Teuvo Heimonen

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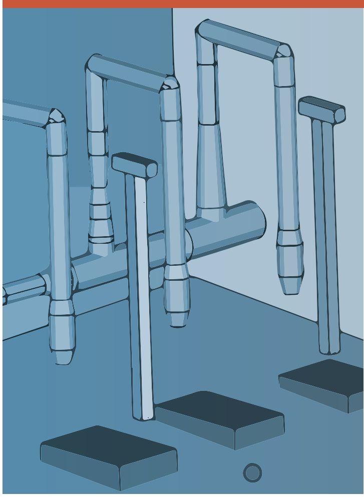
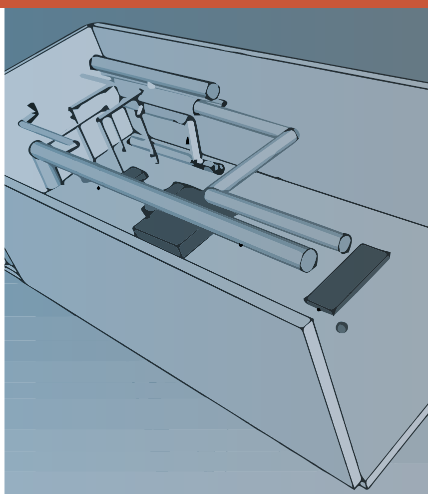
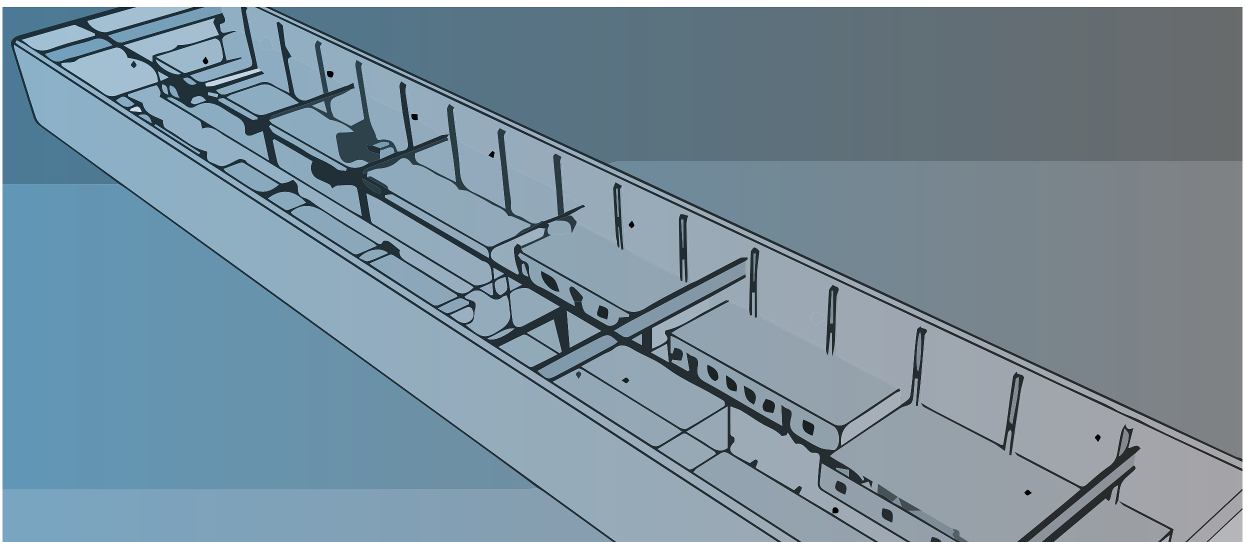
On-line as-built modelling

Learnings from industrial demonstrations







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The Lapland University Consortium is a unique form of strategic alliance in Finland, as it composes a union between University and University of Applied Sciences.
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A new kind of approach for 3D as-built modelling was developed and studied. One of the key objectives of the study was to evaluate the potential of the methods for on-line modelling.

The approach is based on parametric modelling and object designated measurements. The purpose is that all parameters of an object model could be automatically solved by using the data the system obtains while object is measured.

The first part of this publication presents briefly the main principles of the implementation of the approach. These comprised application specific customization of the software, dynamic user interface, and automated analysis (reasoning) of the measured data.

The principles and the implementation were experimented with four industrial demonstrations. The main purpose of this publication is to document the findings of these demonstrations.

The principal idea of the approach proved to be feasible. Demonstrations also revealed some needs and possibilities for further research and development.

