An Indoor Navigation Ontology for Production Assets in a Production Environment

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Abstract This article highlights an indoor navigation ontology for an indoor production environment. The ontology focuses on the movement of production assets in an indoor environment, to support autonomous navigation in the indoor space. Due to the fact that production environments have a different layout than ordinary indoor spaces, like buildings for office or residential use, an ontology focusing on indoor navigation looks different than ontologies in recent publications. Hence, rooms, corridors and doors to separate rooms and corridors are hardly present in an indoor production environment. Furthermore, indoor spaces for production purposes are likely to change in terms of physical layout and in terms of equipment location. The indoor navigation ontology highlighted in this paper utilizes an affordance based approach, which can be exploited for navigation purposes. A brief explanation of the routing methodology based on affordances is given in this paper, to justify the need for an indoor navigation ontology.

1 Introduction

Spatial information systems concentrate on the outdoor space, while humans and things reside indoors and outdoors. Publications show, that an average person spends approximately 90% of their time inside buildings [1]. Compared with the developments for outdoor space, indoor space applications are quite behind and recently got into focus of research and development activities. Worboys [2] highlights the ubiquitous availability of satellite technology (GPS) and aerial photography as utilities used for data collection and positioning in an outdoor space. Due to the emergence and mass market availability of location-based service applications, there is a growing demand for such applications in an indoor environment. Location-based applications in an indoor environment are intended to support people in indoor decision processes – e.g. orientation, navigation and guidance.

The context of a production environment is a special indoor space, as the indoor space is laid out in order to support the production processes best. Hence, a production indoor layout looks different than a piece of architecture constructed for office or residential use. Due to the fact that the purpose of the production indoor space is solely devoted to support efficient production processes there are few fine grained architectural entities that are distinguishable – like rooms. Hence, theory has to cope with non-standard indoor entities that are subject of this paper. Additionally, the positions of equipment can be reordered which alters the layout of the indoor space. This holds especially true for the use case semiconductor industry, which forms the application context of this paper. Due to the fact that any semiconductor production is done in a cleanroom environment, there are several constraints in terms of movements. Not every production asset is allowed to go anywhere in the production line due to clean-room restrictions, and/or certain production processes which have to be separated due to contamination risks.

In order to support production processes accordingly, there is a need to locate two distinct object classes in the indoor environment: production assets that will undergo several production steps, and production equipment that processes the assets accordingly. In a flexible production environment, like the semiconductor industry, equipment and their positions might change. Either the tool itself is replaced by a new one or the location of a piece of equipment is altered. Additionally, the "production line" is not fulfilling a conveyor belt metaphor with a fixed processing chain. The semiconductor production line is a highly flexible and complex system, due to the following reasons:

- Overall processing time (from raw wafer to electronic chip) of a single production artifact can last from several days to a couple of weeks depending on the product.
- Several hundred production steps necessary until the production is finished.
- High number of different products that require different production steps.
- Each production step can be carried out on several tools which are sometimes geographically dispersed over several production halls – also with varying processing time and quality depending on the equipment used.
- High number of production assets – in different degrees of completion – present in the indoor production line.

The overarching goal is to support the transport processes of production assets in an indoor production environment. With such an approach the current production processes can be supported and an optimized physical layout of the indoor space could be computed by conducting specific simulation runs. In this paper we focus on the navigation and autonomous movement of production assets that shall be supported by means of Geographic Information Science and Technology. Autonomous in this context refers to the ability that each production asset knows explicitly where to go next after a completed processing step. Additionally, the indoor informatics system should be resilient in terms of changes to equipment and indoor spaces. The initial goal is to understand and model the movement of production assets in an indoor production environment. In order to model the movement of production assets an ontology is created that describes indoor space, indoor movements and navigation tasks. Both – indoor space and indoor movements – are necessary in order to fully understand the movement processes possible in the indoor production environment. The ontology is based on the work of Yang and Worboys [3] and Worboys [2].

In this paper we focus on the modeling of movements of production assets in an indoor production environment in order to support autonomous navigation in the indoor space. The environment "production line", which differs from ordinary indoor spaces by the unstable behavior of the indoor entities, requires the movement ontology to look different than in current literature. In order to support autonomous routing in an indoor production environment we utilize the concept of affordances.

