7.0
FGI	research systems	0.17	3.4	4.4	3.1	3.0	8.5
TUM		0.33	6.6	4.1	3.1	3.4	3.6
DIIAR		0.28	5.6	6.2	5.0	4.3	7.1

Table 6: Results for the test data set Echallens, accuracy figures (the obtained values have to be compared to the reference results:

$$\sigma_{o,ref} = 3.2 \mu m, \sigma_X = 2.4 \text{ cm}, \sigma_Y = 2.6 \text{ cm}, \sigma_Z = 4.9 \text{ cm})$$

value amounts already to  $3.2 \mu m$ . Thus, the exterior orientation parameters computed in the robust bundle adjustment are confirmed. Despite the larger  $\sigma_o$  value this is true also for the TUM result. Apparently, the large number of less accurate tie points and the resulting high redundancy contributed to precise orientation parameters.

- In the cases where only a small amount of tie points was extracted (BKG, NLS-SWE, UNSW, all using HATS)  $\sigma_{FI}$  is considerably larger than  $\sigma_o$ , indicating that the block shows rather large deformations. In some areas of the block no conjugate points were obtained. As mentioned above HATS calls upon the operator in case of problems, but this feature was deliberately ignored within the test, since only automatic results were to be generated. As exemplified by the results from LHS and SWPH, HATS and HATS\* can be turned into a fully automatic system. A prerequisite, however, seems to be a large number of observations (see again table 5). Otherwise correct matching cannot be guaranteed and the resulting block can be severely deformed. Also, the DIIAR result is inferior to the rest, probably due to the very few multi ray points.
- In AAT the  $\sigma_o$  value from the robust adjustment alone cannot be considered as an indicator for the quality of the aerial triangulation results. The reason is that in contrast to the situation in analytical photogrammetry in AAT an appropriate point distribution in each image and proper connections between the images and strips are not necessarily ensured, see again the results from BKG, NLS-SWE, and UNSW.
- An analysis of the RMS confirms the findings reported in connection with  $\sigma_{FI}$ . For most of the participants the RMS values and the theoretical standard deviations  $\sigma_X$ ,  $\sigma_Y$ , and  $\sigma_Z$  agree as expected. The smallest RMS values are reached by Inpho, SWPH and TUM. For the participants who showed a rather large difference

between  $\sigma_o$  and  $\sigma_{FI}$  also the RMS values are too large. This is most evident in the BKG results.

- However, there are additional participants exhibiting a high RMS value in the Z coordinate (LHS, EPFL, I-graph, CZ and FGI). Given the side overlap of 30 % a block deformation will first of all show up in Z. Therefore, RMS(Z) is more sensitive to block deformations than  $\sigma_{FI}$ . Thus, it must be concluded that also the blocks of the mentioned participants are somewhat deformed. However, it should be mentioned that the larger RMS(Z) values occurred mainly at the border of the block which is known to be more unstable.
- It is interesting to note that success and failure can apparently occur with one and the same software system, and the developers do not necessarily obtain the best results. This fact can be attributed to different settings in the parameter files and / or different experience of the operator.
- One of the major disadvantages is that failure to produce correct results is not indicated by the automatic systems.

Next the results for Montserrat are inspected. Montserrat is a more difficult data set. The scene is rather mountainous and contains forest, especially in the mountainous area in the upper part of the scene between the first and the second strip, leading to unfavourable conditions for image matching. These difficulties show up in the accuracy results, see table 7.

- The  $\sigma_o$  column seems to suggest homogeneous results similar to those for Echallens. An inspection of  $\sigma_{FI}$ , however, reveals the opposite. Some systems obtained a high accuracy in the order of 0.2 pixel and a good agreement between  $\sigma_o$  and  $\sigma_{FI}$ . In a number of cases, however,  $\sigma_{FI}$  is significantly larger than  $\sigma_o$ . As already mentioned, within AAT  $\sigma_o$  alone cannot be used to characterise the block quality. Blocks generated from rather few tie points (BKG, NLS-SF, NLS-SWE, UNSW) or from an overwhelming number of 2-ray points (DIAR) were again found to be severely deformed.
- Discrepancies between  $\sigma_o$  and  $\sigma_{FI}$  also exist in other cases (EPFL, Inpho, HL, OUAT). In order to further analyse these results all the residuals of the forward intersection were plotted. Examples can be seen for BKG and Inpho in the figures 20 and 21. Note that a residual vector of 30  $\mu$ m is shown in the lower right of the figures. Figure 22 shows the same information for a correct block, namely the one of LHS. From the BKG and Inpho plots it can clearly be seen that points in the overlapping area between the first and the second image strip have unacceptably large residuals in the flight direction. The plots of the other participants with large  $\sigma_{FI}$  are similar. Apparently, most matching algorithms had major difficulties in the mountainous and forested area connecting the first and the second strip.
- When looking at the RMS values the size of the deformations is quantified. Only for the blocks of 6 participants (LHS, CGR, B-LVA, GCM, LGN and TUM) out of 20 the RMS values are sufficiently small to consider the block free of deformations. In all other cases partly severe deformations were found. Again, RMS(Z) is more sensitive to distortions than  $\sigma_{FI}$ , note for instance the results of SWPH, I-graph or Ph GmbH. For these participants, problems in connecting the first and the second image strip were again detected using the residual plots.

OEEPE-IPRS Test, Performance of tie point extraction in AAT  
 Part.: Bundesamt fuer Kartographie und Geodäsie, Frankfurt  
 Project: Montserrat, residuals of forward intersection

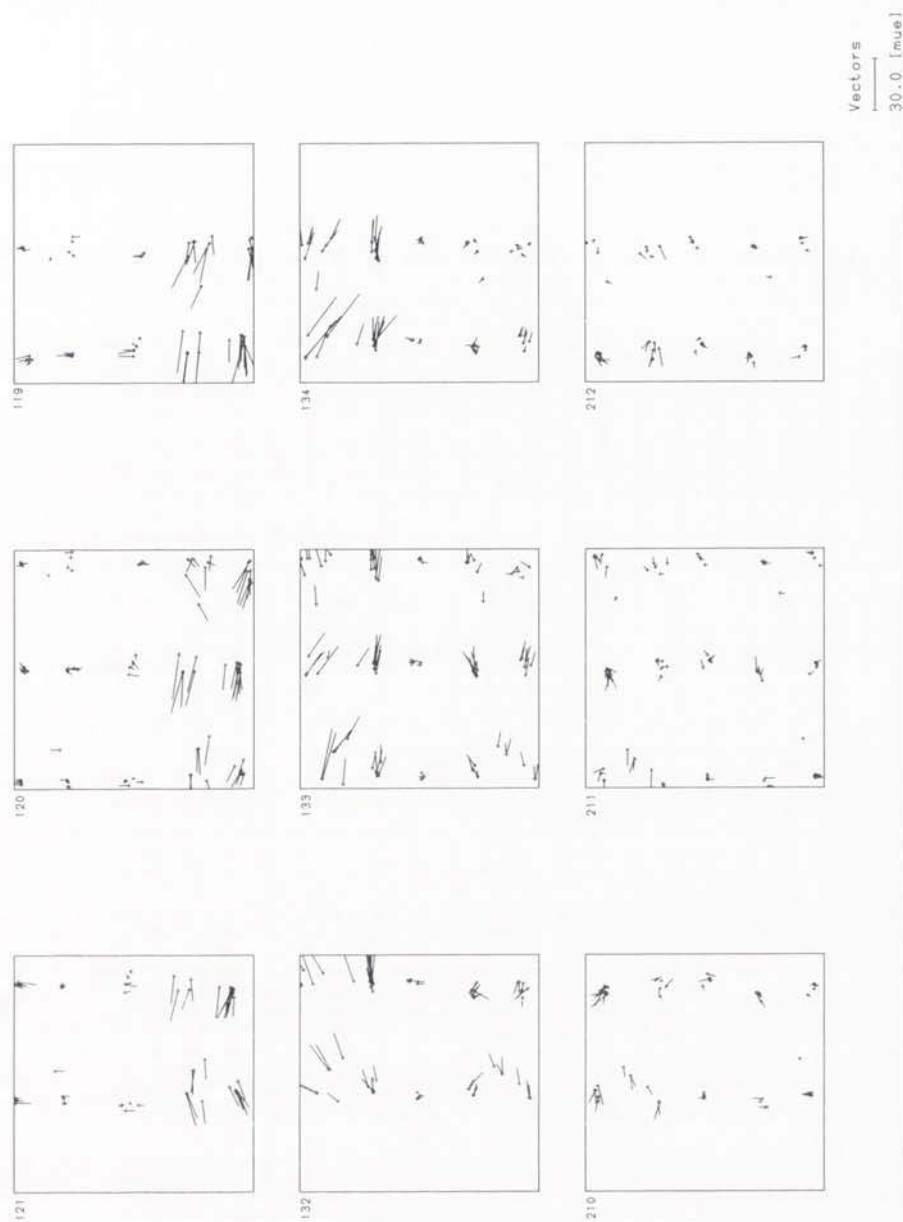


Figure 20: Results for Montserrat / BKG, residuals of forward intersection

*OEEPE-ISPRS Test, Performance of tie point extraction in AAT  
 Part.: Inpho, Stuttgart  
 Project: Montserrat, residuals of forward intersection*

