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Position markers for digital applications on construction sites, structural monitoring and BIM-applications

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Contents

European foreword

This CEN Workshop Agreement has been developed in accordance with the CEN-CENELEC Guide 29 "CEN/CENELEC Workshop Agreements — A rapid prototyping to standardization" and with the relevant provisions of CEN/CENELEC Internal Regulations — Part 2. It was approved by a Workshop of representatives of interested parties on 2023-11-07, the constitution of which was supported by CEN following the public call for participation made on 2023-01-18. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

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Introduction

The digitalization of the construction industry has brought numerous new digital technologies onto construction sites and existing infrastructure.

The spectrum ranges from digital measurement and quality control and the operation of robots and (partly) autonomous vehicles to visualization tasks using augmented and virtual reality systems (AR/VR). Each of these applications relies on precise geometric information about its own position and orientation. However, there are currently no common standards: these machines and applications use a wide variety of optical tags, some of which are proprietary, and all of them have their own data formats and processing strategies.

Precise position measurements on construction sites or in existing structures under monitoring are usually in the responsibility of surveyors. They create a network of control points (targets) whose positions are determined from the official survey points. These targets then serve as the basis for all further measurements. However, currently no standardized process has been available to make this geometry information available to other parties.

This workshop agreement aims to provide digital technologies with measured position data from surveys in a secure manner:

— by defining the properties of suitable position markers and showing example implementations

— by defining a flexible method with which any required tags can be attached at a defined distance to the marker in the course of the project

— by proposing an automated data transfer of the measurement data via «read-out tags»

— and allows to automatically provide/retrieve additional information, such as validity, accuracy of measurement, GUID of the associated BIM element or any other data relevant to the project.

The use of the defined position markers is advantageous:

— In the complexity of large construction sites, the many different trades and companies all use their own markers and tags without their content or information on their validity being accessible. The use of standardized markers avoids duplication and errors.

— Measuring and managing the survey data is in the hands of the commissioned surveyors or the BIM manager, so that the digital applications can work in the project coordinate reference system.

— The method described is ideally suited for use in BIM processes: It is recommended to store the position markers in a marker model in the BIM system. Authorized users can retrieve current, correct and uniform measurement data via the BIM system and password-protected "read-out tags".

The position markers and their usage were originally developed and tested as part of the BIMprove project of the Horizon funding programme (No 958450). This document was commonly created by surveyors, drone scientists, VR specialists, BIM managers and BIM software specialists.

For the future revision of the CWA the authors are grateful for feedback on practical implementation and possible suggestions to marker@bimprove-h2020.eu.

1 Scope

This document is applicable to construction processes where the usual surveyor's control points are to be used not only for geometry control, but other applications such as laser scanning, localization of autonomous vehicles, photogrammetry, or VR/AR applications.

It provides a framework for making accurate survey point information available to digital applications and other trades. This includes the layout of markers, a naming convention for markers and a common digital interface for the read-out-data of markers.

The document builds on existing standards and conventions and collates them where applicable.

The document is intended to be used on construction sites and in existing buildings by planners (architects, civil engineers,…), surveyors, construction companies, software providers, UXV operators, BIM stakeholders, and on site machines/devices/systems.

The survey point information may be utilised not only during the construction but also during maintenance throughout the life of the facility.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 21778:2017, *Information technology — The JSON data interchange syntax*

ISO 19162, *Geographic information — Well-known text representation of coordinate reference systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp/

— IEC Electropedia: available at https://www.electropedia.org/

3.1
marker
physical mark attached to a building or object with known spatial position, carrying a unique marker ID number and allowing for defined later positioning of human- and/or machine-readable tags

Note 1 to entry: The main purpose of the marker is to establish a unique relationship between its ID number and its spatial position. Both information will usually be provided in machine-readable way by a tag, placed in the proximity of the marker. Further tags can be placed next to the marker, such that their spatial position is defined.

3.2
survey targets
targets
crosshairs of varying types that are attached to buildings or objects

Note 1 to entry: The spatial position of their centre is measured by surveyors, i.e. with theodolites.

3.3
tag
human- or machine-readable mark, or digital identity used to communicate information about an entity

Note 1 to entry: A tag can contain information that can be read by sensors to aid in identification of the physical entity.