The remainder of the paper is structured as follows. In section two the relevant literature is presented, followed by a description of the indoor production environment. This is followed by a section elaborating on the movement behavior of production assets in an indoor production environment, which depends on the description of the indoor production space. Consecutively, we present the indoor movement ontology and extend it towards affordance based routing in an indoor environment in the subsequent section. In the last section we summarize the paper, discuss the results and future work.

2 Relevant Work

This section covers the relevant literature for the paper. First we the highlight relevant work covering indoor geography and switch to indoor geography and production line processes with spatio-temporal data mining in an indoor environment. Additionally, this section covers some literature on affordance-based ontologies for navigation purposes.

A significant number of research activities were carried out over the last decades in the context of modeling outdoor space, providing a rich set of methods high level of structuring and applications. However, indoor geography related research has attained increasing attention during the last years due to the fact that an average person spends about 90% inside a building [1, 4]. Early research works on indoor wayfinding include Raubal and Worboys [5] and Raubal [6]. The work in [6] uses an airport as example of an indoor environment and presents an agent-based indoor wayfinding simulation.

In order to model indoor spaces there exist several approaches that use topology, where the indoor space is "reduced" to a graph [5, 7, 8, 9]. Jensen et al. [10] employ a graph based model to track entities in an indoor environment by placing sensors in the indoor space. To model the 3D geometry of buildings Building Information Systems are used, which do not support navigation and routing in general [11]. Worboys [2] mentions hybrid models that include geometrical and topological features, which are well studied in literature [12, 13, 14]. Other approaches provide different levels of granularity of the indoor space. Hence, the user can rely on more details for important points on a journey which requires route generation and visualization in one application [15, 16, 17].

Production line processes represent a challenging research and application field for indoor geography. Due to the fact that any optimization of production processes is depending on allocation and sequencing of production processes. Such optimization can increase the efficiency of production processes and therefore provide an interesting option for cost savings based on an increase of performance and productivity [18, 19, 20]. An increase of productivity can also be realized by analyzing spatio-temporal data, which are generated by storing historical information on production processes. Data mining methods are appropriate to analyze spatio-temporal data accordingly [21]. In order to create maps to visually analyze such data, geovisual analytics can be employed [22]. The main advantage is that a person has the ability to recognize visual patterns [23].

In order to model indoor movement of production assets we use ontologies to formally describe the behavior. Ontologies try to determine the “various types and categories of objects and relations in all realms of being” [24]. A domain ontology describes what is in the specific domain in a general way, resulting in a formal description of the content and the behavior of a part of the physical world [6]. Davis [25] lists the elements of a domain ontology: entities, relations and the rules applied. The theory of affordances is used to model routing and navigation of production assets, as they should be able to move in an autonomous manner, requiring the detection of the best possible path with respect to given constraints. The term “affordances” is coined by Gibson [26, 27]. Affordances and ontologies have been subject to research in outdoor and indoor environments [28, 29, 30]. While Anagnostopoulos et al. [31] and Tsetsos et al. [32] develop an indoor space ontology focusing on navigation, Yang and Worboys [3] develop an ontology for indoor-outdoor space. They separate different “microworlds” by distinguishing between the upper level ontology, domain ontology and a task ontology. The navigation ontology developed in this paper inherits elements describing the indoor space in order partially integrate indoor space entities in the navigation ontology. Hence, the approach in this paper includes a task and domain ontology – indoor space – with respect to Yang and Worboys [3]. Hence, the work here can be related and integrated in the upper as well as the indoor space and task ontology published in [3].

3 Indoor Production Environment

This section describes the indoor production environment under review. As previously mentioned, the objective of this paper is the modeling of production assets in a semiconductor fabrication. Such an indoor environment has several peculiarities that distinguish it from other production environments and ordinary indoor spaces. This section is based on the work of Geng [33], Osswald et al. [34] and personal experience.