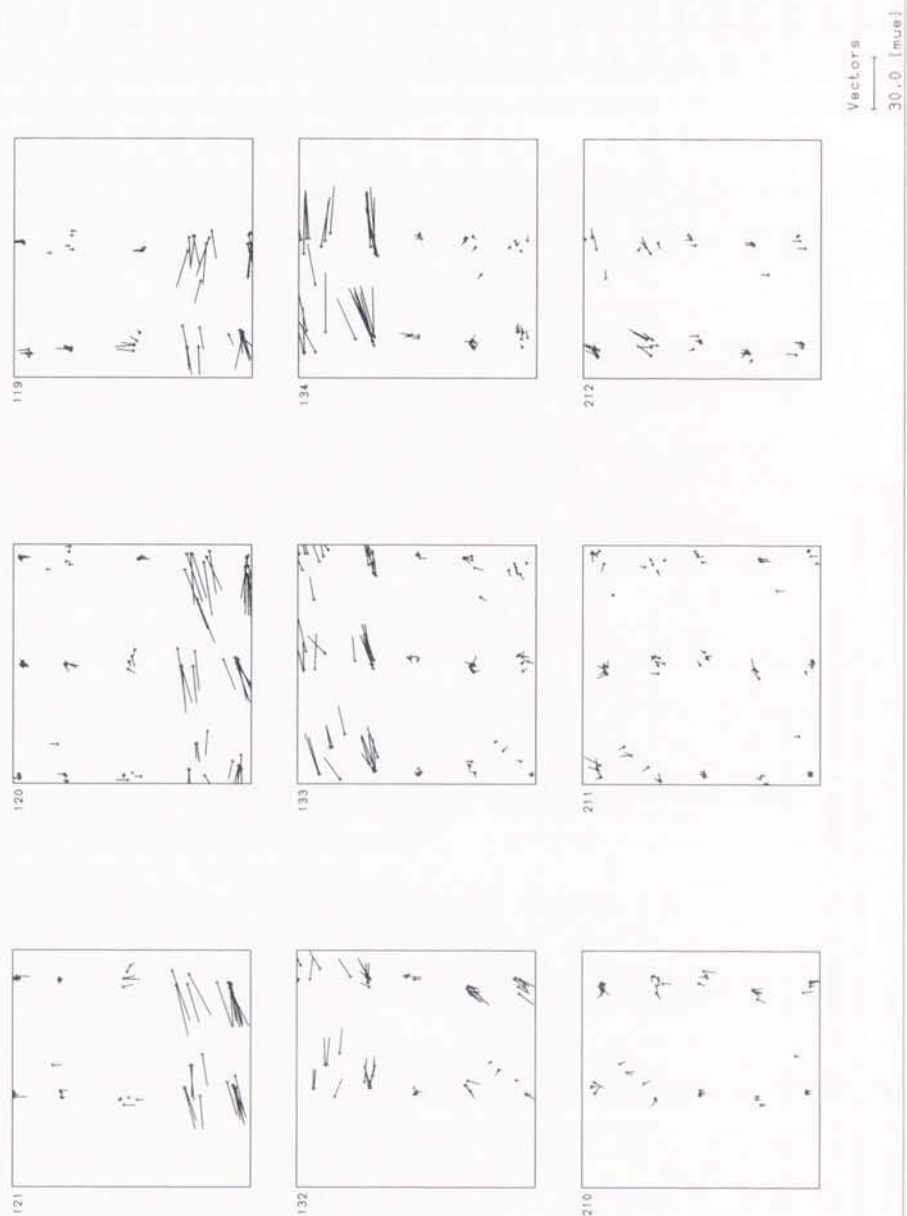


Figure 21: Results for Montserrat / Inpho, residuals of forward intersection

*OEEPE-ISPRS Test, Performance of tie point extraction in AAT  
 Part.: LH-Systems, San Diego  
 Project: Montserrat, residuals of forward intersection*

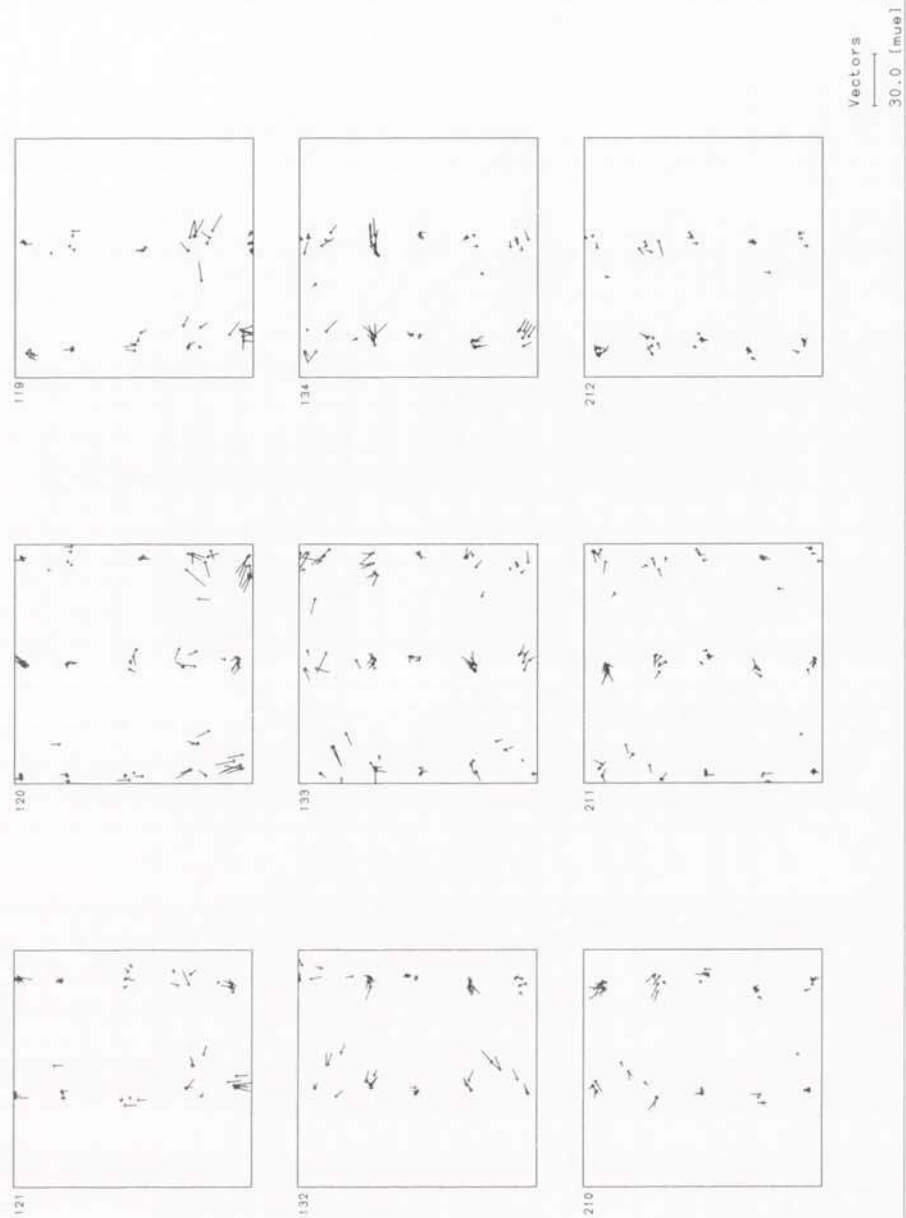


Figure 22: Results for Montserrat / LHS, residuals of forward intersection

Participant	System	$\sigma_o$		$\sigma_{FI}$	RMS values		
		[pel]	[ $\mu m$ ]	[ $\mu m$ ]	X [cm]	Y [cm]	Z [cm]
LHS	HATS	0.19	5.8	4.9	8.9	8.5	12.5
BKG		0.10	3.1	9.7	10.6	7.8	35.8
EPFL		0.20	6.0	13.4	17.4	14.8	42.2
NLS-SF		0.22	6.5	12.2	15.5	17.5	40.4
NLS-SWE		0.25	7.4	18.3	50.0	41.8	42.9
UNSW		0.14	4.3	17.6	28.6	32.5	66.9
SWPH	HATS*	0.21	6.4	5.4	7.8	8.6	55.7
Inpho	Match AT	0.11	3.3	11.4	13.9	10.1	17.9
I-graph		0.20	6.0	7.2	14.3	10.0	30.4
CGR		0.14	4.3	5.9	6.5	7.3	15.0
HL		0.15	4.6	10.6	17.7	11.9	16.2
Ph GmbH		0.17	5.2	6.3	9.4	10.0	50.6
CZ	Phodis AT	0.22	6.7	6.4	19.6	13.7	14.1
B-LVA		0.21	6.2	5.0	7.7	8.8	16.7
GCM		0.19	5.7	5.2	9.5	9.9	12.5
LGN		0.20	5.9	4.4	5.1	5.3	15.6
FGI	research systems	0.18	5.4	5.5	8.0	5.6	32.5
TUM		0.32	9.6	4.5	7.0	6.1	9.2
DIIAR		0.25	7.4	20.1	28.3	23.2	65.5
OUAT		0.25	7.4	13.6	24.0	15.9	29.9

Table 7: Results for the test data set Montserrat, accuracy figures (the obtained values have to be compared to the reference results:  $\sigma_{o,ref} = 3.4 \mu m$ ,  $\sigma_X = 5.2 \text{ cm}$ ,  $\sigma_Y = 5.4 \text{ cm}$ ,  $\sigma_Z = 10.3 \text{ cm}$ )

Given these results the block was split up into two subblocks, one containing only the first strip, the other one containing strip no. 2 and 3 and the complete analysis was repeated with both subblocks. The corresponding results are presented in tables A3.3 and A3.4. For NLS-SWE and DIIAR the first strip contained too few tie points, and thus no results were obtained. For the other participants the results improved and mostly fulfil the expectations, however in some cases (NLS-SF, NLS-SWE, UNSW and OUAT) the strips 2 + 3 still yielded deformed blocks.

The block Montserrat has thus shown the limitations of the available AAT systems. For the correct blocks an accuracy of about 4.5 to 6  $\mu m$  in  $\sigma_{FI}$  corresponding to approximately 0.15 to 0.2 pixel was reached, but this was only the case for 6 out of 20 participants. As for Echallens, success and failure occurred with one and the same system, and a demonstrated failure was not signalled by the systems.

In general the results for OSU (see table A3.5 in the appendix) follow the same pattern as described for Echallens. However, the accuracy level is somewhat worse. This is true for  $\sigma_o$  and also for  $\sigma_{FI}$ . The reasons are probably twofold: first, the FIR film material does not show the same image quality as the panchromatic material used for Echallens and Montserrat. Second, the scanner used for the OSU images was apparently not well calibrated when the images were scanned. This can be deduced from the large  $\sigma_{o,int}$

(see chapter 2). Thus, only an accuracy of approximately 0.3 pixels or 7–8  $\mu\text{m}$  for  $\sigma_{\text{FI}}$  was reached. Since the OSU images were flown with a side overlap of 60 % the blocks are inherently more stable than Echallens and Montserrat. Consequently, the RMS(Z) do not indicate any deformations, if a sufficient number of tie points was extracted.