Contents

1 INTRODUCTION

In the last few years 3D measuring and modelling technology has been developing rapidly. Professional systems has become both more efficient and feature-comprehensive, and due to increase in supply and decrease in prices, they are better obtainable. On the other hand, the low-cost and easy-to-use consumer devices has brought the 3D measuring and modelling closer to the every-day use of non-professionals. They have also given many positive impulses to the development of the professional systems.

Based on the amount of measured data and modelling approaches, the 3D measuring and (geometric) modelling systems can be roughly divided to the point based and to the point cloud based approaches. In the point based approach, separate, designated points are measured (by using e.g. a total station or a modern laser distance measurer), and then, typically in an after-measure process, grouped together to enable the 3D modelling of the objects. In the point cloud based approach instead, one or several point sets comprising a large number (perhaps millions) of more or less undesignated points are rapidly acquired (by using e.g. laser scanner or stereo camera), and then divided afterwards to smaller subsets usable for modelling separate objects or spaces. The comparison studies of these two different approaches (see e.g. Scherer 2004; Pflipsen, B. 2007, and Oleksuik & Sankey 2014) can be summarized as follows: the superiority of one approach to the other depends on the complexity of the task in hand, the details of the objects to be measured and modelled, and the wished properties of the deliverables.

In the New possibilities of 3D measurements and modelling -project (Lapland UAS 2017a), run by Optical Measurement Laboratory of Lapland University of Applied Sciences (Lapland UAS 2017b), a new kind of approach for measurement based 3D modelling (as-built modelling) was developed. One of the key objectives of the research was to study the possibility of the on-line modelling (i.e. modelling while measuring), so that post-measure work would be minimized. The principles of the methods used to pursue this goal will be presented in the chapter 2 of this publication.

The main purpose of this publication is to report the practical tests and demonstrations related to the as-built modelling research of the project. The goal of these experiments was to study as-built modelling process (task description-planning-measuring-modelling) of real industrial cases and, especially, to evaluate the feasibility of the methods developed and implemented in the project. The cases were related to the geometric modelling of buildings (indoors) and the modelling needs for industrial design. The demonstrations and the “lessons learnt” –discussions of these experiments are presented in the chapter 3.

The study was mainly funded by Tekes (the Finnish Funding Agency for Innovation) and from the European Regional Development Fund (ERDF) together with several Finnish companies. Both the financial and also the technical support of the experts of the companies are greatly acknowledged.

2 OBJECT DESIGNATED 3D MEASUREMENT AND MODELLING

The solution proposed in the New possibilities of 3D measurements and modelling -project to as-built modelling problem can be named as object designated 3D measurement and modelling. This approach is based on the following assumptions:

- Objects are modelled by using parametric modelling approach, i.e. the geometry of a model presenting the real object is defined by using an object type -specific and pre-determined set of parameters (e.g. position, direction, length, radius, etc.).
- Measurements are performed object-wise, so that all parameters of the object can be automatically solved by using the measurement data (and perhaps some additional object specific information given while measuring the object).
- Each object is identified while measuring. The identification comprises
  - unique identification label (name) for the object
  - information of the type of the object
  - list of the measured points belonging to the object
  - type of each point belonging to the object
  - information how to solve the geometric parameters of the object
  - information about intersections with other objects.

It is clear that conveying all this information to the system interactively is troublesome, especially while measuring. In order to minimize the distraction of the measurement personnel, the measurement software of the approach should be carefully designed and implemented. In this chapter some principals for such an implementation are proposed. The presentation is divided into three parts: customization of the software, implementation of the user interface, and utilization of simple automated reasoning.

2.1 CUSTOMIZATION

The customization of a software can be divided to two phases: The first step is to code the functionalities of new operations or properties. The second step is to make these functionalities available for the user of the software. It is clear that the second step is practically useless without the first one. On the other hand, when a functional database created by a software engineer is exhaustive enough, the first step is not needed anymore: the customization of a software can be performed just by selecting the functionalities to be offered to the user. Commonly software have certain kind of user editable settings or user selectable preferences to enable this possibility.

In Figures 1-3 three examples about (user interface) customization of our Measurement software are presented. These interfaces offer different functionalities for the user: The first one yields possibility to measure and model basic geometric primitives like lines and planes, the second building related objects like walls and stairs, and the third one also some additional objects needed in industrial as-built modelling tasks like pipes and cranes. The change from example one to two is obtained by changing a value of one parameter of the settings of our software, and the change from example two to three is obtained by selecting the members of a certain list in the settings.