[SOURCE: ISO/IEC 20924:2021, 3.1.33]

3.4
fiducial tag
machine-readable mark, or digital identity used to determine the spatial position of a machine or device, i.e. augmented reality equipment or autonomous vehicles

3.5
building information modelling
BIM
use of a shared digital representation of a built object (including buildings, bridges, roads, process plants, etc.) to facilitate design, construction and operation processes to form a reliable basis for decisions

[SOURCE: ISO 29481-1:2016(en) 3.2, modified — Note 1 to entry has been deleted.]

3.6
BIM collaboration format
BCF
format that allows different BIM applications to communicate model-based issues with each other by leveraging IFC models that have been previously shared among project collaborators

[SOURCE: https://technical.buildingsmart.org/standards/bcf/]

3.7
project coordinate system
PCS
topocentric coordinate reference system of a facility or asset to which the project coordinates are referenced

Note 1 to entry: mandatory CRS that is always a three dimensional local Cartesian CRS [XYZ] specific to the asset or project (BIM coordinate system).

Note 2 to entry: In BIM context the term 'coordinate system' is often found in place of 'coordinate reference system'. These are different concepts: a coordinate system is a component of a coordinate reference system; to be unambiguous coordinates must be referenced to a coordinate reference system.

3.8
spatial coordinate reference system
SRS
national or international coordinate reference system to which a project is referenced or to which a site-specific coordinate reference system may be related

Note 1 to entry: The usage is optional.

Note 2 to entry: Not to be confused with a spatial reference system (ISO 19112:2003, 4.6) which could be a postcode or a street name.

Note 3 to entry: In colloquial usage the term 'coordinate system' is often found in place of 'coordinate reference system'. These are different concepts: a coordinate system is a component of a coordinate reference system; to be unambiguous coordinates must be referenced to a coordinate reference system.

4 Marker

4.1 Functionality

A marker is comprised of

a) two conventional survey targets at a defined distance.

NOTE   It is assumed that the marker will only be mounted to sufficiently accurate vertical or horizontal components. Alternatively, a third survey target can be attached to the marker (important for the normal vector, see chapter 4.6 and Table 2).
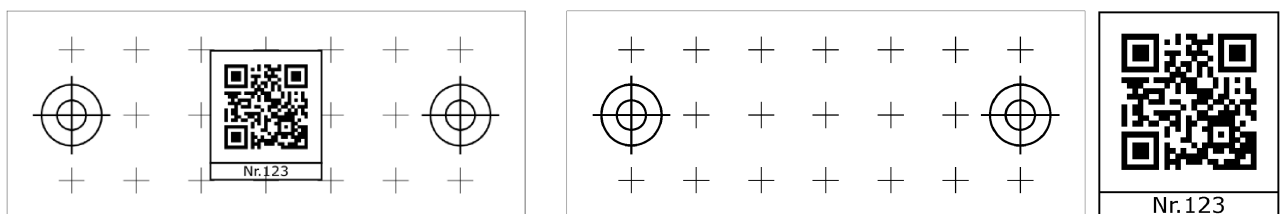
b) a grid of crosses with defined spacing

c) a human-readable marker ID number and

d) optional: a human- or machine-readable tag for data read-out (recommended)

e) optional: further tags for applications

4.1.1 Examples

Examples of markers are given in Figure 1.
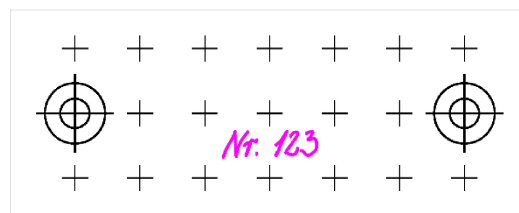
a) Marker with human-readable marker ID number

b) Markers with human-readable marker ID number and machine-readable tag for data read-out

Figure 1 — Examples for markers

4.2 Size and Layout

The size of the marker is defined by the distance between the survey targets.

4.2.1 Size

The marker size for general application is 150 mm.

If other sizes are required for markers to be read from very small or very large distances, the standard sizes as described in Table 1 should be applied:

Table 1 — Marker size

Marker size[a]	Distance between survey targets [mm]	Remarks
1	50	
2	100	
3	**150**	**Recommended for general application**
4	200	
5	400	
6	800	
NOTE Other sizes may be used, if beneficial for the project.		
[a] The marker size selected for the project, should be sufficient to be used with the tags of several envisaged users during project time.		

4.2.1.1   Use of markers of different size in same project

The use of markers of different size in the same project should be avoided.