The results of Kapellen and München (tables A3.6 and A3.7 in the appendix) generally confirm the previously discussed findings. The  $\sigma_o$  and  $\sigma_{\text{FI}}$  values are in the same range as for OSU (around 0.25 to 0.3 pixel) and thus higher than for Echallens and Montserrat. The reason is probably the somewhat lower image quality as judged from visual inspection. In the Kapellen data set, this is mainly visible in the right part of the scene. As for München, besides the fact that no image coordinates for the fiducials were available, it must also be kept in mind that due to the high buildings in the scene and the large scale of the images perspective deformations leading to less accurate matching play a much greater role than for the other data sets.

### 5.3 Influence of $\sigma_{o, \text{a priori}}$ onto the results

As mentioned in section 4.2 one of the input parameters for the robust bundle adjustment is an estimate for the accuracy of the image coordinates without blunders termed  $\sigma_{o, \text{a priori}}$ . In the robust adjustment  $\sigma_{o, \text{a priori}}$  is a type of threshold value for blunder elimination, since image coordinates with larger residuals are iteratively weighed down and eventually eliminated until the computed  $\sigma_o$  becomes smaller than  $\sigma_{o, \text{a priori}}$ . Within the test  $\sigma_{o, \text{a priori}}$  was set to 1/3 of a pixel which reflects a reasonable assumption for image matching within automatic aerial triangulation. One of the results mentioned in section 5.2 was, however, that under good conditions the accuracy  $\sigma_o$  of the automatically extracted tie points is in the range of 0.15 to 0.2 pixels, see the correct results for Echallens and Montserrat.

In this section the influence of different values for  $\sigma_{o, \text{a priori}}$  is investigated with help of the Echallens data set for the three participants LHS, Inpho, and CZ. This data set was chosen because the accuracy potential of Echallens seemed to be the highest. The selected participants represent the developers of the commercial AAT systems HATS, Match AT, and Phodis AT. Both, the first and the second analysis step were repeated with three more values for  $\sigma_{o, \text{a priori}}$ : 0.2, 0.1 and 0.05 pixels. Although at least the last value is most probably an unrealistically small estimate for  $\sigma_o$ , the limitations of the automatic systems could thus be investigated. The results are presented in the tables 8 and 9. The following observations can be made:

- As  $\sigma_{o, \text{a priori}}$  decreases the average number of tie points per image decreases as well.
- At the same time the number and percentage of blunders increases. At the limit of  $\sigma_{o, \text{a priori}} = 0.05$  pixels the values for HATS, Match AT and Phodis AT are 52 %, 47 %, and 61 %, respectively. An additional investigation demonstrated that the residuals of the remaining observations did not show a normal distribution. These findings are obviously an indication that the adjustment results have to be treated with great care.
- As  $\sigma_{o, \text{a priori}}$  decreases the number of multi ray points also decreases. In particular connections between the strips are more and more eliminated, leading to geometrically more unstable and less reliable blocks.

Participant / System	$\sigma_{0,a \text{ priori}}$ [pel]	av. no. of correct tie pts. per image	elim. blunders		no. of multi ray points in object					
			no	%	total	2 ray pts.	3 ray pts.	4 ray pts.	5 ray pts.	6 ray pts.
LHS / HATS	0.33	59	86	14	195	99	63	21	5	7
	0.2	56	113	18	190	100	62	19	5	4
	0.1	43	236	38	163	111	43	8	1	0
	0.05	33	322	52	136	109	24	3	0	0
Inpho / Match AT	0.33	182	0	0	496	180	123	115	11	67
	0.2	182	0	0	496	180	123	115	11	67
	0.1	146	330	20	432	182	119	77	37	17
	0.05	97	766	47	352	221	95	28	7	1
CZ / Phodis AT	0.33	250	179	7	906	538	318	35	10	5
	0.2	233	329	14	858	535	280	30	8	5
	0.1	190	715	29	733	524	183	17	5	4
	0.05	106	1471	61	456	413	40	3	0	0

Table 8: Results for the test data set Echallens, blunder elimination and multi ray points different  $\sigma_{0,a \text{ priori}}$ , 1 pixel = 20  $\mu\text{m}$

- The  $\sigma_0$  values decrease according to the required threshold given by  $\sigma_{0,a \text{ priori}}$ . Whether the reported values realistically reflect the measurement accuracy of the tie points is not clear without use of the independent reference measurements.
- For HATS and Phodis AT  $\sigma_{FI}$  decreases slightly when going from  $\sigma_{0,a \text{ priori}} = 0.33$  pixel to 0.2 pixel. This is an indication that in the standard test analysis (section 5.1 and 5.2) some undetected blunders are still present in the results of the participants. For Match AT both adjustment runs yield identical results, since no blunders are detected in either one.
- When further decreasing  $\sigma_{0,a \text{ priori}}$   $\sigma_{FI}$  remains more or less constant. Due to the limited accuracy of the reference measurements  $\sigma_{FI}$  cannot become smaller. However, the value does not increase either. Thus, even for  $\sigma_{0,a \text{ priori}} = 0.05$  pixel the resulting blocks are not heavily deformed.
- For  $\sigma_{0,a \text{ priori}} = 0.1$  and 0.05 pixel the RMS(Z) value of HATS and Phodis AT starts to rise indicating block deformations in height. The same is true for the Match AT result for  $\sigma_{0,a \text{ priori}} = 0.05$  pixel. The MATCH AT results for  $\sigma_{0,a \text{ priori}} = 0.1$  pixel are still acceptable, therefore it can be concluded that the obtained value of 2.2  $\mu\text{m}$  for  $\sigma_0$  is a realistic figure.

In summary, under optimal condition as found in the data set Echallens a realistic value for the accuracy of the image coordinates of the tie points  $\sigma_0$  for HATS and Phodis AT is about 0.2 pixel in image space, whereas Match AT can reach about 0.1 pixel. This result is in agreement with theory predicting that simultaneous multiple image matching as used in Match AT yields the most accurate results (see e.g. Schenk 1997).

Thus, the results for  $\sigma_0$  reported in section 5.2 are generally confirmed and even show some room for improvement. A proper selection of the threshold value  $\sigma_{0,a \text{ priori}}$  for the

Participant / System	$\sigma_{0,a \text{ priori}}$ [pel]	$\sigma_0$		$\sigma_{FI}$	RMS values		
		[pel]	[ $\mu\text{m}$ ]	[ $\mu\text{m}$ ]	X [cm]	Y [cm]	Z [cm]
LHS / HATS	0.33	0.21	4.2	4.5	3.1	3.6	9.5
	0.2	0.17	3.3	4.0	3.8	3.6	6.7
	0.1	0.09	1.8	4.2	3.1	3.1	13.6
	0.05	0.07	1.3	4.3	2.7	2.7	14.3
Inpho / Match AT	0.33	0.17	3.3	3.7	2.5	2.4	4.7
	0.2	0.17	3.3	3.7	2.5	2.4	4.7
	0.1	0.11	2.2	3.9	2.8	2.6	6.4
	0.05	0.07	1.3	4.0	2.8	2.7	7.8
CZ / Phodis AT	0.33	0.20	4.0	4.5	4.0	4.2	11.3
	0.2	0.15	2.9	4.4	4.1	4.5	8.0
	0.1	0.10	2.0	4.9	5.1	5.5	11.3
	0.05	0.05	0.9	5.1	4.6	5.2	12.8

Table 9: Results for the test data set Echallens, accuracy figures different  $\sigma_{0,a \text{ priori}}$ , 1 pixel = 20  $\mu\text{m}$   
(the obtained values have to be compared to the reference results:  
 $\sigma_{0,\text{ref}} = 3.2 \mu\text{m}$ ,  $\sigma_X = 2.4 \text{ cm}$ ,  $\sigma_Y = 2.6 \text{ cm}$ ,  $\sigma_Z = 4.9 \text{ cm}$ )

robust bundle adjustment was found to be necessary. In case the chosen value is too large some blunders can remain undetected, in case it is chosen too small good measurements are eliminated. In both cases block deformations can be the undesired result.

## 6 Conclusions

Compared to the test goals (see section 2) the following conclusions can be drawn (it should be emphasised again, that point extraction is considered to be a totally **autonomous** process within AAT):

- A good **geometric block stability** can be guaranteed, if and only if a sufficiently large number of tie points (say 100 to 300 per image) is extracted. The reason is that local matching procedures, as they are employed in the tested systems in order to achieve an acceptable level of accuracy, are subject to blunders, and these blunders can only be reliably eliminated if their percentage is relatively small. If too few points are extracted the resulting block can be heavily deformed. Within the test this problem occurred mainly for results generated with HATS. As mentioned before, HATS calls upon the operator if points are missing or need to be remeasured, but this feature was deliberately not used in the test.
- Especially in larger blocks the geometric stability also depends on the number and distribution of the available GCP and/or the quality of the direct measurements for the orientation parameters from GPS and/or INS. Such information can lead to a somewhat reduced number of necessary tie points per image. As mentioned before, however, no such effects were investigated within the test.