By including only needed functionalities (and buttons to the user interface), the distraction of the measurer can be reduced and the execution of the task in hand enhanced. Naturally, this can also be used to limit the possibilities what he or she is allowed to model on-line.

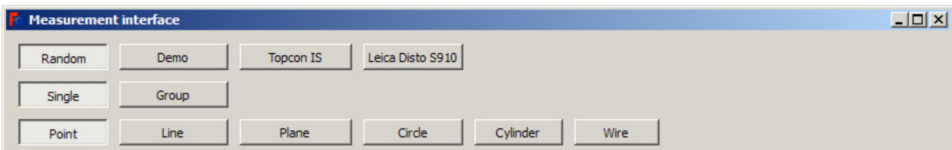

Figure 1. Measurement interface when *activePrimitiveGroup* setting is 'Geometric'

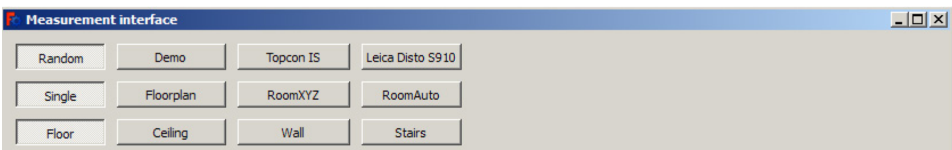

Figure 2. Measurement interface when *activePrimitiveGroup* setting is 'Buildings'

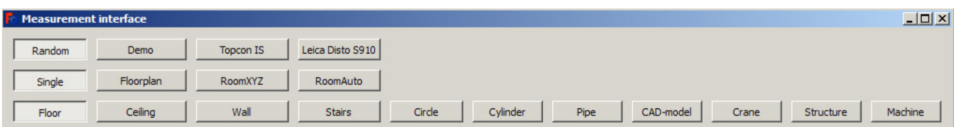

Figure 3. Measurement interface when *activePrimitiveGroup* setting is 'Buildings' and more primitives are included

2.2 DYNAMIC USER INTERFACE

Besides the possibility to customize the user interface by using settings, a dynamic user interface concept was utilized. Based on the selections the user makes, the interface is changed so that different options for further selections will be available.

In Figure 4 the same user interface as in Figure 3 is presented. The only difference is that the user has activated the Floorplan group for the following measurements. It can be noted, that in this case, user is allowed to model only walls and stairs on-line.

The main objective of the dynamic user interface concept is similar to customization: to reduce the user distraction. This “less possibilities to choose from” -feature may also decrease the number of mistakes in the user-software interaction.

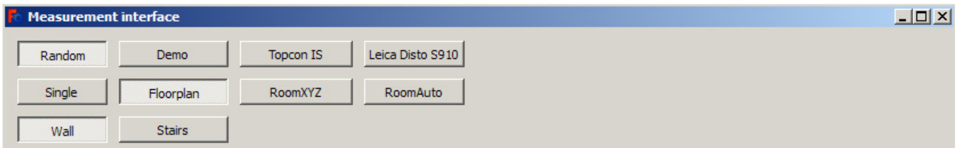

Figure 4. Same Measurement interface as in Figure 3, but instead the Single group the Floorplan group is activated

2.3 AUTOMATED REASONING

Implemented measurement and modelling software utilizes some simple automated reasoning based on its inputs. Examples of this comprise:

- Performing geometric fitting computations as soon as enough data is available (enough points belonging to the object in question has been measured).
- Automatic parametric modelling and visualization of the objects as soon as the results of fitting computations are available.
- Checking for need to update already modelled objects (and update if needed).
- Adaptation of fitting computations based on the type of the object and the number of points measured.
- Using automatically certain assumptions or constraints in the fitting computations (if allowed).
- Automatically solving intersections between certain objects and thus solving e.g. dimensions of the object models.

These reasonings vary based e.g. on object types, and are not presented here in detail. However, as a simple example the measuring and modelling of a ceiling is presented in the following. In this case the reasoning and assumptions are as follows:

1. If measuring rectangular space (room), using gravity axis of the instrument, and only one point is available: Model ceiling into the position indicated the z-coordinate of the measured point, fix normal of the ceiling with the z-axis, and intersect ceiling with all walls belonging to same space.
2. If measuring rectangular space (room), using gravity axis of the instrument, and more than one point are available: Model ceiling into the position indicated by the average of z-coordinates of the measured points, fix normal of the ceiling with the z-axis, and intersect ceiling with all walls belonging to the same space.
3. If measuring single (separate) ceiling and more than two points are available: Fit a plane to the measured points and model the ceiling based on the fitting results and the positions of the measured points.