If markers of different sizes are used in the same project,

— the number of different sizes should be minimised

— the numbering system might be adopted to different sizes

4.2.2   Survey targets

No special requirements. Survey targets can be of any commonly used design. They may be reflective or not. Objects like measuring bolts may also be used as targets, if the marker position can be accurately determined.

Although not recommended targets of different types may be combined in one marker, if required.
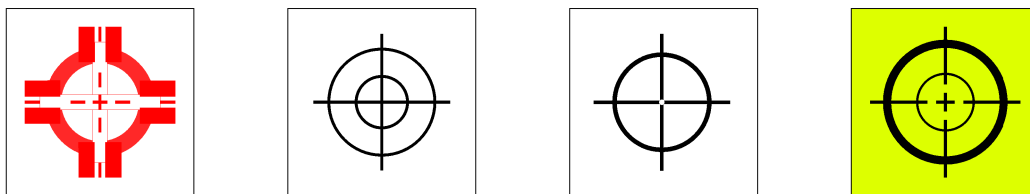
4.2.2.1   Examples of survey targets

Figure 2 — Examples of survey targets

4.2.3   Grid

A grid of crosses with a horizontal and vertical distance of 25 mm shall be placed on the marker.

The central row as well as the first and last columns of crosses align with the survey targets. There shall be at least 1 row, the use of 3 rows is recommended.

4.3 Marker ID number

Each marker in project shall be given a unique marker ID number. The number shall be positive and visible in a human-readable way.

4.4 Tags for data read-out

The placement of a tag providing further information about the marker in a machine-readable format is strongly recommended. This may be via a URL as in an information link (see Clause 5).

4.5 Fiducial tags for machine applications

Fiducial tags may be positioned onto the marker grid as required in the project (see Clause 6).

4.6 Handling and application

4.6.1 Vertical

In general, the marker is placed on vertical elements and it should be applied such that its orientation is roughly horizontal.

4.6.2 Non-vertical

If the marker is placed on non-vertical or non-horizontal elements, a marker with three targets shall be used (see Figure 3).

Placement of markers on irregular elements (e.g. circular columns or free form structures), that are not plane or cannot be classified as either vertical or horizontal, shall be avoided.
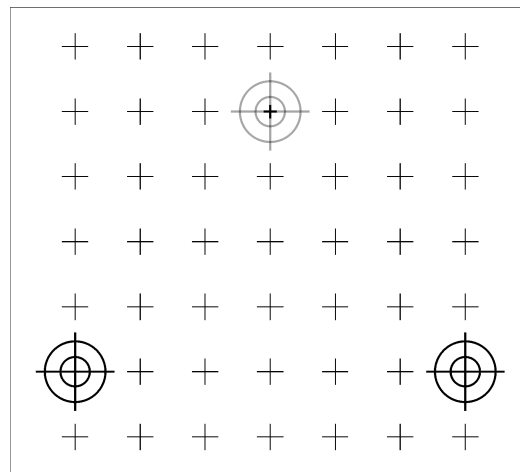

Figure 3 — Example for markers for exceptional circumstances, e.g. on non-vertical elements

4.6.3 Application of tags

At the time of application, markers shall in minimum consist of the targets, the grid and the ID number as described in chapter 4.1. Read-out tags and/or tags for applications may be printed compounded with the markers and applied at the same time, if they are already determined and available. This is recommended, as accuracy of positioning will be improved. Otherwise they can be added whenever needed.
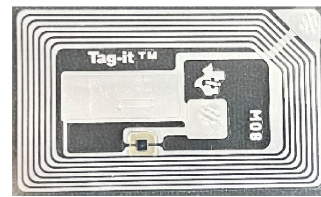
5   Tags for data read-out

5.1   Functionality

Tags for data-read-out either contain additional information about their marker themselves or provide a link to machine readable further information. The additional information is then stored in the marker database, accessible with a standard HTTP request to the URL, readable by NFC or other machine-reading process.

5.1.1   Examples

a) QRcode containing a link to read out data   **b) RFID tag giving read-out data**

Figure 4 — Examples of machine-readable tags for data read-out

The example QR code in Figure 4a) directs to: https://example.com/m/1/123 with the following components:

example.com	is the website
m	is the part containing the marker databases
1	is the project/site specific ID
123	is the marker ID

NOTE   ISO/IEC DIS 8506, Information technology — Automatic identification and data capture technology — AIDC application in industrial construction, uses read-out tags for the unique identification of building components. Depending on the project requirements and interoperability considerations users may wish to equip the read-out tags of the position markers described here with such unique identifiers. These identifiers may then be included in addition to the content described in chapter 5.2.