Any semiconductor fabrication has to be operated in a clean room environment that ensures a low proportion of contaminating particles – both in size and quantity. Due to the fact that clean room space is expensive to construct and maintain, clean rooms are designed to be as compact as possible for the chosen equipment to be placed inside. Hence, the space dedicated to movement (people and production assets) and storage of production assets is limited. In addition, different quality classes of clean rooms exist, that are distinguishable by air quality (particles per m^3 air). Generally, the changeover between different clean room quality classes – often adjacent – is not easily possible. While it is allowed to switch to a clean room of lower quality at any time through doors, the switch to a clean room of higher quality is only possible through special airlock. This is especially true for the process of entering a clean room environment, which is only possible via specific airlocks. Hence, any humans – i.e. operators – can only leave and enter a production line using the airlocks. Similar, production assets can only enter the clean room at a specific airlock designed for production assets and are thoroughly cleaned thereafter, in order to prevent any contamination in the main production line.

The movement of operators and production assets is additionally restricted to other quality issues. Specific production asset types are prone to contamination due to chemical processes which are a result of certain production processes. Hence, selected production assets are not allowed to enter or leave a certain area of the production line to prevent them from contamination. As the production is located on different floors there are several possibilities to switch floors. Some staircases can be used by operators carrying production assets, while others can only be used by operators. In general production assets change floors by using elevators.

The indoor space under review is highly unstable, due to constant change of market demand and, thus altered production necessities. Hence, equipment has to be relocated, removed or new equipment is brought into the production facility. These processes can result in an altered layout of the indoor space, as corridors might change according to the space needed for certain equipment. This has consequences for the navigation of production assets as the "best" paths connecting two devices are altered.

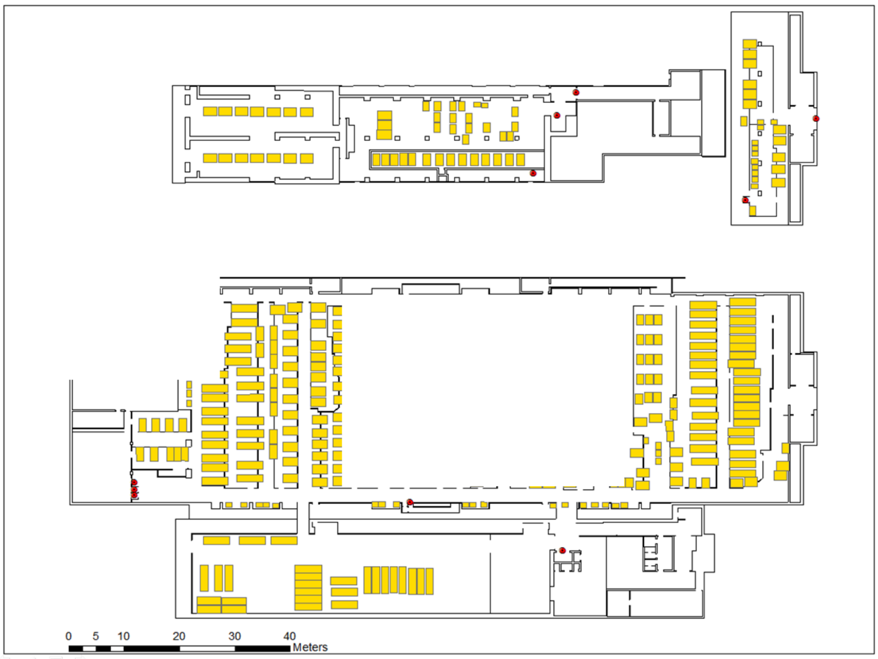

Fig. 1. Indoor space layout of the semiconductor production which is subject of this paper. Yellow rectangles represent devices in the clean room, and red dots represent transfer nodes. The white spaces are intentionally to disguise the complete production layout.

Generally, the layout of the production hall differs from classical production environments and ordinary indoor environments. Office or residential buildings' indoor space can be divided into rooms and corridors that are connected by doors. In a semiconductor environment, rooms are hardly present due to the fact that the indoor space is organized in distinguishable corridors with considerable length (see Fig. 1).

The production of microchips is a complex process chain that involves several hundred different production steps not aligned on a conveyor belt. Hence, there movement processes have a multifaceted structure due to a multitude of different microchip types having different production process chains. Additionally, each production step can possibly be done on several tools which increases the flexibility in terms of production, and increases the complexity of the movement behavior. In addition, the equipment suitable for a certain production step may be geographically dispersed. Nevertheless, each microchip type has a specific production plan that defines the process chain. Hence, each production asset in the clean room has a certain grade of completion and the next production step can easily be determined.