The purpose of the automated reasoning is naturally to decrease the need for user interaction. Thus the number of the user errors may be reduced and the execution of the measurement task enhanced.

3 DEMONSTRATIONS

Four as-built modelling experiments and demonstrations were performed. Since the measuring and modelling software was developed based on experiences of the demonstrations, they will be presented here in this chapter in the same order than they were performed.

The first demonstration was an as-built modelling case of the indoors of a building. The second and the third were mostly related to modelling small piping systems, but comprised also a building modelling. The second one was more or less a preliminary test for the third one. The fourth demonstration was again an indoor modelling case, but in this case there were several industrial specific objects present to be measured and modelled.

The prototype software utilized in the demonstrations was implemented by using Python programming language (Python Software Foundation 2017) and several third party Python modules. For the 3D modelling and visualization FreeCAD (FreeCAD Community 2017) was utilized.

3.1 TEST LABORATORY -CASE

The main purpose of the test laboratory -demonstration was to evaluate the measurement and modelling ideas, and the first version of the measurement software. Another goal was to study the feasibility of the approach for collecting input data for virtual building models.

For planning the measurements a floor plan (partly out-of-date) of the test laboratory was obtained. No images were available.

The layout of the test laboratory was close to isosceles, right-angled triangle with area about 26 m x 26 m / 2 ~= 340 m^2. There were rooms (or spaces) with different heights, curved and planar walls, windows, doors and other openings in the walls, circular and rectangular columns, and stairs to be measured and modelled.

Totally 178 points were measured by using a total station (Topcon IS, Figure 5) from five different measurement stations. The field work took about four hours.

As an off-line work some fine tuning of the model was performed and the model was exported in a few different formats for further virtual modelling tests. Besides this off-line work focusing purely to finalize the model obtained on-line, the measurement and modelling results were studied and found errors of the software were corrected. Thus the total office time was as much as about five hours in this case.

Figure 5. Topcon IS (Topcon Positioning Systems 2017)

Findings of the experiment

The experiment was successful. The software worked properly and the model obtained was like it was expected to be (Figure 6). The model also suited for virtual modelling software when exported e.g. in obj-format.

Naturally, as this was the first practical test for the approach, several deficiencies were noted both in measurement practices and the software. Many ideas for improvement were discovered, which may also be thought as a good result considering the phase of the development work.

The number of measured points could be significantly reduced. About ten percent of the points were measured more or less for research purposes, and they were not necessary for creating the model. Also, the software and modelling algorithms were later, based on the findings of this experiment, development so that less points per object would be needed in this kind of as-built modelling tasks. For example, in the demonstration the cylindrical columns were measured and modelled by using three to nine points (33 in total) for each, while later it has been possible to use known radius and one point only to localize and model this kind of columns (so totally only six points would have been needed).

The measurement personnel were unexperienced both for this kind of field work and, naturally, using the software. It was estimated that by using more developed version of the software and after personnel has gained more experience and practice, the field time could have been reduced significantly, even halved.

The quite long office time was mainly caused by two kind of deficiencies of the software: small errors in the computations and a lack of easy-to-use tools for making off-line corrections. At least half of the office time was spent for tasks, which were not directly targeted at finalizing the model obtained on-line. Also the actual finalizing work, e.g. creating suitable output for virtual modelling, could be automatized. So, based on the experiences of this demonstration, the goal to reduce the office time close to zero seemed to be feasible.

The accuracy, or geometric correctness, of the model was not much in concern in this case. However, it was noted that especially modelling cylinders was somewhat vague. This was due to the well-known sensitivity of the geometric fitting computations when using small number of points: even small deviations of the measured points from the assumed model may deteriorate the fitting result significantly. The implication of this kind deviations is especially significant, when measured points are close to each other, which, in particular, is the case with the (cylindrical) columns.