5.2   Content

The requirements on the information contained in the tags is described in Table 2.

The first 6 data fields are prescribed. Depending on the project requirements, different pieces of information may be added. The data is represented as JSON objects (ISO/IEC 21778:2017).

Coordinate and accuracy triplets are given as a standard JSON list of three floats where values correspond in the order described in the remarks. I.e. a position of the left target measured at x=1, y=2 and z=3 may be represented in the data as l_xyz=[1.0,2.0,3.0], and is added as any other field.

On errors, e.g. requesting invalid data or the server timing out a status message stating the cause is returned.

An example file can be found in Annex A.

Table 2 — Content of tags for data read-out

Content	Common name	Need	Remarks
version	version	mandatory	Shall be "1.0.0" when using this version of this document.
marker number	marker_nr	mandatory	Corresponds to ID number of markers in the current project (integer)
validity	valid	mandatory	true/false
description of PCS [a]	pcs_description	mandatory	Add a specific description e.g. well known text (ISO 19162)
coordinates of left target in the PCS [a]	l_xyz	mandatory	Describing the position (x,y,z)
coordinates of right target in PCS [a]	r_xyz	mandatory	Describing the position (x,y,z)
coordinates of additional target in the PCS [a]	a_xyz	optional	Describing the position (x,y,z)
accuracy of left target coordinates	l_dxdydz	recommended	(dx,dy,dz) Usually standard deviation from surveying
accuracy of right target coordinates	r_dxdydz	recommended	(dx,dy,dz) Usually standard deviation from surveying
accuracy of additional target coordinates	a_dxdydz	optional	(dx,dy,dz) Usually standard deviation from surveying
date of measurement	measured_date	recommended	yyyy-mm-dd (string)
EPSG Code of SRS [c]	srs_epsg_1	optional	Defining the SRS used
EPSG Code of SRS [c]	srs_epsg_2	optional	For compound CRS [d], this field is especially for the vertical CRS.
coordinate epoch of dynamic SRS [c]	srs_epoch	optional	Decimal year in Gregorian calendar; mandatory if SRS is dynamic, not required if SRS is static.

Content	Common name	Need	Remarks
SRS [c] coordinates of left target	l_srs_xyz	optional	Describing the SRS position (x,y,z)
SRS [c] coordinates of right target	r_srs_xyz	optional	Describing the SRS position (x,y,z)
SRS [c] coordinates of additional target	a_srs_xyz	optional	Describing the SRS position (x,y,z)
BCF [b] issue guid	issue_guid	optional	Corresponds to an issue with additional information.
BIM GUID	bim_guid	optional	GUID used in the BIM model (IFC)
related fiducial tags [e]	related_tags	optional	List of Strings with identification for tags: {identifier}_{index}, e.g APR_01
marker normal vector	normal	optional	Describing normal (x,y,z)
name of the project	project_name	optional	
contact person	contact_person	optional	Contact information like i.e. name and / or email-address, phone number
additional information	additional_information	optional	Additional information

NOTE 1 Other variables may be defined in addition to the variables in Table 2 according to individual project needs.

NOTE 2 If additional targets are required as described in Clause 4.6 and Figure 3, the respective additional variables for its coordinates and accuracy shall be added.

[a]   PCS is short for the project coordinate system.

[b]   Defined in 3.6.

[c]   In the geodetic domain, also the term coordinate reference system (CRS) is used.

[d]   For "SRS" reference a BIM/construction project may want to refer to both a horizontal CRS and a separate vertical CRS. In ISO 19111, this pairing is called a 'compound CRS'.[1] In some cases the horizontal and vertical CRSs are in the EPSG Dataset but the compound CRS for the two is not.)

[e]   Described in Clause 6.

5.3   Layout and size

No special requirements.

5.4 Naming convention

If the tags contain a human-readable number, it shall correspond to the marker ID number. Independent projects shall have different project indices.

5.5 Handling and application

Tags for data read-out shall be placed in the proximity of the marker.