- The high redundancy in the adjustment leads to a smaller theoretical standard deviation and an improved reliability for the exterior orientation parameters as compared to analytical photogrammetry. These parameters, of course, must be regarded as the prime result of AAT.
- While the significance of a large number of multi ray points is not as high as in analytical photogrammetry neglecting this aspect too much can also lead to severe block deformations. In the test all commercial systems generated enough multi ray points, but it seems safe to predict that more emphasis should be concentrated on this point.
- Under favourable conditions (open and flat terrain, good texture; see Echallens) the **accuracy of the tie point coordinates** as expressed by  $\sigma_0$  can reach 0.15–0.2 pixels or 3–4  $\mu\text{m}$  using only natural tie points if least squares matching is employed for coordinate refinement. In one of the projects Match AT has even achieved 0.11 pixel or 2.2  $\mu\text{m}$ . In analytical photogrammetry a comparable accuracy has only been achieved using signalised points.
- Taking all test results into account a realistic value for  $\sigma_0$  lies in the range of 0.2–0.3 pixels or 4–9  $\mu\text{m}$  (again with only natural tie points and least squares matching), at least when the images were scanned with a pixel size of 20–30  $\mu\text{m}$ . The values are rather similar across the different systems. Since most systems use least square matching in the final coordinate measurement this result seems plausible. In this test the effect of pixel size was not separately investigated. Experience and the literature (e.g. Ackermann, Krzystek 1997) suggest that pixel sizes smaller than about 20  $\mu\text{m}$  will not increase the accuracy of the tie points accordingly.
- **Limitations of existing systems** showed up in the Montserrat example which contains mountainous and forested terrain. Some participants failed to produce correct and accurate results. The strip connection seems to be the weak point.
- Failure to produce an acceptable result is not indicated by the systems (with the partial exception of HATS, see above), because internal self control is not sufficiently accounted for. Elements of self control are the individual matching results, the distribution of the tie points and the number of multi ray points within the block, the measurement accuracy, and the covariance matrix of the unknowns. As was shown in a number of cases the  $\sigma_0$  of the block adjustment is by itself not a valid indicator of errors or deformations within the block. The adjustment theory developed for analytical photogrammetry including measures for reliability and blunder detection and elimination seems to be the proper starting point for the necessary improvements.
- Due to the large amount of required observations (see above) the self control mechanism should be automatic.
- A minimum requirement for assessing the quality of the results is a graphical output similar to the plots presented in figures 9 to 17. In larger blocks one should be able to roam through the whole block and zoom in and out in such graphical representations of the results, possibly even with the images as back drops.
- It is interesting that both success and failure occurred partly within one and the same system. This suggests that an extensive amount of experience in handling the software is necessary in order to appropriately tune any available free parameters.

Taking also the results into account which due to gross errors are not contained in the presented tables this experience seems to be especially necessary for using Match AT and for HATS. If the number of free parameters cannot be significantly reduced additional effort should be focused on training of the AAT operators.

As already mentioned in the introduction, not all topics related to a complete system analysis were investigated within this test. For instance, issues related to an economical use (e.g. the time and cost needed for preparation, computation, and post processing) have not been considered. Furthermore, the behaviour of AAT systems for larger and non-regular blocks, and the influence of control information were not investigated. From the results obtained, it can be concluded that the current AAT systems after only a few years of market presence, show a remarkable level of performance. A number of details, however, need further refinement. In summary, it can be predicted, that in a production environment fully autonomous tie point extraction while feasible in many cases, will be followed by a verification and editing stage carried out by a human operator. Software development should be concentrated on creating more reliable self control mechanisms and on designing user friendly interfaces for an efficient verification and editing of the AAT results including a stereo measurement capability for high accuracy requirements. Further work is needed to create proper quality specifications for the results of automatic aerial triangulation, especially for the parameters of exterior orientation.

### Acknowledgements

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## Appendix 1

### A1: Detailed information on test data sets

Block name:	Echallens
average scale:	1 : 5000
average end overlap:	60%
average side overlap:	30%
flight datum:	Sept-2-1992
camera:	Wild RC 10
film:	panchromatic
average flying height above ground:	850 m
average terrain height:	600 m

### Exterior orientation - initial values

Image	X[m]	Y[m]	Z[m]	Phi[gon]	Omega[gon]	Kappa[gon]
806	537150.0	167500.0	1450.0	0.0	0.0	370.0
807	537550.0	167350.0	1450.0	0.0	0.0	370.0
808	537950.0	167200.0	1450.0	0.0	0.0	370.0
824	536900.0	166800.0	1450.0	0.0	0.0	370.0
825	537250.0	166650.0	1450.0	0.0	0.0	370.0
826	537650.0	166500.0	1450.0	0.0	0.0	370.0
842	536600.0	166000.0	1450.0	0.0	0.0	370.0
843	536950.0	165850.0	1450.0	0.0	0.0	370.0
844	537300.0	165700.0	1450.0	0.0	0.0	370.0

### Digital data:

Scanner:	DSW 200
Material scanned:	negative
Channel scanned:	(pan)
Scan datum:	Jan-1996
Image format:	raw
Pixelsize:	20.0 mue

Image file	No. of rows	No. of columns
806_20.raw	12346	12270
807_20.raw	11270	11442
808_20.raw	11266	11198
824_20.raw	11295	11280
825_20.raw	11295	11280
826_20.raw	11295	11280
842_20.raw	11418	11134
843_20.raw	11418	11134
844_20.raw	11418	11134

Table A1.1: Detailed information for data set Echallens

Block name:	Montserrat
average scale:	1 : 15000
average end overlap:	60%
average side overlap:	30%
flight datum:	May-6/7-1995
camera:	Zeiss RMK TOP
film:	panchromatic
average flying height above ground:	2350 m
average terrain height:	150 m

#### Exterior orientation - initial values

Image	X[m]	Y[m]	Z[m]	Phi[gon]	Omega[gon]	Kappa[gon]
119	408700.0	4603100.0	2500.0	0.0	0.0	200.0
120	407400.0	4603100.0	2500.0	0.0	0.0	200.0
121	406100.0	4603100.0	2500.0	0.0	0.0	200.0
132	406100.0	4600800.0	2500.0	0.0	0.0	0.0
133	407400.0	4600800.0	2500.0	0.0	0.0	0.0
134	408700.0	4600800.0	2500.0	0.0	0.0	0.0
210	406100.0	4598500.0	2500.0	0.0	0.0	0.0
211	407400.0	4598500.0	2500.0	0.0	0.0	0.0
212	408700.0	4598500.0	2500.0	0.0	0.0	0.0

#### Digital data:

Scanner:	PS1
Material scanned:	negative (density: neg-pos transformation during scanning)
Channel scanned:	(pan)
Scan datum:	Nov-15-1996
Image format:	raw
Pixelsize:	30.0 mue

Image file	No. of rows	No. of columns
119_30.raw	7936	7936
120_30.raw	7936	7936
121_30.raw	7936	7936
132_30.raw	7936	7936
133_30.raw	7936	7936
134_30.raw	7936	7936
210_30.raw	7936	7936
211_30.raw	7936	7936
212_30.raw	7936	7936

Table A1.2: Detailed information for data set Montserrat

Block name:	OSU
average scale:	1 : 4000
average end overlap:	60%
average side overlap:	60%
flight datum:	Sept.-19-1995
camera:	Wild RC 10
film:	false colour infrared
average flying height above ground:	600 m
average terrain height:	250 m

#### Exterior orientation - initial values

Image	X[m]	Y[m]	Z[m]	Phi[gon]	Omega[gon]	Kappa[gon]
8924	556100.0	222000.0	850.0	0.0	0.0	0.0
8925	555800.0	222000.0	850.0	0.0	0.0	0.0
8926	555400.0	222000.0	850.0	0.0	0.0	0.0
8930	556100.0	222200.0	850.0	0.0	0.0	0.0
8931	555800.0	222200.0	850.0	0.0	0.0	0.0
8932	555400.0	222200.0	850.0	0.0	0.0	0.0
8937	556100.0	222500.0	850.0	0.0	0.0	0.0
8938	555800.0	222500.0	850.0	0.0	0.0	0.0
8939	555400.0	222500.0	850.0	0.0	0.0	0.0

#### Digital data:

Scanner:	DSW200
Material scanned:	positive
Channel scanned:	red (corresponds to IR information)
Scan datum:	Oct-1995
Image format:	raw
Pixelsize:	25.0 mue

Image file	No. of rows	No. of columns
8924_25.raw	9152	9280
8925_25.raw	9216	9216
8926_25.raw	9216	9216
8930_25.raw	9152	9280
8931_25.raw	9152	9280
8932_25.raw	9152	9280
8937_25.raw	9216	9216
8938_25.raw	9216	9216
8939_25.raw	9216	9216

Table A1.3: Detailed information for data set OSU

Block name:	Kapellen
average scale:	1 : 4000
average end overlap:	60%
average side overlap:	60%
flight datum:	April-6-1992
camera:	Zeiss RMK A
film:	panchromatic
average flying height above ground:	600 m
average terrain height:	30 m

Exterior orientation - initial values

Image	X[m]	Y[m]	Z[m]	Phi[gon]	Omega[gon]	Kappa[gon]
50	2541300.0	5698500.0	630.0	0.0	0.0	140.0
51	2541150.0	5698800.0	630.0	0.0	0.0	140.0
52	2541000.0	5699100.0	630.0	0.0	0.0	140.0
57	2541200.0	5699250.0	630.0	0.0	0.0	340.0
58	2541350.0	5698950.0	630.0	0.0	0.0	340.0
59	2541550.0	5698650.0	630.0	0.0	0.0	340.0

Digital data:

Scanner:	Wehrli RM1
Material scanned:	negative
Channel scanned:	(pan)
Scan datum:	Jun-1996
Image format:	raw
Pixelsize:	24.0 mue

Image file	No. of rows	No. of columns
50_24.raw	9728	9728
51_24.raw	9728	9728
52_24.raw	9728	9728
57_24.raw	9728	9728
58_24.raw	9728	9728
59_24.raw	9728	9728

Table A1.4: Detailed information for data set Kapellen

Block name:	Muenchen
average scale:	1 : 2000
average end overlap:	60%
flight datum:	May-1975
camera:	Zeiss RMK A
film:	colour
average flying height above ground:	650 m
average terrain height:	550 m