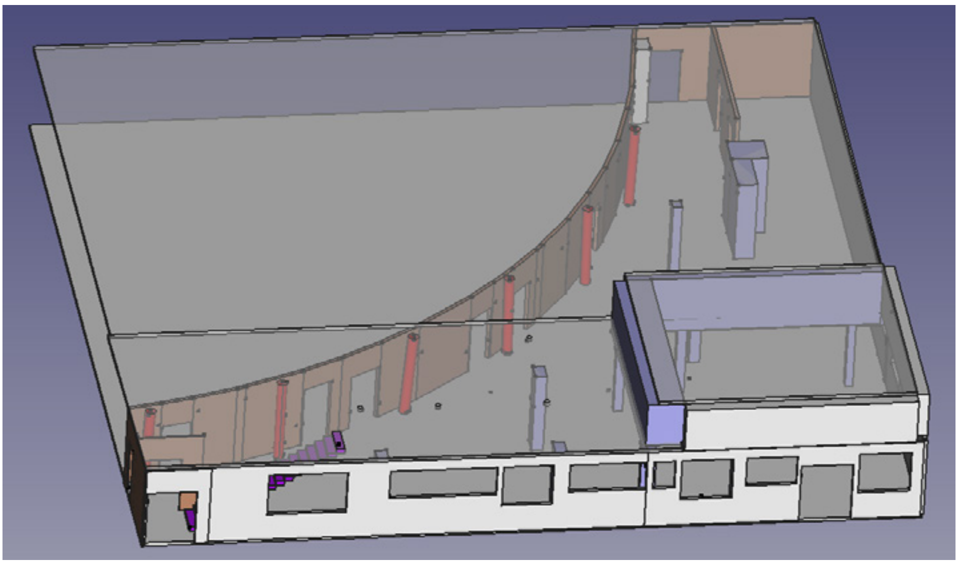

Figure 6. Model of the test laboratory

3.2 PUMP ROOM -CASE

The goal of the pump room -demonstration was to evaluate (preliminary) measuring and modelling approach for getting as-built data for industrial design. Especially measuring and modelling small pipe systems were in interest.

For planning the measurements a bit outdated floorplan and five digital images of the pump room were obtained. The objects to be measured and modelled were not exactly specified before measurements.

The layout of the pump room was square with area about 13 m x 5.5 m ~= 72 m^2. The other end was open. The height of the pump room was about 3.4 m.

The objects that were chosen to be measured comprised floor, ceiling, walls with one door, four foundations of the pumps, several different sized pipes, and two flanges. Totally 147 points were measured by using a laser distance measurer (Leica Disto S910, Figure 7) from two different measurement stations. The field work took about three hours.

As an off-line work some error corrections and fine tuning of the model were performed. The model was also exported to different CAD-formats in order to be evaluated by the customer (whether the exported model can opened and utilized in their own CAD-systems). The total office time was about four hours in this case.

Figure 7. Leica Disto S910 (Leica Geosystems 2017)

Findings of the experiment

Even though the result of the measuring and modelling process was reasonable (Figure 8), there were some difficulties during the measurements. The measurement device was accidentally moved a bit, and thus the last few measurements from the first measurement station (measurements of the flanges) were in incorrect position. Because of this movement the alignment of the second measurement station with respect to the first one was also poor. These deviations leaded to some extra office work and to rejection of some measurements (flanges) from the final model. Thus the success of the experiment was estimated to be only moderate.

The measurement and modelling of the pipes was proved to be vague. The pipe modelling computation assumes that the measurement rays of all measured points of a pipe segment (at least two points needed) and the non-visible center line of the pipe segment are all in the same plane. Measurements fulfilling this assumption are difficult to make especially with pipes which are large and relatively nearby. Because of this and other measurement uncertainties, the intersections of the adjacent pipe segments may also easily be erroneous and thus the model of the pipe system may deteriorate significantly.

Fortunately the accuracy of the pipes is usually not the key factor in this kind of as-built modelling cases (more critical is the accuracy of the flanges). So the modelling approach of the pipes was agreed to be feasible for further usage.