5.6 How to set up the URL

The valid URLs are linked to a JSON file on the server on a project basis. For the end user, these are read-only. The specific file can be updated or added directly in the project folder on the backend. It is in the folder:

```
{project_folder}/scanner_data/markers.json
```
(See Annex A.5)

Each marker is represented in this file as

```
"marker_id":{"param1": "value1", "param2": "value2"}
```
The parameters and values are those found in the table.

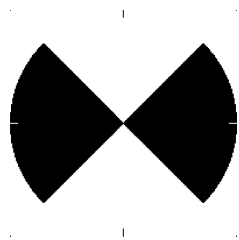# 6 Fiducial tags

6.1 Functionality

Fiducial tags are used for systems that rely on optical methods to process captured data or for deducing position and orientation of machines, such as:

— various (laser) scanning applications

— autonomous vehicles or robots identifying their own position and orientation in space

— Augmented Reality (AR) applications.

Usually black and white patterns of different types are used, that are printed and placed on real world objects. They usually code a non-negative integer in a black and white pattern. The pattern is machine-readable by optical processes, and the coordinates of the associated number read from a lookup table.

The checkerboard patterns used for scanning applications are fiducial tags, that do not contain alphanumeric information.
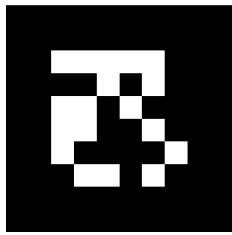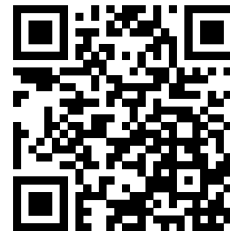
6.1.1 Examples

a) black and white target, checkerboard
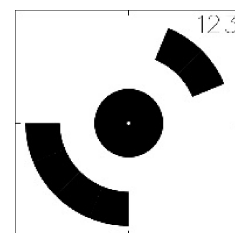
b) ring code

c) Chili tag   **d) QR code**

Figure 5 — Examples of fiducial tags

6.2 Content

No special requirements. The content, if any, may be determined by the machine application.

6.3 Layout and size

No special requirements. The appropriate size may be determined by the machine application.

6.4 Naming convention

If the fiducial tags code a number, the use of the same tag number as the marker ID number is strongly recommended.

6.5 Handling and application

Tags should be geometrically associated to the targets of the marker. The marker grid is intended to be used for precise positioning. Transformation calculations are in the responsibility of the user.

7 Workflow

7.1 Introduction

The coordinate frames of the project, surveying and geometric position information are important during planning, the construction and possibly even operation phase of a building.

In the following the workflow for setting up this geometric framework of a (BIM-) construction project is outlined and a method for managing the markers within this framework is described.

7.2 Workflow scheme

Projects that use BIM, define the employer information requirements (EIR) which contains the project coordinate system (PCS) and spatial coordinate reference system (SRS).

For this process there shall be a common control point numbering system defined.

The first process diagram in Figure 6 concerns the design phase, when the project coordinate system and the position of the building on the site are defined.
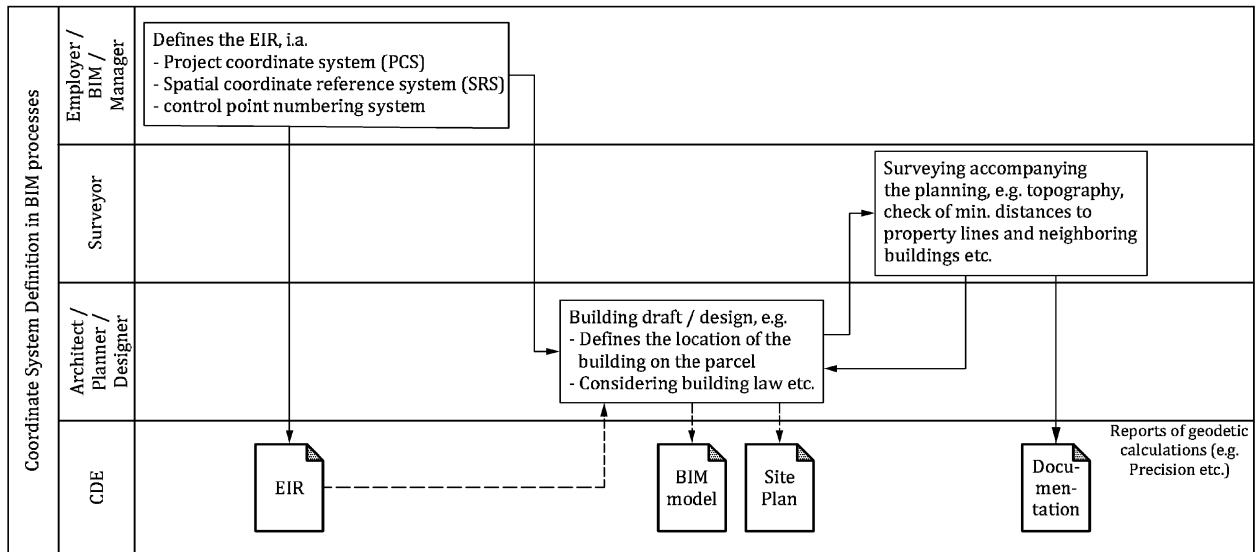
Process Diagram: Design

