WoTDT: an Extension of the WoT Thing Description Ontology for Digital Twins in the Construction Domain

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LDAC 2024
Digital Twins (DTws)?

- Physical Space
- Virtual Space
- Data
- Information
- Materials Tracking
- Safety Monitoring
- Equipment Utilization
- Earth Work Estimation
3-dimensional approach for DTws

Real-World Entity

Digital Entity

Real-world actions

Simulations

Bidirectional Information Flow

Digital Twin artefacts

Real-World Entity

Digital Entity

Sources of Data

3D Models

Ontologies

Rest Services

KGs

IFC

…

Real-world actions

Simulations

Bidirectional Information Flow
Real-world actions

Sources of Data

Real-World Entity

Digital Entity

Models

Data

Services

Virtual Entity *

DT Connections *

DT Services *

Bidirectional Information Flow

Digital Twin artefacts research background

Real-World Entity

Digital Entity

Model the Digital Entity dimension by using ontologies

Improve Models accuracy and understanding by using Ontologies and WoT

Models

Sources of Data

Real-world actions

Data

Services

Improve Data visualisation and understanding by using WoT and Ontologies

Improve Services functionalities by using WoT
WoTDT: The WoT Digital Twin Ontology

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0.3.0

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https://github.com/oeg-upm/WoT-DT-ontology
**WoTDT ontology** has been developed in the COGITO project to **describe the 5 dimensions of a DTw** and its **features** extending **WoT**.

**WoTDT** in **DTws** allows to:

- **Conceptualise** the five-dimensional model architecture and its features
- **Describe** services of different dimensions
- **Discover** services across dimensions
- **Define** the **security** specification of each dimension
- Facilitates data **accessibility** of a specific dimension
- Promotes data **interoperability** in all dimensions
- **Provide** **direct access** to all DTw functionalities
## Requirements for WoTDT ontology

<table>
<thead>
<tr>
<th>ID</th>
<th>Competency Question / Statement - Possible answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOTDT-1</td>
<td>A Digital Twin is a Thing.</td>
</tr>
<tr>
<td>WOTDT-2</td>
<td>A Digital Twin contains 5 dimensions.</td>
</tr>
<tr>
<td>WOTDT-3</td>
<td>Physical Entity is a dimension that represents the real world asset of the Digital Twin.</td>
</tr>
<tr>
<td>WOTDT-4</td>
<td>Virtual Entity is a dimension that represents the different models used in the Digital Twin.</td>
</tr>
<tr>
<td>WOTDT-5</td>
<td>Digital Twin Data is a dimension where are stored all the data used in the Digital Twin.</td>
</tr>
<tr>
<td>WOTDT-6</td>
<td>Digital Twin Services is a dimension where all the services of the Digital Twin are described.</td>
</tr>
<tr>
<td>WOTDT-7</td>
<td>Digital Twin Connection is a dimension where all the connections between other dimensions in the Digital Twin are described.</td>
</tr>
<tr>
<td>WOTDT-8</td>
<td>Physical Entity dimension can have components.</td>
</tr>
<tr>
<td>WOTDT-9</td>
<td>Which kind of components can be described in the Physical Entity dimension? - The component can be from the physical asset that the Digital Twin is modelling, to the different devices like sensors or actuators that read or act over the specific physical asset.</td>
</tr>
<tr>
<td>WOTDT-10</td>
<td>Virtual Entity dimension can have models.</td>
</tr>
<tr>
<td>WOTDT-11</td>
<td>Which kind of models can be described in the Virtual Entity dimension? - The models can be from rules, behavioral, physical and geometric models to semantic models like ontologies.</td>
</tr>
<tr>
<td>WOTDT-12</td>
<td>Digital Twin Data dimension can have resources that can be used to represent the different type of data stored at the Digital Twin.</td>
</tr>
<tr>
<td>WOTDT-13</td>
<td>Digital Twin Service dimension can have Interaction Affordances from the WoT Thing Descriptions ontology to represent the different services used at the Digital Twin.</td>
</tr>
<tr>
<td>WOTDT-14</td>
<td>Digital Twin Connection dimension can have different connections.</td>
</tr>
<tr>
<td>WOTDT-15</td>
<td>Which type of connections the Digital Twin Connection dimension can describe? - The connections defined in the Digital Twin Connection dimension are described with the different existing elements of other dimensions of the Digital Twin such as models, resources and interaction affordances; and the connections with external Things such as other Digital Twins.</td>
</tr>
</tbody>
</table>
WoTDT Ontology

Physical Entity
- dt:PhysicalEntity
  - dt:hasComponent (1..N)
  - dt:hasModel (1..N)
  - dt:Component
  - dt:Model
  - dt:Format
    - dcterms:title: xsd:string
    - dcterms:description: xsd:string
    - hct:hasTarget: xsd:anyURI
    - dt:hasExtension: xsd:string