The indoor production line under review consists of one production hall of an Austrian semiconductor manufacturer. The layout of the indoor space is depicted in Fig. 1, showing the equipment positions as yellow and blue rectangles. In order to track production assets accordingly, an indoor tracking system called LotTrack is employed that relies on RFID and ultrasound technology. A detailed description of the system, the rationale behind the utilized technology and the application itself is found in [35].

4 Movement of Production Assets

In order to model the movement of production assets in an indoor environment, we start with a monitoring of the current in-situ "behavior" of production assets. The evaluation of trajectories collected gives insight in the behavior and helps shaping the navigation ontology accordingly. Thus, the following section elaborates on the movement behavior of production assets in the indoor environment. It is intended to show that we can model the movement of the agents using a graph, consisting of edges and nodes respectively.

The hypothesis regarding the movement is that production assets are moving along the corridors, most probably along the centerline of a corridor. Hence, the positions of production assets are compared with a graph consisting of corridor center lines and connection lines to equipment only in areas that are traversable by humans and production assets (see Fig. 2). To evaluate the spatial nearness between gathered asset positions and the graph a 1m buffer around the graph is created. In total a number of 41097 position recordings are tested (see Fig. 3) with respect to the buffer zone. In total 97.3% of the positions are inside the network buffer of 1m.

Problematic in this respect is the position of the antennas used to gather the production assets' position. The positioning antennas are placed on the ceiling with special rails and the positioning algorithm of LotTrack snaps positions to the nearest antenna rail. Hence, any tracked positions are generally shifted.

The evaluation of tracked positions of production assets as well as the layout of the indoor space – i.e. corridors – gives evidence that movements can be modeled utilizing a graph [7, 8, 9]. The graph used to model the movement of assets comprises of nodes and edges, which are described in detail in the navigation ontology in section 5.

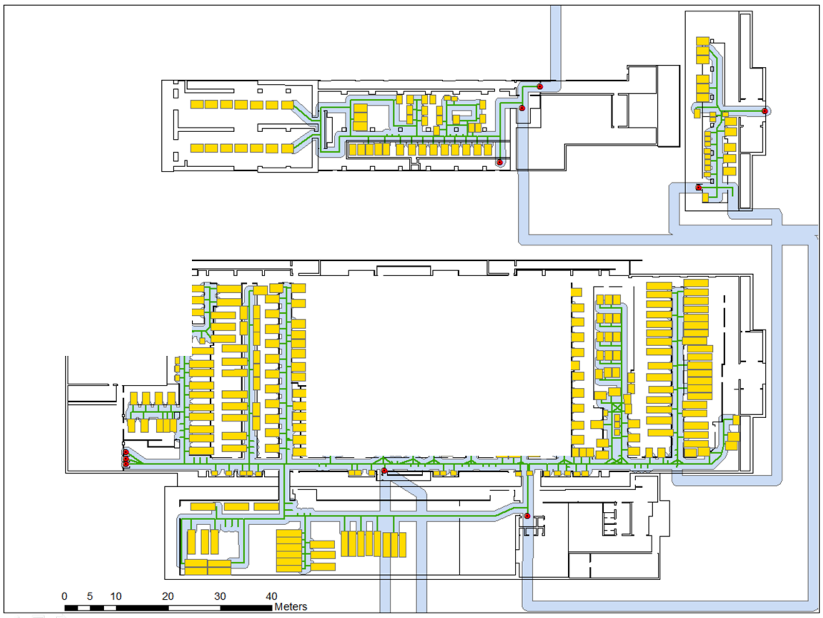

Fig. 2. Indoor space of the production hall under review. The green line represents the network that is traversable by humans and production assets, whereas the blue areas mark a 1m buffer around the network. Blue areas without green network lines are intentionally created, and represent the "virtual" connection of transfer nodes. The white spaces are intentionally to disguise the complete production layout.