#### Exterior orientation - initial values

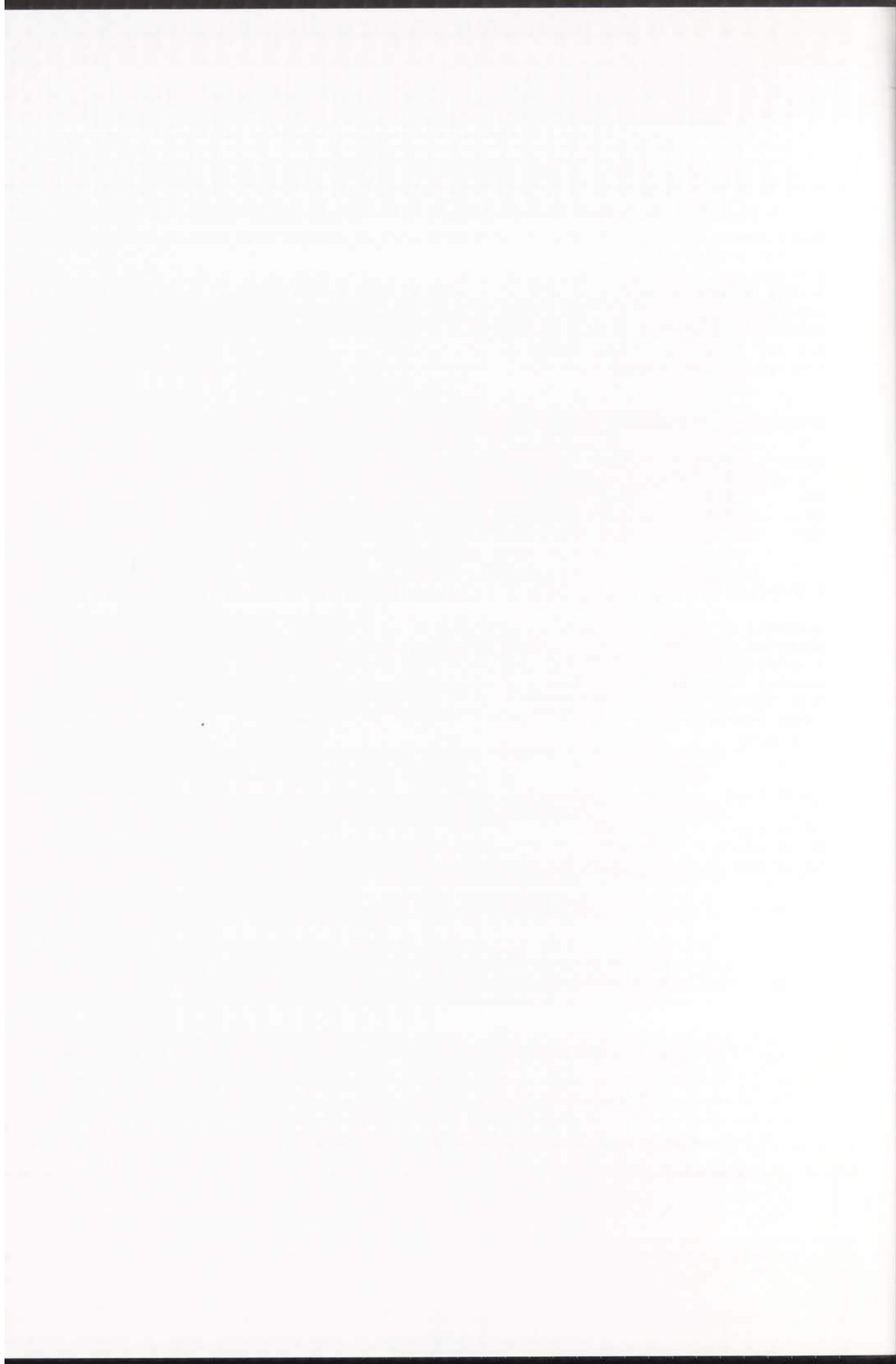
Image	X[m]	Y[m]	Z[m]	Phi[gon]	Omega[gon]	Kappa[gon]
55	0.0	0.0	1200.0	0.0	0.0	0.0
56	175.0	0.0	1200.0	0.0	0.0	0.0
57	350.0	0.0	1200.0	0.0	0.0	0.0

#### Digital data:

Scanner:	PS1
Material scanned:	positive
(transmissivity)	
Channel scanned:	red
Scan datum:	Dec-12-1996
Image format:	raw
Pixelsize:	30.0 mue

Image file	No. of rows	No. of columns
56_30.raw	8000	8000
57_30.raw	8000	8000
58_30.raw	8000	8000

Table A1.5: Detailed information for data set München



A2: Results for blunder detection and multi ray points

Participant	System	av. no. of correct tie pts. per image	elim. blunders		no. of multi ray points in object					
			no	%	total	2 ray pts.	3 ray pts.	4 ray pts.	5 ray pts.	6 ray pts.
LHS	HATS	59	86	14	195	99	63	21	5	7
BKG		14	24	16	48	31	6	7	2	2
EPFL		25	65	22	88	57	16	11	2	2
NLS-SWE		26	15	6	93	63	17	6	4	3
UNSW		12	6	5	41	22	9	8	1	1
SWPH	HATS*	73	0	0	235	128	55	33	4	15
Inpho	Match AT	182	0	0	496	180	123	115	11	67
I-graph		98	0	0	327	194	70	44	0	19
CZ	Phodis AT	250	179	7	906	538	318	35	10	5
B-LVA		245	208	9	895	549	293	42	6	5
LGN		275	234	9	988	555	381	41	7	4
FGI	research systems	379	0	0	1433	1097	175	133	6	22
TUM		468	46	1	1591	839	534	163	43	12
DIAR		115	200	16	479	404	70	4	1	0

Table A2.1: Results for the test data set Echallens, blunder elimination and multi ray points

Participant	System	av. no. of correct tie pts. per image	elim. blunders		no. of multi ray points in object					
			no	%	total	2 ray pts.	3 ray pts.	4 ray pts.	5 ray pts.	6 ray pts.
LHS	HATS	62	43	7	209	125	44	26	8	6
BKG		18	10	6	66	48	9	5	3	1
EPFL		49	60	12	168	103	36	19	6	4
NLS-SF		17	21	12	60	36	16	6	1	1
NLS-SWE		22	23	10	81	56	16	6	2	1
UNSW		10	18	17	32	17	8	4	2	1
SWPH	HATS*	69	0	0	243	165	40	26	2	10
Inpho	Match AT	184	0	0	574	265	182	82	13	32
I-graph		148	0	0	508	286	154	49	11	8
CGR		160	0	0	550	334	138	54	2	22
HL		102	0	0	337	182	89	51	5	10
Ph GmbH		98	0	0	352	227	76	41	5	3
CZ	Phodis AT	358	371	10	1315	824	413	56	15	7
B-LVA		330	373	12	1245	841	335	58	7	4
GCM		495	573	11	1969	1523	384	51	7	4
LGN		349	429	12	1307	849	396	52	6	4
FGI	research systems	395	0	0	1506	1112	286	74	26	8
TUM		325	0	0	1005	473	285	148	58	41
DIAR		123	354	24	524	475	39	9	1	0
OUAT		147	0	0	493	285	122	62	0	24

Table A2.2: Results for the test data set Montserrat, blunder elimination and multi ray points

Participant	System	av. no. of correct tie pts. per image	elim. blunders		no. of multi ray points in object								
			no	%	total	2 ray pts.	3 ray pts.	4 ray pts.	5 ray pts.	6 ray pts.	7 ray pts.	8 ray pts.	9 ray pts.
EPFL	HATS	22	28	12	67	34	14	9	3	6	1	0	0
NLS-SWE		19	66	27	61	34	13	6	4	3	0	1	0
UNSW		9	32	28	26	13	5	4	2	1	0	0	1
SWPH	HATS*	61	42	7	184	97	34	29	13	7	2	1	1
Inpho	Match AT	242	126	5	631	234	150	123	38	60	3	6	17
I-graph		121	94	8	398	235	90	42	7	22	0	0	2
CGR		195	176	9	613	324	146	89	17	31	2	1	3
CZ	Phodis AT	247	961	30	906	591	230	70	11	4	0	0	0
B-LVA		247	981	31	909	607	221	63	14	3	0	1	0
GCM		337	1281	30	1319	1021	223	58	11	5	1	0	0
IPI	research systems	351	1169	27	1429	1242	123	31	17	12	2	1	1
TUM		361	127	4	1055	485	262	160	76	46	7	15	4
DIIAR		53	392	45	220	186	31	3	0	0	0	0	0

Table A2.3: Results for the test data set OSU, blunder elimination and multi ray points

Participant	System	av. no. of correct tie pts. per image	elim. blunders		no. of multi ray points in object					
			no	%	total	2 ray pts.	3 ray pts.	4 ray pts.	5 ray pts.	6 ray pts.
LHS	HATS	57	113	25	128	76	26	18	7	1
BKG		13	49	38	33	25	3	4	1	0
NLS-SWE		26	40	20	58	31	17	7	1	2
SWPH	HATS*	56	31	8	120	64	22	29	2	3
Inpho	Match AT	181	0	0	353	148	79	94	11	21
I-graph		113	58	8	251	133	75	33	2	8
CZ		195	467	28	492	345	108	37	2	0
B-LVA	Phodis AT	188	536	32	479	342	105	30	1	1
GCM		236	726	34	632	515	83	30	4	0
IPI		118	483	40	347	331	13	3	0	0
TUM	research systems	493	58	2	1125	613	357	124	21	10

Table A2.4: Results for the test data set Kapellen, blunder elimination and multi ray points

Participant	System	av. no. of correct tie pts. per image	elim. blunders		no. of multi ray points in object		
			no	%	total	2 ray pts.	3 ray pts.
LHS	HATS	45	35	21	63	54	9
BKG		12	8	18	17	15	2
UNSW		8	4	14	11	8	3
SWPH	HATS*	71	0	0	104	99	5
Inpho	Match AT	159	0	0	199	118	81
I-graph		147	0	0	189	126	63
CGR		90	34	11	128	112	16
Ph GmbH	Phodis AT	50	15	9	64	41	23
CZ		202	121	17	274	214	60
B-LVA		493	357	19	712	657	52
GCM	research systems	301	188	17	424	369	55
IPI		323	143	13	483	479	4
TUM		201	11	2	272	213	59
DIIAR		77	164	41	112	103	9

Table A2.5: Results for the test data set München, blunder elimination and multi ray points