Figure 6 — Design Phase

The second process diagram in Figure 7 addresses the realisation of the coordinate reference system on the construction site.

Key personnel with respect to markers are the technical manager/surveyor manager and the surveyor, who provide the markers as well as the related geometric information for the digital applications used on site.
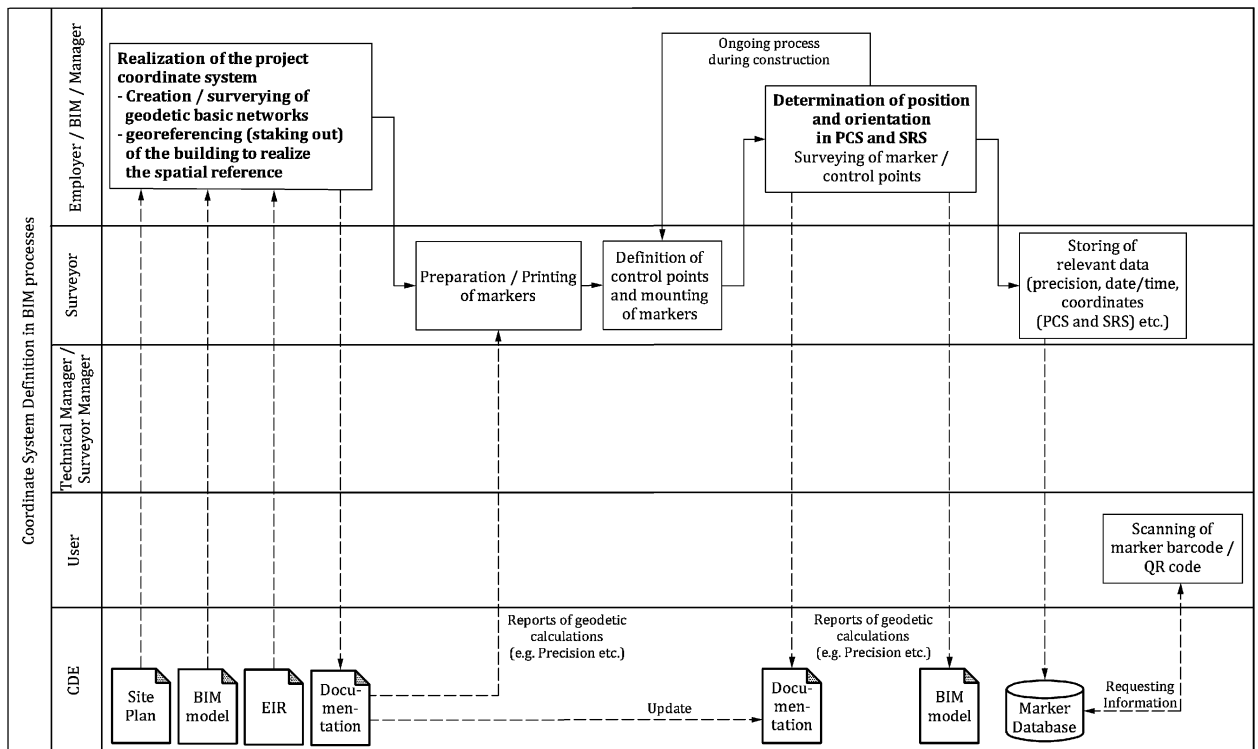
Process Diagram: Construction

Figure 7 — Construction Phase

Annex A
(informative)

Example of implementation on European pilot construction sites

A.1 Use on construction sites

The layout of markers and their use has been developed during the EU-supported research project **BIMprove** (grant agreement No 958450) on three pilot construction sites. They are in Norway, Spain and Switzerland and thus allowed an overview on todays practice of the construction industry in Europe.