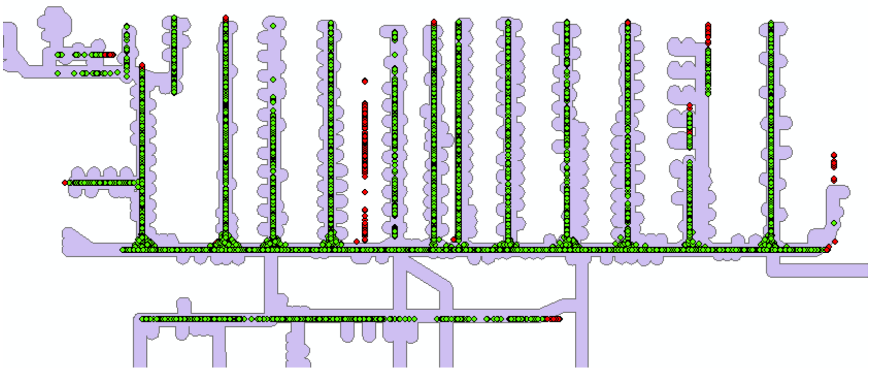

Fig. 3. Tracked production asset positions (approx. 41000) in relation to the 1m buffer around the network (marked in purple). The network positions are marked in green if they are inside the buffer and red if outside.

5 Affordance-based Indoor Navigation Ontology for Production Environments

Creating the navigation ontology for production assets is closely related to the work of Yang and Worboys [3]. The navigation ontology developed in this paper inherits also elements describing the indoor space in order to have an integration of the navigation ontology and indoor space entities. The ontology developed here is based on affordance theory [26, 27] which can be used to establish connections between indoor and outdoor space. In addition, we employ the theory proposed by Jonietz and Timpf [36] of an affordance-based simulation framework for spatial suitability for navigation purposes.

5.1 Indoor Navigation Ontology

The indoor navigation ontology for production assets is presented in the following section. The ontology is depicted in Fig. 4 providing an overview of the model itself. The definitions of the concepts are given in this section.

Production Unit: A production unit represents the whole equipment of a production line. For example a Facility or a Device that are used during the various production steps. The subclasses are *ProductionUnit_Facility* and *ProductionUnit_Device*.

- *ProductionUnit_Device:* A device is the production unit used for the processing of goods. The device has a fixed position in the production line.
- *ProductionUnit_Facility:* The facility supports transport processes in the production line. The goods can be placed on shelves or tables if they are waiting to be processed or transported. The subclasses of a facility are *ProductionUnit_Facility_Moveable* and *ProductionUnit_Facility_Fixed*.
  - *ProductionUnit_Facility_Moveable:* A moveable facility is used to support a high stock of goods in the production line. They are e.g. bottleneck shelves used to store an extra amount of production assets. Such objects are removed if the stock in the production line is decreasing.
  - *ProductionUnit_Facility_Fixed:* Fixed facilities represent tables, shelves and other not moveable equipment in the production line.

Barrier: A barrier is limiting the transportation or movement behavior in the production line. The subclasses are *Barrier_Fixed* and *Barrier_Moveable*.

- *Barrier_Fixed:* A fixed barrier is limiting the movement behavior and cannot be changed very easily. Subclasses are *Barrier_Fixed_Wall*, *Barrier_Fixed_ProductionDevice* and *Barrier_Fixed_AirQuality*,
  - *Barrier_Fixed_Wall:* A wall is a fixed barrier. It is limiting the transport behavior within a production line.
  - *Barrier_Fixed_ProductionDevice:* The device in a production unit is linked with several infrastructure items such as electricity and gas lines and is regarded as a fixed or not easily changeable barrier.

  - *Barrier_Fixed_AirQuality:* For several production goods the air quality in a clean room is of importance and is also a barrier for the transport and movement behavior.
- Barrier_Moveable: Moveable barriers represent mainly barriers that can change over time very easily. The subclasses are *Barrier_Moveable_ProductionFacility* and *Barrier_Moveable_Contamination*.
  - *Barrier_Moveable_Contamination:* A contamination is a barrier over time. Hence, a certain production good is not allowed to enter a specific area of the production line.
  - *Barrier_Moveable_ProductionFacility:* Any production facility can impede movement as it is limiting the space for transportation. E.g. The position of shelves may easily be changed if they are not necessary anymore.