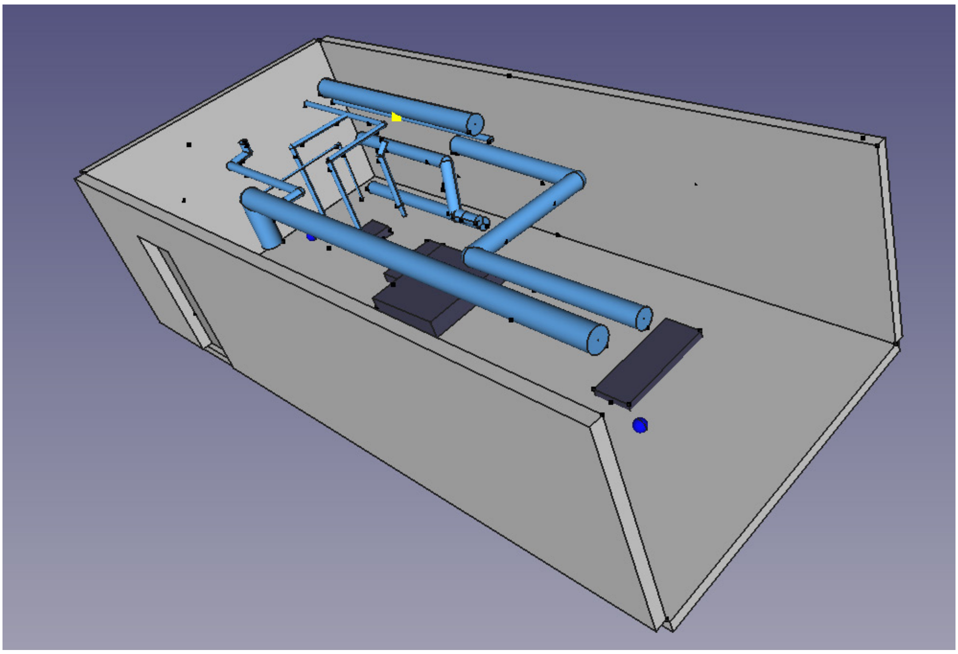

Figure 8. Model of the pump room

3.3 PIPING SYSTEM -CASE

In the piping system -case a relatively small piping unit was measured and modelled. As-built modelling was needed in order to design a supporting structure for the piping.

A digital image and a screen capture of a 3D CAD model of the piping system was obtained for planning the measurements. Besides the pipe segments a floor, a ceiling, a wall, foundations of three pumps, and two columns of supporting structure already present were to be measured and modelled. The measurements and the model were to be aligned to the internal coordinate system of the factory.

The size of the piping system to be measured was about 3 m x 4 m x 4 m. The closest reference points of the coordinate system of the factory were about 25 m away and out of sight from the piping system in interest.

The objects in interest were measured from one measurement station. Another measurement station was needed to transfer the coordinate system of the factory. Totally 80 points were measured to model the objects in interest and additional 11 points were used to transfer the coordinate system. A total station (Topcon IS) was used. The field work took about three hours.

The off-line work comprised some fine tuning of the model. The model was also exported to the step-format in order to be usable by the customer. The total office time was about one hour in this case.

Findings of the experiment

The experiment was quite successful. The software worked properly and the model of all objects in interest were obtained (Figure 9).

The total station was not able to measure from some dark (oily) surfaces, especially the pump foundations were problematic. Also the steel pipes caused some difficulties if the normal of the surface measured was significantly tilted from the direction of the measurement ray.

The geometric accuracy of the obtained model was not studied in depth. However, in the office checks made afterwards, it was noted that the other vertical column of the existing supporting structure was significantly rotated around the vertical axis (z-axis). This was probably not the real situation, but due to an error in measurements of the column. The reason for the deviation is most likely similar to the one made with the cylinders: when the measured points span only a relatively small volume in space, even small deviations in the measurements may cause quite significant artefacts to the model. Some kind of automatic checking and warning system of (small) deviations may have helped to detect the error on-line.

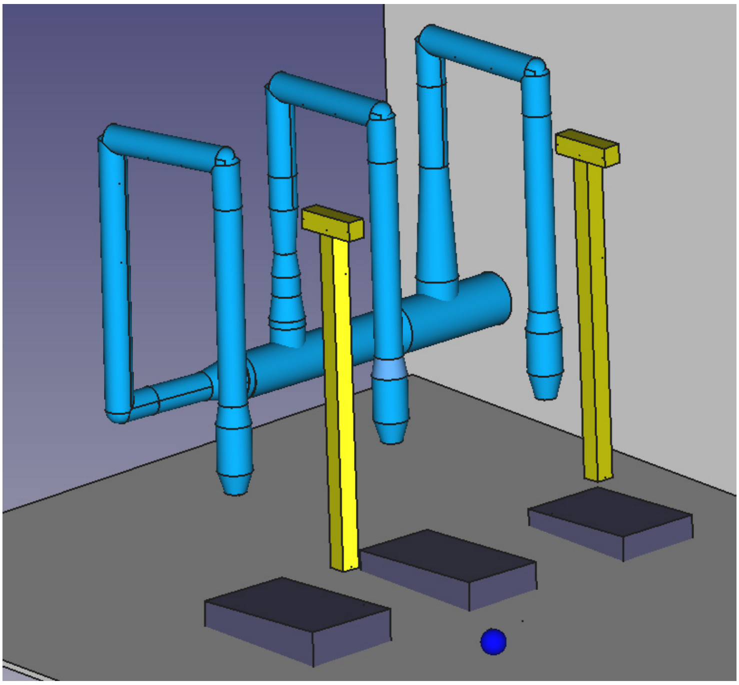

Figure 9. Model of the piping system

3.4 MACHINE HALL -CASE

The objective of the machine hall -case was to study and demonstrate the feasibility of the approach to model a large industrial hall. Also the customization of the measurement software was studied.