While the system was developed for use in the planning and construction phase, it will be similarly useful for monitoring of structures and maintenance or renovation.

A.1.1 Involved

Systems that were used in the project are listed in Table A.1:

Table A.1 — Examples of digital technologies used

Application	Device	Purpose	Required tags
Augmented Reality (AR) system	Augmented Reality/Mixed Reality headset	Visualisation of planned versus current state	proprietary tags, customized tags
Autonomous robot	Ground-based wheeled vehicle	mobile laser scanning	April tags
Indoor UAV	Custom made research drone	mobile scanning (optical, infrared, depth)	Chili tags
Outdoor UAV	Commercial drone	mobile scanning (optical, infrared, depth)	Chili tags
Laserscanning	Various commercial scanners	Stationary laser scanning	black and white tags

A.1.2 Open data

An introduction to the markers is published together with sample files under:

https://www.bimprove-h2020.eu/marker.

A.2 Markers

A.2.1 Placement of markers

Markers are produced in sizes fitting to project needs.

They are put physically onto vertical or horizontal objects on site or inside the building by the technical manager/surveyor manager of the project. Preferably machine-readable read-out tags are provided and placed in the proximity of the marker.
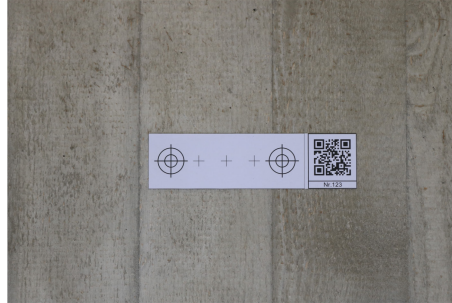
a) Example of small marker

b) Example of marker with recommended size of 150 mm (distance between targets)
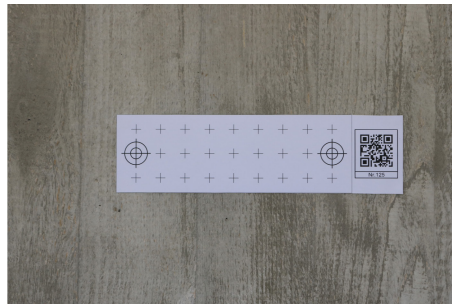
c) Example of larger marker

**Figure A.1 — Prepared markers, placed on structure**

A.2.2 Surveying

The surveyor measures the target positions of each marker and makes the data available in the project coordinate frame.
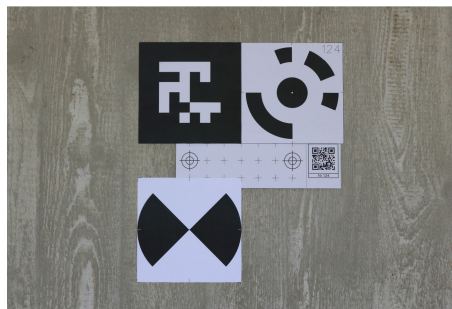
For BIM projects it is recommended to set up a marker model and store all associated data there.

If read-out tags are provided, the information is transferred there. In this case the information is stored in a project database and send out via Internet by scanning a QR code.
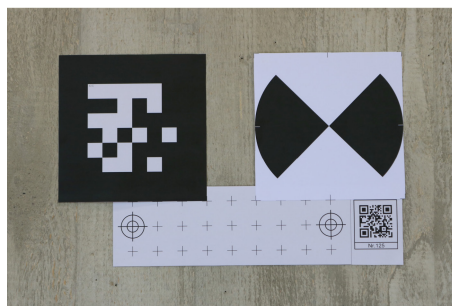
A.3 Use with different (fiducial) tags
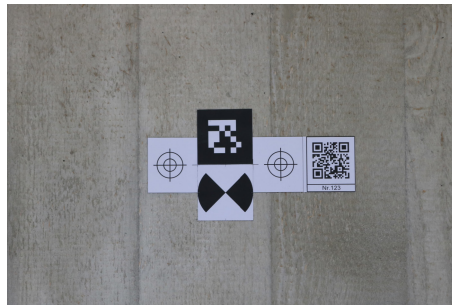
a) Example of small marker

**b) Example of marker with recommended size
of 150 mm (distance between targets)**

c) Example of larger marker

Figure A.2 — Markers with different tags for digital applications

A.4 Read-out data of QR code

The scope of read-out data is determined by the project needs. Here three examples are presented:

— minimal content

— the proposed standard content

— full set of information as in Table 2.