A3: Results for accuracy figures

Participant	System	$\sigma_o$		$\sigma_{FI}$	RMS values		
		[pel]	[ $\mu m$ ]	[ $\mu m$ ]	X [cm]	Y [cm]	Z [cm]
LHS	HATS	0.21	4.2	4.5	3.1	3.6	9.5
BKG		0.14	2.7	8.1	8.7	6.1	22.8
EPFL		0.18	3.6	4.8	3.3	3.9	12.0
NLS-SWE		0.18	3.5	6.0	3.0	5.0	8.7
UNSW		0.15	3.0	5.5	4.2	6.9	5.5
SWPH	HATS*	0.17	3.4	3.6	2.2	2.6	4.0
Inpho	Match AT	0.17	3.3	3.7	2.5	2.4	4.7
I-graph		0.18	3.6	4.5	3.0	3.4	16.8
CZ	Phodis AT	0.20	4.0	4.5	4.0	4.2	11.3
B-LVA		0.18	3.5	4.4	4.3	4.7	6.9
LGN		0.17	3.4	4.4	4.5	4.8	7.0
FGI	research systems	0.17	3.4	4.4	3.1	3.0	8.5
TUM		0.33	6.6	4.1	3.1	3.4	3.6
DIIAR		0.28	5.6	6.2	5.0	4.3	7.1

Table A3.1: Results for the test data set Echallens, accuracy figures  
 (the obtained values have to be compared to the reference results:  
 $\sigma_{o,ref} = 3.2 \mu m$ ,  $\sigma_X = 2.4 \text{ cm}$ ,  $\sigma_Y = 2.6 \text{ cm}$ ,  $\sigma_Z = 4.9 \text{ cm}$ )

Participant	System	$\sigma_o$		$\sigma_{FI}$	RMS values		
		[pel]	[ $\mu m$ ]	[ $\mu m$ ]	X [cm]	Y [cm]	Z [cm]
LHS	HATS	0.19	5.8	4.9	8.9	8.5	12.5
BKG		0.10	3.1	9.7	10.6	7.8	35.8
EPFL		0.20	6.0	13.4	17.4	14.8	42.2
NLS-SF		0.22	6.5	12.2	15.5	17.5	40.4
NLS-SWE		0.25	7.4	18.3	50.0	41.8	42.9
UNSW		0.14	4.3	17.6	28.6	32.5	66.9
SWPH	HATS*	0.21	6.4	5.4	7.8	8.6	55.7
Inpho	Match AT	0.11	3.3	11.4	13.9	10.1	17.9
I-graph		0.20	6.0	7.2	14.3	10.0	30.4
CGR		0.14	4.3	5.9	6.5	7.3	15.0
HL		0.15	4.6	10.6	17.7	11.9	16.2
Ph GmbH	Phodis AT	0.17	5.2	6.3	9.4	10.0	50.6
CZ		0.22	6.7	6.4	19.6	13.7	14.1
B-LVA		0.21	6.2	5.0	7.7	8.8	16.7
GCM		0.19	5.7	5.2	9.5	9.9	12.5
LGN		0.20	5.9	4.4	5.1	5.3	15.6
FGI	Research systems	0.18	5.4	5.5	8.0	5.6	32.5
TUM		0.32	9.6	4.5	7.0	6.1	9.2
DIIAR		0.25	7.4	20.1	28.3	23.2	65.5
OUAT		0.25	7.4	13.6	24.0	15.9	29.9

Table A3.2: Results for the test data set Montserrat, accuracy figures  
 (the obtained values have to be compared to the reference results:  
 $\sigma_{o,ref} = 3.4 \mu m$ ,  $\sigma_X = 5.2 \text{ cm}$ ,  $\sigma_Y = 5.4 \text{ cm}$ ,  $\sigma_Z = 10.3 \text{ cm}$ )

Participant	System	whole block			strip 1			strip 2 + 3		
		$\sigma_0$		$\sigma_{FI}$	$\sigma_0$		$\sigma_{FI}$	$\sigma_0$		$\sigma_{FI}$
		[pel]	[ $\mu m$ ]	[ $\mu m$ ]	[pel]	[ $\mu m$ ]	[ $\mu m$ ]	[pel]	[ $\mu m$ ]	[ $\mu m$ ]
LHS	HATS	0.19	5.8	4.9	0.17	3.6	5.2	0.13	5.8	3.8
BKG		0.10	3.1	9.7	0.20	6.1	6.3	0.11	3.3	5.4
EPFL		0.20	6.0	13.4	0.16	4.8	4.5	0.19	5.6	4.5
NLS-SF		0.22	6.5	12.2	0.18	5.4	5.1	0.17	5.0	9.2
NLS-SWE		0.25	7.4	18.3	-	-	-	0.24	7.2	14.4
UNSW		0.14	4.3	17.6	0.25	7.5	7.1	0.16	4.8	13.0
SWPH	HATS*	0.21	6.4	5.4	0.15	4.4	4.6	0.20	6.0	3.9
Inpho	Match AT	0.11	3.3	11.4	0.10	3.1	4.8	0.11	3.2	4.2
I-graph		0.20	6.0	7.2	0.17	5.2	4.6	0.20	6.0	4.8
CGR		0.14	4.3	5.9	0.15	4.6	4.5	0.11	3.9	3.3
HL		0.15	4.6	10.6	0.15	4.5	4.4	0.15	4.4	5.2
Ph GmbH	Phodis AT	0.17	5.2	6.3	0.18	5.3	4.7	0.16	4.7	4.0
CZ		0.22	6.7	6.4	0.18	5.5	4.1	0.18	5.5	4.0
B-LVA		0.21	6.2	5.0	0.13	4.9	3.9	0.23	6.8	4.9
GCM		0.19	5.7	5.2	0.13	5.2	3.9	0.15	6.1	4.6
LGN	research systems	0.20	5.9	4.4	0.13	5.0	3.9	0.15	6.4	4.5
FGI		0.18	5.4	5.5	0.20	3.9	5.9	0.17	5.5	5.1
TUM		0.32	9.6	4.5	0.28	8.3	4.4	0.33	9.8	3.8
DIAR		0.25	7.4	20.1	-	-	-	0.25	7.5	7.9
OUAT		0.25	7.4	13.6	0.23	5.8	6.9	0.26	7.7	6.0

Table A3.3: Results for the test data set Montserrat, whole block as compared to strip 1 and strips 2+3 processed separately accuracy of image coordinates

Participant	System	whole block			strip 1			strip 2 + 3		
		RMS			RMS			RMS		
		X [cm]	Y [cm]	Z [cm]	X [cm]	Y [cm]	Z [cm]	X [cm]	Y [cm]	Z [cm]
LHS	HATS	8.9	8.5	12.5	3.5	5.7	8.9	5.9	7.4	12.3
BKG		10.6	7.8	35.8	7.2	10.5	10.2	6.1	8.6	17.9
EPFL		17.4	14.8	42.2	4.1	7.1	7.8	6.2	6.9	13.7
NLS-SF		15.5	17.5	40.4	9.0	11.1	12.0	9.6	10.9	33.7
NLS-SWE		50.0	41.8	42.9	-	-	-	36.5	31.4	41.0
UNSW		28.6	32.5	66.9	14.0	13.0	15.6	20.7	23.7	39.3
SWPH	HATS*	7.8	8.6	55.7	4.2	5.6	9.6	4.9	6.5	13.3
Inpho	Match AT	13.9	10.1	17.9	3.5	4.6	6.9	5.3	7.5	9.1
I-graph		14.3	10.0	30.4	3.9	5.2	8.7	11.3	12.8	9.4
CGR		6.5	7.3	15.0	4.3	6.8	9.0	6.8	8.9	13.7
HL		17.7	11.9	16.2	5.1	8.3	10.8	10.4	12.8	9.8
Ph GmbH	Phodis AT	9.4	10.0	50.6	9.3	11.6	8.8	4.4	8.8	10.7
CZ		19.6	13.7	14.1	3.9	6.2	7.4	7.9	8.7	16.0
B-LVA		7.7	8.8	16.7	3.8	5.8	7.6	7.7	8.4	14.7
GCM		9.5	9.9	12.5	3.4	5.0	7.3	6.4	7.6	13.5
LGN	research systems	5.1	5.3	15.6	3.6	5.5	7.3	5.3	7.0	14.5
FGI		8.0	5.6	32.5	6.1	7.8	11.0	6.9	9.1	18.1
TUM		7.0	6.1	9.2	4.0	5.0	7.7	5.0	7.0	11.7
DIAR		28.3	23.2	65.5	-	-	-	9.2	12.8	16.8
OUAT		24.0	15.9	29.9	4.0	7.7	8.4	6.9	8.9	22.7

Table A3.4: Results for the test data set Montserrat, whole block as compared to strip 1 and strips 2+3 processed separately RMS values of object coordinates

Participant	System	$\sigma_o$		$\sigma_{FI}$	RMS values		
		[pel]	[ $\mu m$ ]	[ $\mu m$ ]	X [cm]	Y [cm]	Z [cm]
EPFL	HATS	0.28	7.0	9.3	2.8	3.6	5.5
NLS-SWE		0.27	6.7	10.8	5.1	4.5	9.1
UNSW		0.25	6.2	21.5	12.8	17.0	18.9
SWPH	HATS*	0.28	6.9	7.6	2.6	3.0	5.2
Inpho	Match AT	0.30	7.6	8.4	2.0	2.3	3.6
I-graph		0.30	7.5	7.2	1.9	2.7	4.5
CGR		0.30	7.4	7.5	1.6	2.2	5.4
CZ	Phodis AT	0.33	8.2	8.2	2.9	2.9	4.5
B-LVA		0.31	7.7	7.6	3.7	3.8	3.5
GCM		0.31	7.7	8.8	2.8	3.4	4.3
IPI	research systems	0.28	7.1	8.1	2.9	3.0	4.4
TUM		0.37	9.3	9.7	3.2	4.6	6.1
DIIAR		0.33	8.3	22.7	6.3	6.9	21.4

Table A3.5: Results for the test data set OSU, accuracy figures  
(the obtained values have to be compared to the reference results:  
 $\sigma_{o,ref} = 4.8 \mu m$ ,  $\sigma_X = 1.7 \text{ cm}$ ,  $\sigma_Y = 2.2 \text{ cm}$ ,  $\sigma_Z = 3.8 \text{ cm}$ )