AccessNode: An AccessNode is linking outdoor and indoor space or vice versa. The subclasses are *AccessNode_Outdoor2Indoor*, *AccessNode_Indoor2Indoor* and *AccessNode_Indoor2IndoorTransfer*.

- *AccessNode_Outdoor2Indoor:* The connection from outdoor geography into the indoor environment. Therefore, the subclasses *Entrance*, *Exit* and *EntranceExit* are necessary.
  - *AccessNode_Outdoor2Indoor_Exit:* The exit is representing the way from an indoor geography back to the outdoor geography. This is necessary as there exist designated doors for leaving a production line (especially true for a production environment with clean rooms)
  - *AccessNode_Outdoor2Indoor_EntranceExit:* The EntranceExit represents both the way from outdoor geography to indoor geography and backwards.
  - *AccessNode_Outdoor2Indoor_Entrance:* The entrance enables the interaction and movement from outdoor into the indoor space.
- *AccessNode_Indoor2IndoorTransfer:* The transfer indoor is representing the connection in the same indoor space, thus connecting e.g. different floors.
  - *AccessNode_Indoor2IndoorTransfer_Elevator:* The transfer of production assets with an elevator in order to change the floor level.
    - *AccessNode_Indoor2IndoorTransfer_Elevator_TimeDependend:* The time dependence of an elevator is used in order to integrate the average waiting time until an elevator is available, due to the fact that elevators are mostly not available instantaneously.
  - *AccessNode_Indoor2IndoorTransfer_Stair:* A stair enables the transfer between different floors in an indoor space.
    - *AccessNode_Indoor2IndoorTransfer_Stair_NonRestricted:* Traversing a stair is allowed for all production asset types.
    - *AccessNode_Indoor2IndoorTransfer_Stair_Restricted:* The traversal of a stair is not allowed for certain production asset types.
- *AccessNode_Indoor2Indoor:* This class represents the transfer between different indoor spaces – e.g. different production halls.
  - *AccessNode_Indoor2Indoor_QualityCheckpoint:* A quality check such as an e.g. air quality check with an airlock.

- *AccessNode_Indoor2Indoor_SecurityCheckpoint:* The entrance to certain areas can be restricted.

Corridor: A corridor is describing and including the ways where an operator – i.e. human being – can walk and transport the production goods in the production line. The subclasses are *Corridor_Node*, *Corridor_Passage* and *Corridor_Entrance*.

- *Corridor_Node:* Corridor nodes include the starting point, end point or interaction point of a navigation process.
  - *Corridor_Node_ProductionFacility:* A start point, end point or interaction point can be a production facility. For example a good has to be brought to a shelf because something has to be controlled.
  - *Corridor_Node_ProductionDevice:* A production device is mainly a start or end point for the transportation or navigation as the production goods are processed here.
- *Corridor_Passage:* The passage itself is representing the way between two consecutive navigation tasks.
  - *Corridor_Passage_Edge:* An edge is used between the different nodes and is combined to a passage along the corridor.
- *Corridor_Entrance:* Corridors need entrance points to the network for navigation and transportation in the production line.
  - *Corridor_Entrance_AccessNode:* The access node is one opportunity where operators or production assets are accessing the transportation network.
  - *Corridor_Entrance_Node:* Entrance nodes can also be production devices or facilities.

Navigation_Event: Any navigation task is described through the classes *Navigation_End*, *Navigation_Start* and *Navigation_Turn*.

- *Navigation_End:* This class represents the destination of a transportation or navigation task.
  - *Navigation_End_AccessNode:* An access node is the destination node of the navigation process if e.g. a production asset leaves the production line.
  - *Navigation_End_ProductionUnit:* The transportation between devices or facilities implies that a production facility or device is the end of the navigation task.
- *Navigation_Start:* The navigation start is representing the start of a navigation task, which can either be an *AccessNode* or a *ProductionUnit*.
  - *Navigation_Start_AccessNode:* An access node is the start of the navigation if a production asset is entering the production line.
  - *Navigation_Start_ProductionUnit:* The production unit is a starting point for the navigation.
- *Navigation_Turn:* During the navigation a production asset can perform several actions. These actions are the subclasses *Navigation_Turn_Right*, *Navigation_Turn_Left*, *Navigation_Turn_Backward* and *Navigation_Turn_Forward*.
  - *Navigation_Turn_Right:* The production asset turns right.
  - *Navigation_Turn_Left:* Represents a turn to the left.