The functionality can be tested by scanning the printed example QR codes.

A.4.1 Example of minimal read-out data

Figure A.3 —Read-out tag with minimal data; URL: https://www.bimprove-h2020.eu/m/1/123

The URL sends a .json file to the scanning device, containing the marker information as described in Table 2. This is then processed by the machine. In the simplest case it can be displayed on a smartphone:

```
{
      "version": "1.0.0",
      "marker_nr": 123,
      "valid": true,
      "pcs_description": "Swisstopo LV95",
      "l_xyz": [
            310.208,
            201.489,
            97.363
      ],
      "r_xyz": [
            310.051,
            201.61,
            97.364
      ],
}
```

A.4.2 Example of standard read-out data

Figure A.4 —Read-out tag with standard data; URL: https://www.bimprove-h2020.eu/m/1/124

```
{
      "version": "1.0.0",
```

```
      "marker_nr": 124,
      "valid": true,
      "pcs_description": "Swisstopo LV95",
      "l_xyz": [
            310.208,
            201.489,
            97.363
      ],
      "r_xyz": [
            310.051,
            201.61,
            97.364
      ],
      "l_dxdydz": [
            0.001,
            0.001,
            0.001
      ],
      "r_dxdydz": [
            0.001,
            0.001,
            0.001
      ],
      "measured_date": "2020-01-01",
      "project_name": "CWA demo project",
      "contact_person": "someone@example.com",
}
```

A.4.3 Example of large set of read-out data

Figure A.5 —Read-out tag with large set of data; URL: https://www.bimprove-h2020.eu/m/1/125

Please note, that in this case the information is password-protected to show, how the information can be protected. (User: CWA; Password: 125)

```
{
      "version": "1.0.0",
      "marker_nr": 125,
      "valid": true,
      "pcs_description": "ENGINEERINGCRS["A local CRS for BIM",
                  ENGINEERINGDATUM["BIM    PCS",ANCHOR["Intersection    of
building axis 1 with building axis A at height 0"]],
```

```
            CS[Cartesian,3],
            AXIS["bldg axis 1 (x)",southWest,ORDER[1]],
            AXIS["bldg axis A (y)",southEast,ORDER[2]],
            AXIS["bldg height (z)",up,ORDER[3]],
            LENGTHUNIT["metre",1.0],
            USAGE[SCOPE["BIM"],AREA["Building site"]]]",
"l_xyz": [
     310.208,
     201.489,
     97.363
],
"r_xyz": [
     310.051,
     201.61,
     97.364
],
"a_xyz": [
     310.14,
     201.51,
     97.564
],
"l_dxdydz": [
     0.001,
     0.001,
     0.001
],
"r_dxdydz": [
     0.001,
     0.001,
     0.001
],
"a_dxdydz": [
     0.001,
     0.001,
     0.001
],
"measured_date": "2020-01-01",
"srs_epsg_1": "4326",
"l_srs_xyz": [
     10.826834,
     59.910968,
     102.032
],
"r_srs_xyz": [
     10.82683,
     59.910968,
     102.032
],
"a_srs_xyz": [
     10.82683,
     59.910968,
     102.032
],
"issue_guid": "f6a6afb7-b4cc-4760-a4b8-7085a9a7d696",
"related_tags": [
```

```
        "APR_00",
        "CHI_00"
    ],
    "normal": [
        0.707107,
        0.707107,
        0.0
    ],
    "project_name": "CWA demo project",
    "contact_person": "someone@example.com",
}
```

A.5 Example of folder location in project

Marker file of the specific project with the guid `6b07072541a24c1ead1902757473c47b`. The full path is based on where the base project folder is.

```
/home/ubuntu/workspace/bimprove/project_data/projects/6b07072541a24c1ead1
902757473c47b/scanner_data/markers.json
```

Annex B
(informative)

Cybersecurity

Please note that requirements on cybersecurity are not within the scope of this document. Nevertheless, this topic needs to be addressed. If software is able to read QR codes from images or point clouds, it could open any link contained in any scanned QR code. As a QR code might contain a link to a corrupted website, usual security measures need to be considered.

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[7]   ISO/IEC DIS 8506:2023, Information technology — Automatic identification and data capture technology — AIDC application in industrial construction