Virtual Entity
- dt:VirtualEntity
  - dt:hasComponent (1..N)
  - dt:hasModel (1..N)
  - dt:Component
  - dt:Model
  - dt:Format
    - dcterms:title: xsd:string
    - dcterms:description: xsd:string
    - hct:hasTarget: xsd:anyURI
    - dt:hasExtension: xsd:string

Data
- dt:DigitalTwinData (1..N)
  - dt:hasData (1..N)
  - dt:Data
    - dcterms:title: xsd:string
    - dcterms:description: xsd:string
    - hct:hasTarget: xsd:anyURI
    - dt:hasExtension: xsd:string
    - dt:InteractionAffordance
      - dcterms:title: xsd:string
      - dcterms:description: xsd:string
      - td:hasForm
      - dt:hasUriTemplateSchema

Services
- dt:DigitalTwinService (1..N)
  - dt:containsInteractionAffordance (1..N)
  - dt:InteractionAffordance
    - dcterms:title: xsd:string
    - dcterms:description: xsd:string
    - td:hasForm
    - dt:hasUriTemplateSchema

Connections
- dt:DigitalTwinConnection (1..N)
  - dt:hasConnection (1..N)
  - dt:Connection
    - dcterms:title: xsd:string
    - dcterms:description: xsd:string
    - td:hasProvider (1..1)
    - dt:hasConsumer (1..1)
    - dt:ConnectionPoint
      - dcterms:title: xsd:string
      - dcterms:description: xsd:string
      - td:isInternal: xsd:boolean
      - hct:hasTarget: xsd:anyURI

https://w3id.org/def/digitaltwin#
Application in COGITO Project

Real-World Entity

Austria
Denmark
Spain

Digital Entity

LDAC 2024 WoTDT ontology
WoTDT in COGITO project

Physical Entity *

WoTDT

Austria

Denmark

Spain

DT Data *

DT Connections

DT Services *

Real-time capture tools

Satellite images

3D scanning & photogrammetry

Unmanned Aerial Vehicles

Devices and Sensors

Weather forecasts

3D geometry

Activities scheduling

Budget and Costs

As-planned data

Linked data

Construction Phase Digital Twin Platform

Virtual Entity *

WoTDT

WoTDT Ontology

https://w3id.org/def/digitaltwin#
WoTDT Context Example

{
  "@context": [
    # Ontology URIs
    "https://www.w3.org/2019/wot/td/v1",
    "https://w3c.github.io/wot-discovery/context/discovery-core.jsonld",
    # Namespaces for data
    {
      "element": "https://data.cogito.iot.linkeddata.es/resources/element/",
      "sdt": "https://data.cogito.iot.linkeddata.es/resources/sdt/",
      "dt_ve": "https://data.cogito.iot.linkeddata.es/resources/ve/",
      "dt_dd": "https://data.cogito.iot.linkeddata.es/resources/dd/",
      ...
    },
  ],
...
}
"@context": [...],
"id": "sdt:01U2O",
"@type": "DigitalTwin",
"title": "Element 10486",
"physical_entity": {
  "id": "dt_pe:fb12b",
  "component": {
    "id": "component:7d6e5",
    "title": "Basic Wall",
    "description": "A vertical",
    "href": "...
  }
}
...
WoTDT Virtual Entity

Virtual Entity

- dt:DigitalTwin
  - dt:hasDigitalTwinData (1..N)
  - dt:hasDigitalTwinService (1..N)
  - dt:hasDigitalTwinConnection (1..N)
  - dt:PhysicalEntity
    - dt:hasComponent (1..N)
    - dt:VirtualEntity
      - dt:hasModel (1..N)
        - dt:Format
          - dcterms:title: xsd:string
          - dcterms:description: xsd:string
          - hct:hasTarget: xsd:anyURI
          - dt:hasExtension: xsd:string
  - dt:Component
  - dt:Model
    - dt:hasFormat (1..N)
  - dt:DigtalTwinData
    - dt:hasData (1..N)
  - dt:DigtalTwinService
    - dt:containsInteractionAffordance (1..N)
  - dt:DigtalTwinConnection
    - dt:hasConnection (1..N)
  - dt:InteractionAffordance
    - dcterms:title: xsd:string
    - dcterms:description: xsd:string
    - td:hasFormat
    - dcterms:hasTemplateSchema
  - dt:Connection
    - dcterms:title: xsd:string
    - dcterms:description: xsd:string
    - dt:hasProvider (1..1)
    - dt:hasConsumer (1..1)
  - dt:ConnectionPoint
    - dcterms:title: xsd:string
    - dcterms:description: xsd:string
    - dt:isInternal: xsd:boolean
    - hct:hasTarget: xsd:anyURI