The demands for the geometric accuracy or the completeness of the model were not high. The practical needs for this kind of as-built modelling may comprise e.g. the planning of the logistics and working areas of machine halls.

For planning the measurements five digital images of the machine hall was obtained. Rough dimensions of the hall were also known in advance.

The layout of the machine hall was rectangular with area about 160 m x 30 m ~= 4800 m^2. The height of the hall was about 12 m. The objects to be measured and modelled comprised a floor, a ceiling, and walls of the hall, 16 rectangular columns, several enclosures for machines, a machine, a machinery area, six cranes (three big cranes and three smaller of two different types) with safety areas, a walking bridge, and two ventilation pipes.

Totally 216 points were measured by using a laser distance measurer (Leica Disto S910) from four different measurement stations. The field work took about four hours.

As an off-line work some fine tuning of the model was needed. During the measurement some of the points in interest were out of sight, so some points were measured with an offset. These offsets were corrected in the office afterwards. Also a couple of user errors were made during the measurements, which also were corrected off-site. The total office time was about two hours in this case.

Findings of the experiment

The experiment was successful and a decent model was obtained (Figure 10). There were some shortcomings in the modelling computations customized specially for this case, but otherwise the software worked properly. Also the laser distance measurer worked finely, even when measuring long distances.

It was noted that tools for on-site error corrections need to be developed. Also some automatic error checking intelligence and warning system should be considered to be implemented. When the measurement work gets bigger and longer, the focus of the measurement personnel may fade time to time, for several reasons, and mistakes are possible. It would always be better if these errors could be easily corrected right away, so that on-line modelling will continue flawless.

Also a possibility to make offset measurements should be integrated to the software. If offset corrections are left to be made off-line in the office, the probability to accidentally leave some of the corrections unmade will increase.

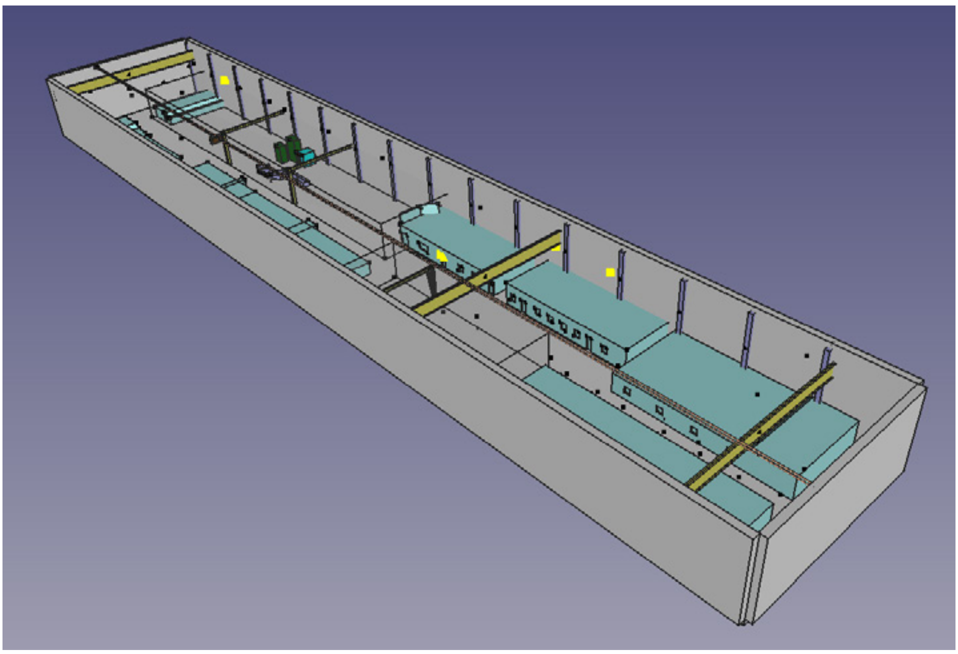

Figure 10. Model of the machine hall.

3.5 SUMMARY OF THE FOUR CASES

Proposed as-built modelling approach seemed to be feasible for modelling the indoors of the buildings. Either the space to be measured and modelled was a bit labyrinthine (test laboratory) with several obstacles for sight, or quite large in dimensions (machine hall), the implementations seemed to work properly.

