Section 2: Capturing Data for CAD Projects#

2.1 Data Acquisition: Precision and Accuracy#

One of the first decisions that must be made by the project director concerns the methods that will be used to capture data into the CAD model. This may involve a combination of field survey and digitisation or off-site data capture, yielding data with different levels of precision, and separate CAD layers or cross-referenced files may be created as the data are incorporated.

A range of different techniques are available to capture data for CAD projects. The most common sources of data for CAD models are:

- annotated lists of measurement points derived from traditional hand measurement survey techniques
- digital data logs derived from total station or GPS survey techniques
- digital data logs produced by direct object scanning e.g. laser scanning
- digitisation of maps, plans and drawings
- digitisation of photographs, including rectification and photogrammetry
- existing CAD models.

The selection of an appropriate technique and methodology will depend on a number of factors. Project planning will involve careful consideration of both the object to be modelled and the type of CAD model to be produced and its uses. For example, a two-dimensional plan or elevation will require fewer data-points to be captured than a three-dimensional wire frame or surface model. A three-dimensional solid model will require even more data-points as both visible and invisible surfaces must be modelled.

Project directors must also consider the appropriate levels of precision and accuracy required for the project, the methods of survey to be used and the availability of maps, plans or photographs for digitisation. Before commencing data capture, project directors are recommended to select an appropriate CAD layer-naming convention (see Section 3.2).

2.1.1 Precision

It is important to consider and document at the project design stage the appropriate level(s) of precision to be used. The **precision** of a measurement refers to how exactly that measurement was made and not the correctness of the measurement. For example, a measurement made to the nearest millimetre is more precise than a measurement made to the nearest centimetre.

The precision of a measurement is reflected in the number of significant (or meaningful) digits with which it is expressed. Thus, a measurement of a block of wood known to be 2.01034 metres long, expressed with two significant digits, is 2.0 metres. If the block was measured with a micrometer precise to a tenth of a millimetre we would show it as being 2.0103m long. If the same block was measured with a steel tape precise to the nearest millimetre the measurement would be 2.010m. The trailing 0 seems to offer no information, but in fact shows that the measurement is precise to the nearest millimetre. A measurement of 2.01m would be accurate to the nearest centimetre. For a detailed discussion about precision and the relationship to significant digits see Eiteljorg 2002b, chapter 2.1.

The high precision offered by modern instruments should be used, as a rule, since data can always be degraded but cannot subsequently be improved in precision. The precision of survey control points is of particular importance, as readings taken from a control point whose coordinates are given to two decimal places can only be given to the same level of precision.

2.1.2 Accuracy

The **accuracy** of a measurement refers to how correctly it was taken and not how precise that measurement is.

A measurement made at a low level of precision should be as accurate but not as precise as a measurement taken with a higher level of precision. Making certain that measurements are accurate should involve both calibration of equipment and repetition (see Appendix 1). Calibration tests the accuracy with which instruments measure while repeatability tests the efficiency of personnel and procedures and project directors should develop schedules for calibrating instruments, training and evaluating personnel and procedures.

To summarise, accuracy relates to the correctness of a result while precision essentially relates to the size of the smallest unit of measurement.

2.1.3 Appropriate Levels of Precision

Different levels of precision are appropriate for different projects, depending on the intended uses for the model produced. Modern survey methods make it easy to obtain very high levels of precision and there may be a temptation to seek the precision that is possible rather than that which is appropriate. For example, survey instruments like total stations automatically take measurements with high levels of precision. This can yield very misleading models; for example a rendered model illustrating a reconstruction of a building may imply that the original builders and craftsmen worked to very tight tolerances. The actual tolerances, however, are more likely to have been much looser.

For example, a project to record surviving concrete walls at Pompeii might decide that measurements should be taken to the nearest centimetre, but not to the nearest millimetre. In this case, higher levels of precision were not required, since the dimensions of the buildings measured to the finished surfaces do not survive. The concrete wall cores that do survive were not constructed to tight tolerances and measuring with great precision therefore provides no useful information.

Ancient cut-stone architecture that does not involve mortar, on the other hand, was constructed to very precise tolerances because of the absence of mortar and the unforgiving, inelastic nature of stone. The precision of measurement must be similarly high. In general the rule is that high levels of precision in construction and design need to be reflected in measuring the finished product. Lower levels of precision in construction, on the other hand, call for lower levels of measurement precision.

For paper drawings a more practical approach is matching appropriate precision to drawing scale so that the most precise measurements can be expressed in a drawing at the scale to be used (see also Section 3.2). Thus measurements are taken with the scale of the final drawings in mind, to the level of precision that would be useful in those drawings. Andrews *et al*. (English Heritage, 2005) suggest that survey precision will be affected by the scale(s) at which surveyors expect drawings to be produced. This is certainly the case when surveyors are attuned to hand-drawing methods rather than CAD.

2.1.4 Indicating Precision on Drawings and in CAD

Precision is indicated on drawings through the use of significant digits. Where dimensions are shown, precision is clear. When dimensions are not shown on a drawing, they can be retrieved by making measurements on the drawing and, where appropriate, applying the scale factor. In such cases, the scale of the drawing is a limiting factor, and precision is limited by the double problem of scale - the accuracy with which the draughtsperson, working at reduced scale, can produce a line of appropriate length and the accuracy with which a user can measure and scale up a line on the drawing.

CAD models present a different problem for determining precision. All points are specified in a three-dimensional Cartesian grid system, and dimensions are calculated from those point locations. The precision of the point locations depends on the CAD system used but is the same for all points in any given model with trailing zeros being added or additional digits truncated. In most CAD systems, users may decide on the number of decimal places to be displayed. However, all point locations and dimensions must have the same number and will appear to have the same precision. Thus the number of decimal places displayed in a CAD model does not reflect the actual precision of any specific measurement and false precision may be suggested.

2.1.5 Mixed Levels of Precision

A model may contain very precise measurements alongside less precise ones because combined data capture techniques have been used. For example, a total station may be used along with steel tape measures to capture certain dimensions and, while the survey data may be accurate to the nearest millimetre, other data may have a 1cm tolerance. Separate CAD layers or cross-referenced drawings may be used to hold items with different levels of precision.

Levels of precision must be documented so that users of the model have ways to determine which measurements or locations have been more or less precisely determined. With this information the model can be used to extract additional measurements whose precision is known. The precision of any measurements can be no better than that of the reference points, but the situation is more complex still, since measurements taken from a single reference point may be very precise when compared with one another but not when compared with other points in the model. Careful documentation allows users to avoid the practice of using points from lower-tolerance data sources as reference points and also allows users to know when to expect good high-precision measurements.

2.1.6 Documenting Precision

Since CAD systems cannot display differing levels of precision and may indicate spurious levels of precision, CAD models must be documented (see Sections 4). This documentation should explain how precisely the dimensions and data points were determined, and how users can discriminate between more and less precise measurements if both are present. For example, different layers might be used for different levels of precision. The setting for displaying decimal places, if set within the model rather than the CAD program, should be appropriate to the precision used in measuring.