- *Navigation_Turn_Backward:* This event is a turn backward or represents backwards moving.
- *Navigation_Turn_Forward:* This is a move forward.

Navigation_Agent: The agent that is navigating through the indoor space.

– *Production_Asset:* This class represents the navigation agent, and encompasses various types of production assets with different properties that have an influence on the suitability of a certain route and the choice of a certain route.

Navigation_Structure: This class contains generic entities that are necessary for route calculation proposes. A sequence of instances of the subclasses *Navigation_Node* and *Navigation_Edge* on which an agent moves defines a *Navigation_Path*. The objects of the class *Navigation_Structure* are help to specify the indoor space entities in terms of representation in a graph with nodes and edges.

5.2 Affordance-based Routing

The navigation of production assets is based on affordances offered by the objects in indoor space with an approach similar to [36]. Affordances, initially coined Gibson [26, 27], describes a concept where an object offers its meaning. Gibson [27] further specifies the concept, that an affordance is not only defined by attributes of an object, but also by the abilities and properties of the interacting object [36]. In this context this approach is applied to the relations of machines and production assets with respect to their properties respectively.

For the case of production assets, several types of assets with specific properties exist that have to be respected when navigating. In addition, in order to define a navigation task the determination of a destination point – i.e. equipment offering a certain production process – and the selection of an appropriate path has to be carried out. This section gives only a rough overview of the algorithm in order to give an impression on the usage of the indoor navigation ontology.