Modelling cylinders, pipes and piping systems by using measurement information is challenging by using point based approach. Measurement uncertainties and sometimes also the deviations in the geometry of the pipe surfaces may cause significant errors in the parameters obtained with fitting computations. In order to minimize the effect of the measurement uncertainties more points should be measured, which is not reasonable: as can be seen from the pump room and from the piping system cases, the direction and the radius of a pipe may change several times in rather short distance. It is impractical (in point based measurement approach) to measure e.g. ten or more points from each different pipe segment in order to obtain more reliable fitting result.

One possibility to get around the need for dozens of points per each pipe segment is to use some assumptions, e.g. known radius, of the pipe to be modelled. Unfortunately, as noted in the pump room case, the effective use of these kind of a priori assumptions also constrains the measurements to be performed in a way, which may also result in an erroneous model.

Field times and office times were not followed up attentively. Especially the office times reported in the previous chapters comprised also some corrections of errors in the software implementations and such studies of the measurement results that were not directly related to the as-built modelling. Table 1 summarizes the coarse key figures of the demonstrations.

Table 1. Approximate key figures of the demonstrations

	Dimensions [m] (area [m2])	Points	Stations	Field time [h]	Office time [h]
Test laboratory	26 x 26 x 3/5 (340)	178	5	4	5
Pump room	13 x 5,5 x 3,4 (72)	147	2	3	4
Piping system	3 x 4 x 4 (12)	91	2	3	1
Machine hall	160 x 30 x 12 (4800)	216	4	4	2

4 DISCUSSION

The main objective of the demonstrations was to evaluate the 3D measurement and modelling approach proposed with real, industrial as-built modelling cases. This kind of demonstrations are outstanding opportunities both to detect shortcomings of the implementation, to find ideas to further develop the approach, and to reject the solutions, which are not operational in practice. To this end, the demonstrations made, served excellently.

Another goal was to show to the project partners the possibilities of a new kind of as-built modelling approach. Even though the demonstrations were made during the development work in progress, while some deficiencies were still troubling some part of the experiments, it is believed that the feasibility of the principal ideas of the approach were quite successfully demonstrated.

The proposed object designated approach for as-built modelling increases a bit the workload of the personnel while measuring. On the other hand, the amount of off-line modelling work reduces significantly. Based on the demonstrations, an on-line modelling process without any modelling work after measurements, seems to be achievable in many cases.

The benefits of the application customized approach will be especially notable if as-built modelling work similar to previous ones is to be performed or comprehensive a priori information is otherwise available. Digital images of the space and object(s) to be measured and a floorplan helps greatly in planning the measurements and modelling. In case of new kind of modelling tasks, detailed specifications of what (and how) need to be modelled and what kind assumptions (if any) e.g. about the sizes or directions of the objects can be made, would also be precious for proper customization empowering the on-line modelling. The value of precise and detailed task description cannot be overrated.

Several ideas and needs for further development and study were found during the development work and with the demonstrations. Firstly, the easiness to use the software can and should be developed. Perhaps this can be reached for by implementing following automation and machine intelligence methods

- on-line intelligence for error and uncertainty checking
- both interactive and autonomous on-line correction tools of errors and small deviations introduced by measurement uncertainty
- possibility to make offset measurements
- on-line guidance for measuring (help for personnel)
- further development of the software customization possibilities
- utilization of object libraries and custom objects.

Secondly, in many, if not in all, applications matters related to the geometric accuracy of the results are important, and the performance and potential of the proposed as-built modelling approach with respect to this aspect should be studied. Besides the question of increasing the accuracy of the results, the study should consider perhaps even more important question of managing the accuracy, i.e.

- how to estimate the uncertainty of the measurements (measured points and objects) and generated as-built models
- how to incorporate accuracy (or uncertainty) information to the model
- how to report, archive, and utilize the accuracy information.

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In the New possibilities of 3D measurements and modelling -project, run by Optical Measurement Laboratory of Lapland University of Applied Sciences, a new kind of approach for as-built modelling has been developed. The approach is based on parametric modelling and object designated measurements of 3D points. In order to minimize the manual modelling work, the feasibility of the approach for modelling measured objects automatically on-line (modelling while measuring) was stressed in the development work.

Proposed as-built modelling approach proved to be feasible alternative especially for modelling the indoors of the buildings. Also industrial designers dealing with as-built modelling tasks in which all-inclusive point clouds are not needed, may find the findings of the study interesting.

In this publication both the main principles of the implementation of the approach and learnings from four industrial demonstrations are presented. Topics for further research and development are also suggested.

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