Participant	System	$\sigma_o$		$\sigma_{FI}$	RMS values		
		[pel]	[ $\mu m$ ]	[ $\mu m$ ]	X [cm]	Y [cm]	Z [cm]
LHS	HATS	0.29	7.0	8.7	2.5	3.4	4.6
BKG		0.23	5.5	27.4	11.3	10.4	20.3
NLS-SWE		0.25	6.1	12.4	4.9	3.0	6.1
SWPH	HATS*	0.25	6.0	8.1	2.7	3.4	5.9
Inpho	Match AT	0.33	7.8	8.0	2.1	1.8	5.0
I-graph		0.30	7.2	7.7	2.2	1.9	3.5
CZ	Phodis AT	0.36	8.3	9.7	2.9	3.4	5.9
B-LVA		0.31	7.5	9.4	2.1	2.5	6.4
GCM		0.29	7.0	8.4	2.1	1.9	3.7
IPI	research systems	0.28	6.7	12.6	8.5	4.3	8.0
TUM		0.36	8.7	9.4	1.4	2.6	3.7

Table A3.6: Results for the test data set Kapellen, accuracy figures  
(the obtained values have to be compared to the reference results:  
 $\sigma_{o,ref} = 6.1 \mu m$ ,  $\sigma_X = 2.7 \text{ cm}$ ,  $\sigma_Y = 2.2 \text{ cm}$ ,  $\sigma_Z = 4.3 \text{ cm}$ )

Participant	System	$\sigma_o$		$\sigma_{FI}$	RMS values		
		[pel]	[ $\mu m$ ]	[ $\mu m$ ]	X [cm]	Y [cm]	Z [cm]
LHS	HATS	0.23	7.0	8.6	1.1	1.1	4.2
BKG		0.16	4.8	24.9	6.7	6.7	9.9
UNSW		0.22	6.5	28.9	8.2	10.2	21.4
SWPH	HATS*	0.28	8.4	7.6	1.0	1.4	3.3
Inpho	Match AT	0.26	7.9	7.0	1.3	1.7	3.8
I-graph		0.28	8.3	8.1	1.1	1.3	4.2
CGR		0.22	6.6	8.2	0.8	1.0	2.8
Ph GmbH		0.24	7.3	8.3	1.7	1.9	3.9
CZ	Phodis AT	0.27	8.1	6.7	0.8	1.1	3.8
B-LVA		0.25	7.6	8.3	1.4	1.5	4.5
GCM		0.25	7.5	9.2	1.4	1.3	4.5
IPI	research systems	0.32	9.6	8.5	1.3	1.5	4.2
TUM		0.33	9.8	7.5	0.9	1.1	2.9
DIIAR		0.26	7.7	28.4	4.1	5.8	15.2

Table A3.5: Results for the test data set OSU, accuracy figures  
(the obtained values have to be compared to the reference results:  
 $\sigma_{o,ref} = 4.8 \mu m$ ,  $\sigma_X = 1.7 \text{ cm}$ ,  $\sigma_Y = 2.2 \text{ cm}$ ,  $\sigma_Z = 3.8 \text{ cm}$ )



## LIST OF THE OEEPE PUBLICATIONS

State – March 1997

### A. Official publications

- 1 *Trombetti, C.*: „Activité de la Commission A de l'OEEPE de 1960 à 1964“ – *Cunietti, M.*: „Activité de la Commission B de l'OEEPE pendant la période septembre 1960 – janvier 1964“ – *Förstner, R.*: „Rapport sur les travaux et les résultats de la Commission C de l'OEEPE (1960–1964)“ – *Neumaier, K.*: „Rapport de la Commission E pour Lisbonne“ – *Weele, A. J. v. d.*: „Report of Commission F.“ – Frankfurt a. M. 1964, 50 pages with 7 tables and 9 annexes.
- 2 *Neumaier, K.*: „Essais d'interprétation de »Bedford« et de »Waterbury«. Rapport commun établi par les Centres de la Commission E de l'OEEPE ayant participé aux tests“ – „The Interpretation Tests of »Bedford« and »Waterbury«. Common Report Established by all Participating Centres of Commission E of OEEPE“ – „Essais de restitution »Bloc Suisse«. Rapport commun établi par les Centres de la Commission E de l'OEEPE ayant participé aux tests“ – „Test »Schweizer Block«. Joint Report of all Centres of Commission E of OEEPE.“ – Frankfurt a. M. 1966, 60 pages with 44 annexes.
- 3 *Cunietti, M.*: „Emploi des blocs de bandes pour la cartographie à grande échelle – Résultats des recherches expérimentales organisées par la Commission B de l'O.E.E.P.E. au cours de la période 1959–1966“ – „Use of Strips Connected to Blocks for Large Scale Mapping – Results of Experimental Research Organized by Commission B of the O.E.E.P.E. from 1959 through 1966.“ – Frankfurt a. M. 1968, 157 pages with 50 figures and 24 tables.
- 4 *Förstner, R.*: „Sur la précision de mesures photogrammétriques de coordonnées en terrain montagneux. Rapport sur les résultats de l'essai de Reichenbach de la Commission C de l'OEEPE“ – „The Accuracy of Photogrammetric Co-ordinate Measurements in Mountainous Terrain. Report on the Results of the Reichenbach Test Commission C of the OEEPE.“ – Frankfurt a. M. 1968, Part I: 145 pages with 9 figures; Part II: 23 pages with 65 tables.
- 5 *Trombetti, C.*: „Les recherches expérimentales exécutées sur de longues bandes par la Commission A de l'OEEPE.“ – Frankfurt a. M. 1972, 41 pages with 1 figure, 2 tables, 96 annexes and 19 plates.
- 6 *Neumaier, K.*: „Essai d'interprétation. Rapports des Centres de la Commission E de l'OEEPE.“ – Frankfurt a. M. 1972, 38 pages with 12 tables and 5 annexes.
- 7 *Wiser, P.*: „Etude expérimentale de l'aérotiangulation semi-analytique. Rapport sur l'essai »Gramastetten«.“ – Frankfurt a. M. 1972, 36 pages with 6 figures and 8 tables.

- 8 „Proceedings of the OEEPE Symposium on Experimental Research on Accuracy of Aerial Triangulation (Results of Oberschwaben Tests)“

*Ackermann, F.:* „On Statistical Investigation into the Accuracy of Aerial Triangulation. The Test Project Oberschwaben“ – „Recherches statistiques sur la précision de l'aérottriangulation. Le champ d'essai Oberschwaben“ – *Belzner, H.:* „The Planning. Establishing and Flying of the Test Field Oberschwaben“ – *Stark, E.:* Testblock Oberschwaben, Programme I. Results of Strip Adjustments“ – *Ackermann, F.:* „Testblock Oberschwaben, Program I. Results of Block Adjustment by Independent Models“ – *Ebner, H.:* Comparison of Different Methods of Block Adjustment“ – *Wiser, P.:* „Propositions pour le traitement des erreurs non-accidentelles“ – *Camps, F.:* „Résultats obtenus dans le cadre du project Oberschwaben 2A“ – *Cunietti, M.; Vanossi, A.:* „Etude statistique expérimentale des erreurs d'enchaînement des photogrammes“ – *Kupfer, G.:* „Image Geometry as Obtained from Rheidt Test Area Photography“ – *Förstner, R.:* „The Signal-Field of Baustetten. A Short Report“ – *Visser, J.; Leberl, F.; Kure, J.:* „OEEPE Oberschwaben Réseau Investigations“ – *Bauer, H.:* „Compensation of Systematic Errors by Analytical Block Adjustment with Common Image Deformation Parameters.“ – Frankfurt a. M. 1973, 350 pages with 119 figures, 68 tables and 1 annex.

- 9 *Beck, W.:* „The Production of Topographic Maps at 1 : 10,000 by Photogrammetric Methods. – With statistical evaluations, reproductions, style sheet and sample fragments by Landesvermessungsamt Baden-Württemberg Stuttgart.“ – Frankfurt a. M. 1976, 89 pages with 10 figures, 20 tables and 20 annexes.

- 10 „Résultats complémentaires de l'essai d'«Oberriet» of the Commission C de l'OEEPE – Further Results of the Photogrammetric Tests of «Oberriet» of the Commission C of the OEEPE“

*Hárry, H.:* „Mesure de points de terrain non signalisés dans le champ d'essai d'«Oberriet» – Measurements of Non-Signalized Points in the Test Field «Oberriet» (Abstract)“ – *Stickler, A.; Waldhäusl, P.:* „Restitution graphique des points et des lignes non signalisés et leur comparaison avec des résultats de mesures sur le terrain dans le champ d'essai d'«Oberriet» – Graphical Plotting of Non-Signalized Points and Lines, and Comparison with Terrestrial Surveys in the Test Field «Oberriet»“ – *Förstner, R.:* „Résultats complémentaires des transformations de coordonnées de l'essai d'«Oberriet» de la Commission C de l'OEEPE – Further Results from Co-ordinate Transformations of the Test «Oberriet» of Commission C of the OEEPE“ – *Schürer, K.:* „Comparaison des distances d'«Oberriet» – Comparison of Distances of «Oberriet» (Abstract).“ – Frankfurt a. M. 1975, 158 pages with 22 figures and 26 tables.

- 11 „25 années de l'OEEPE“

*Verlaine, R.:* „25 années d'activité de l'OEEPE“ – „25 Years of OEEPE (Summary)“ – *Baarda, W.:* „Mathematical Models.“ – Frankfurt a. M. 1979, 104 pages with 22 figures.

- 12 *Spiess, E.:* „Revision of 1 : 25,000 Topographic Maps by Photogrammetric Methods.“ – Frankfurt a. M. 1985, 228 pages with 102 figures and 30 tables.