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"virtual_entity": [
  {
    "id": "dt_ve:fb237",
    "type": "Virtual Entity",
    "title": "Virtual Entity",
    "description": "Virtual Entity of DTw 01U2O from project 308736f9-f533-4b4b-9a49-14b5363690db",
    "models": [
      {
        "type": "Ontology_Model",
        "title": "Building Element Ontology",
        "description": "The Building Element Ontology provides an ontology based on the IfcBuildingElement subtree in the IFC specification, containing a taxonomy of classes that allow to define common building elements.",
        "formats": [
          {
            "id": "format:fea24",
            "type": "Format",
            "title": "JSON-LD",
            "description": "JSON-LD format.",
            "href": "https://pi.pauwel.be/voc/buildingelement/ontology.json",
            "extension": "json"
          },
          {
            "id": "format:ca7ea",
            "type": "Format",
            "title": "RDF/XML",
            "description": "RDF/XML Format.",
            "href": "https://pi.pauwel.be/voc/buildingelement/ontology.xml",
            "extension": "xml"
          }
        ]
      }
    ]
  }
]
"dt_data": {
  "id": "dt_dd:f538c",
  "data": {
    "type": "dcat:Dataset",
    "title": "Knowledge Graph",
    "description": "Knowledge Graph of SDT 01U2O from project 308736f9-f533-4b4b-9a49-14b5363690db",
    "distribution:abae0": {
      "type": "dcat:Distribution",
      "dcat:accessURL": "https://triplestore.cogito.iot.linkeddata.es/resource?uri=https:\%2F\%2Fdata.cogito.iot.linkeddata.es\%2F308736f9-f533-4b4b-9a49-14b5363690db&role=context",
      "dcat:mediaType": "application/sparql-results+json",
      "data_service:f1526": {
        "type": "dcat:DataService",
        "dcat:endpointURL": "https://triplestore.cogito.iot.linkeddata.es/repositories/cogito-triplestore",
        "dcat:endpointDescription": "SPARQL endpoint of the Triplestore where the Knowledge Graph is stored."
      }
    }
  }
}

WoTDT Digital Twin Data Example
WoTDT Digital Twin Services

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"dt_services": [
  "id": "dt_ss:075c1",
  "properties": {
    "validate_rdf": {
      "forms": [
        {
          "href": "https://data.cogito.iot.linkeddata.es/validation/api/validate_rdf/data",
          "type": "text/turtle"
        }
      ]
    }
  },
  "actions": {
    "register_shacl_model": {
      "forms": [
        {
          "href": "https://data.cogito.iot.linkeddata.es/validation/api/rdf_shacl/model",
          "type": "application/octet-stream"
        }
      ]
    }
  },
  "events": {}
],
"td:InteractionAffordance"
Types of Connection Points

- dcat:Resource
- td:InteractionAffordance
- dtw:Model
"dt_cn": [
  "id": "dt_cn:38cca",
  "connection": {
    "id": "connection:190d0",
    "type": "Connection",
    "title": "Materialization connection.",
    "consumer": {
      "type": "DTw_Service",
      "title": "Helio",
      "description": "Materialization service used to generate RDF data.",
      "href": "https://data.cogito.iot.linkeddata.es/validation/api/project_to_rdf/data",
      "internal": "true"
    },
    "provider": {
      "type": "dcat:Dataset",
      "title": "IFC File",
      "description": "IFC File of SDT 01U2O from project 308736f9-f533-4b4b-9a49-14b5363690db.",
      "href": "https://dtp.cogito-project.com/file/508bfae6-dada-46d1-8d40-beb18c1619b8/download",
      "internal": "false"
    }
  }
],
...

"dt_cn": [
  "id": "dt_cn:38cca",
  "connection": {
    "id": "connection:190d0",
    "type": "Connection",
    "title": "Materialization connection.",
    "consumer": {
      "type": "DTw_Service",
      "title": "Helio",
      "description": "Materialization service used to generate RDF data.",
      "href": "https://data.cogito.iot.linkeddata.es/validation/api/project_to_rdf/data",
      "internal": "true"
    },
    "provider": {
      "type": "dcat:Dataset",
      "title": "IFC File",
      "description": "IFC File of SDT 01U2O from project 308736f9-f533-4b4b-9a49-14b5363690db.",
      "href": "https://dtp.cogito-project.com/file/508bfae6-dada-46d1-8d40-beb18c1619b8/download",
      "internal": "false"
    }
  }
],
...
}
WoTDT ontology is developed as an extension of TD ontology to describe the five-dimensional architecture approach of DTws.

Thanks to WoT, this ontology enables a more precise comprehension of the DTws and provides direct access to all the system functionalities.

Despite being initially designed for the construction domain, the ontology is flexible enough to incorporate new classes and subclasses to the different dimensions, to cover other domains.

In future research, WoTDT can be useful for the aggregation of DTws, where different DTws can be defined, and use this definition to perform the aggregation process.
Many Thanks!

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