- 13 *Timmerman, J.; Roos, P. A.; Schürer, K.; Förstner, R.*: On the Accuracy of Photogrammetric Measurements of Buildings – Report on the Results of the Test “Dordrecht”, Carried out by Commission C of the OEEPE. – Frankfurt a. M. 1982, 144 pages with 14 figures and 36 tables.
- 14 *Thompson C. N.*: Test of Digitising Methods. – Frankfurt a. M. 1984, 120 pages with 38 figures and 18 tables.
- 15 *Jaakkola, M.; Brindöpke, W.; Kölbl, O.; Noukka, P.*: Optimal Emulsions for Large-Scale Mapping – Test of “Steinwedel” – Commission C of the OEEPE 1981–84. – Frankfurt a. M. 1985, 102 pages with 53 figures.
- 16 *Waldhäusl, P.*: Results of the Vienna Test of OEEPE Commission C. – Kölbl, O.: Photogrammetric Versus Terrestrial Town Survey. – Frankfurt a. M. 1986, 57 pages with 16 figures, 10 tables and 7 annexes.
- 17 *Commission E of the OEEPE*: Influences of Reproduction Techniques on the Identification of Topographic Details on Orthophotomaps. – Frankfurt a. M. 1986, 138 pages with 51 figures, 25 tables and 6 appendices.
- 18 *Förstner, W.*: Final Report on the Joint Test on Gross Error Detection of OEEPE and ISP WG III/1. – Frankfurt a. M. 1986, 97 pages with 27 tables and 20 figures.
- 19 *Dowman, I. J.; Ducher, G.*: Spacelab Metric Camera Experiment – Test of Image Accuracy. – Frankfurt a. M. 1987, 112 pages with 13 figures, 25 tables and 7 appendices.
- 20 *Eichhorn, G.*: Summary of Replies to Questionnaire on Land Information Systems – Commission V – Land Information Systems. – Frankfurt a. M. 1988, 129 pages with 49 tables and 1 annex.
- 21 *Kölbl, O.*: Proceedings of the Workshop on Cadastral Renovation – Ecole polytechnique fédérale, Lausanne, 9–11 September, 1987. – Frankfurt a. M. 1988, 337 pages with figures, tables and appendices.
- 22 *Rollin, J.; Dowman, I. J.*: Map Compilation and Revision in Developing Areas – Test of Large Format Camera Imagery. – Frankfurt a. M. 1988, 35 pages with 3 figures, 9 tables and 3 appendices.
- 23 *Drummond, J. (ed.)*: Automatic Digitizing – A Report Submitted by a Working Group of Commission D (Photogrammetry and Cartography). – Frankfurt a. M. 1990, 224 pages with 85 figures, 6 tables and 6 appendices.
- 24 *Ahokas, E.; Jaakkola, J.; Sotkas, P.*: Interpretability of SPOT data for General Mapping. – Frankfurt a. M. 1990, 120 pages with 11 figures, 7 tables and 10 appendices.
- 25 *Ducher, G.*: Test on Orthophoto and Stereo-Orthophoto Accuracy. – Frankfurt a. M. 1991, 227 pages with 16 figures and 44 tables.
- 26 *Dowman, I. J. (ed.)*: Test of Triangulation of SPOT Data – Frankfurt a. M. 1991, 206 pages with 67 figures, 52 tables and 3 appendices.

- 27 *Newby, P. R. T.; Thompson, C. N. (ed.):* Proceedings of the ISPRS and OEEPE Joint Workshop on Updating Digital Data by Photogrammetric Methods. – Frankfurt a. M. 1992, 278 pages with 79 figures, 10 tables and 2 appendices.
- 28 *Koen, L. A.; Kölbl, O. (ed.):* Proceedings of the OEEPE-Workshop on Data Quality in Land Information Systems, Apeldoorn, Netherlands, 4–6 September 1991. – Frankfurt a. M. 1992, 243 pages with 62 figures, 14 tables and 2 appendices.
- 29 *Burman, H.; Torlegård, K.: Empirical Results of GPS – Supported Block Triangulation.* – Frankfurt a. M. 1994, 86 pages with 5 figures, 3 tables and 8 appendices.
- 30 *Gray, S. (ed.):* Updating of Complex Topographic Databases. – Frankfurt a. M. 1995, 133 pages with 2 figures and 12 appendices.
- 31 *Jaakola, J.; Sarjakoski, T.: Experimental Test on Digital Aerial Triangulation.* – Frankfurt a. M. 1996, 155 pages with 24 figures, 7 tables and 2 appendices.
- 32 *Dowman, I.: The OEEPE GEOSAR Test of Geocoding ERS-1 SAR Data.* – Frankfurt a. M. 1996, 126 pages with 5 figures, 2 tables and 2 appendices.
- 33 *Kölbl, O.: Proceedings of the OEEPE-Workshop on Application of Digital Photogrammetric Workstations.* – Frankfurt a. M. 1996, 453 pages with numerous figures and tables.
- 34 *Blau, E.; Boochs, F.; Schulz, B.-S.: Digital Landscape Model for Europe (DLME).* – Frankfurt a. M. 1997, 72 pages with 21 figures, 9 tables, 4 diagrams and 15 appendices

## B. Special publications

### – Special Publications O.E.E.P.E. – Number I

*Solaini, L.; Trombetti, C.*: Relation sur les travaux préliminaires de la Commission A (Triangulation aérienne aux petites et aux moyennes échelles) de l'Organisation Européenne d'Etudes Photogrammétriques Expérimentales (O.E.E.P.E.). 1<sup>ère</sup> Partie: Programme et organisation du travail. – *Solaini, L.; Belfiore, P.*: Travaux préliminaires de la Commission B de l'Organisation Européenne d'Etudes Photogrammétriques Expérimentales (O.E.E.P.E.) (Triangulations aériennes aux grandes échelles). – *Solaini, L.; Trombetti, C.; Belfiore, P.*: Rapport sur les travaux expérimentaux de triangulation aérienne exécutés par l'Organisation Européenne d'Etudes Photogrammétriques Expérimentales (Commission A et B). – *Lehmann, G.*: Compte rendu des travaux de la Commission C de l'O.E.E.P.E. effectués jusqu'à présent. – *Gotthardt, E.*: O.E.E.P.E. Commission C. Compte-rendu de la restitution à la Technischen Hochschule, Stuttgart, des vols d'essai du groupe I du terrain d'Oberriet. – *Brucklacher, W.*: Compte-rendu du centre «Zeiss-Aerotopograph» sur les restitutions pour la Commission C de l'O.E.E.P.E. (Restitution de la bande de vol, groupe I, vol. No. 5). – *Förstner, R.*: O.E.E.P.E. Commission C. Rapport sur la restitution effectuée dans l'Institut für Angewandte Geodäsie, Francfort sur le Main. Terrain d'essai d'Oberriet les vols No. 1 et 3 (groupe I). – I.T.C., Delft: Commission C, O.E.E.P.E. Déroulement chronologique des observations. – *Photogrammetria XII (1955–1956) 3*, Amsterdam 1956, pp. 79–199 with 12 figures and 11 tables.

### – Publications spéciales de L'O.E.E.P.E. – Numéro II

*Solaini, L.; Trombetti, C.*: Relations sur les travaux préliminaires de la Commission A (Triangulation aérienne aux petites et aux moyennes échelles) de l'Organisation Européenne d'Etudes Photogrammétriques Expérimentales (O.E.E.P.E.). 2<sup>e</sup> partie. Prises de vues et points de contrôle. – *Gotthardt, E.*: Rapport sur les premiers résultats de l'essai d'«Oberriet» de la Commission C de l'O.E.E.P.E. – *Photogrammetria XV (1958–1959) 3*, Amsterdam 1959, pp. 77–148 with 15 figures and 12 tables.

- *Trombetti, C.*: Travaux de prises de vues et préparation sur le terrain effectuées dans le 1958 sur le nouveau polygone italien pour la Commission A de l'OEEPE. – Florence 1959, 16 pages with 109 tables.
- *Trombetti, C.; Fondelli, M.*: Aérotiangulation analogique solaire. – Firenze 1961, 111 pages, with 14 figures and 43 tables.

### – Publications spéciales de l'O.E.E.P.E. – Numéro III

*Solaini, L.; Trombetti, C.*: Rapport sur les résultats des travaux d'enchaînement et de compensation exécutés pour la Commission A de l'O.E.E.P.E. jusqu'au mois de Janvier 1960. Tome 1: Tableaux et texte. Tome 2: Atlas. – *Photogrammetria XVII (1960–1961) 4*, Amsterdam 1961, pp. 119–326 with 69 figures and 18 tables.

- „OEEPE – Sonderveröffentlichung Nr. 1“

*Gigas, E.:* „Beitrag zur Geschichte der Europäischen Organisation für photogrammetrische experimentelle Untersuchungen“ – N. N.: „Vereinbarung über die Gründung einer Europäischen Organisation für photogrammetrische experimentelle Untersuchungen“ – „Zusatzprotokoll“ – *Gigas, E.:* „Der Sechserausschuß“ – *Brucklacher, W.:* „Kurzbericht über die Arbeiten in der Kommission A der OEEPE“ – *Cunietti, M.:* „Kurzbericht des Präsidenten der Kommission B über die gegenwärtigen Versuche und Untersuchungen“ – *Förstner, R.:* „Kurzbericht über die Arbeiten in der Kommission B der OEEPE“ – „Kurzbericht über die Arbeiten in der Kommission C der OEEPE“ – *Belzner, H.:* „Kurzbericht über die Arbeiten in der Kommission E der OEEPE“ – *Schwidefsky, K.:* „Kurzbericht über die Arbeiten in der Kommission F der OEEPE“ – *Meier, H.-K.:* „Kurzbericht über die Tätigkeit der Untergruppe „Numerische Verfahren“ in der Kommission F der OEEPE“ – *Belzner, H.:* „Versuchsfelder für internationale Versuchs- und Forschungsarbeiten.“ – Nachr. Kt.- u. Vermess.-wes., R. V, Nr. 2, Frankfurt a. M. 1962, 41 pages with 3 tables and 7 annexes.

- *Rinner, K.:* Analytisch-photogrammetrische Triangulation eines Teststreifens der OEEPE. – Österr. Z. Vermess.-wes., OEEPE-Sonderveröff. Nr. 1, Wien 1992, 31 pages.

- *Neumaier, K.; Kasper, H.:* Untersuchungen zur Aerotriangulation von Überweitwinkelaufnahmen. – Österr. Z. Vermess.-wes., OEEPE-Sonderveröff. Nr. 2, Wien 1965, 4 pages with 4 annexes.

- „OEEPE – Sonderveröffentlichung Nr. 2“

*Gotthardt, E.:* „Erfahrungen mit analytischer Einpassung von Bildstreifen.“ – Nachr. Kt.- u. Vermess.-wes., R. V, Nr. 12, Frankfurt a. M. 1965, 14 pages with 2 figures and 7 tables.

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