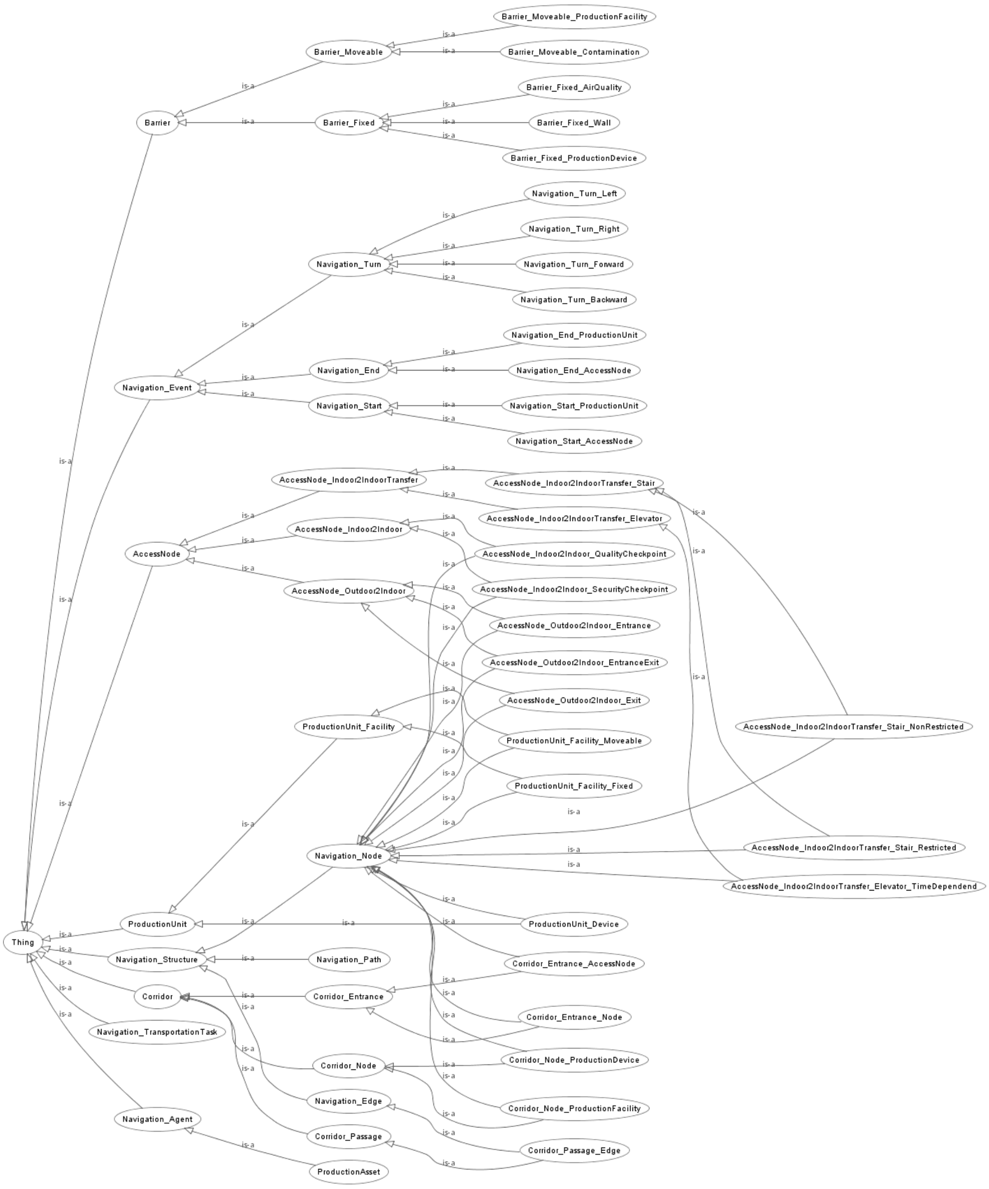

Fig. 4. Navigation ontology for indoor production space focusing on the movement of production assets.

In order to facilitate autonomous navigation of production assets in a semiconductor production environment each instance of the class *ProductionAsset* has certain characteristics:

- Product type: The product type reveals information on possible means of transport (e.g. thin wafer shall be carefully handled [i.e. only elevator, no stairs], 300mm wafers can withstand a low quality clean room due to a specialized plastic enclosure, with 300mm wafers it is not possible to open doors due to the weight of wafers including the plastic enclosure). In addition, the product type reveals information on barriers (quality, contamination) applicable that impede movement.
- List of production processes: This holds information on the sequence of production processes that have to be carried out. Due to the fact that certain processes can be done on several machines, with different processing results in terms of quality, each production asset has to select the piece of equipment that fulfills the requirements “best”.

To support navigation processes in an indoor production space we apply the framework laid out in Fig. 5, which shares similarities with the approach of Jonietz and Timpf [36]. The methodology comprises of the collection of actions of a single production asset – e.g. move to the next production step “cleaning” starting from equipment “etcher_12”. In order to determine the sub-actions contained in an action, the framework starts to analyze the destination production step of the action and moves towards the start point until the starting point is reached. For the action ‘move to the next production step “cleaning” starting from equipment “etcher_12”’ the approach starts to find indoor entities offering the production step “cleaning”. If there is one piece of equipment affording the process of “cleaning” the algorithm analyzes the properties of the cleaning equipment, the start equipment “etcher_12” and the production asset. This results in differences in terms of indoor location – e.g. equipment located on different floors – and/or additional properties that have to be respected – e.g. thin wafers, where no stairs are allowed. Based on the differences and properties of indoor space entities and production assets the sub-actions are determined, starting from the destination equipment towards the start node. Based on the sub-actions found, the algorithm determines the nodes offering the required movement processes. E.g. a sub-action ‘change from floor 1 to floor 2 with an elevator’ searches for a node offering a connecting floor 1 and 2 by an elevator. This process finally results in a set of candidate nodes that are the basis for the navigation of the production assets.

Based on the set of candidate nodes a routing algorithm calculates the “best” route which will be traversed by the production asset. First, candidate routes from start node to target node are determined and evaluated regarding overall route cost. Costs in this respect could be time, overall path length, or any other metric applied. Finally, the route with the lowest cost is returned.

Fig. 6 shows an application prototype for affordance based routing in the indoor production environment. There a production asset starts at an entrance node – labeled with 1 – and has 5 actions to perform, i.e. navigate to five devices in a certain order, where equipment 6 is located on a different floor. In addition, the production asset requires to be moved with care, thus the transition between the floors must be done with an elevator.

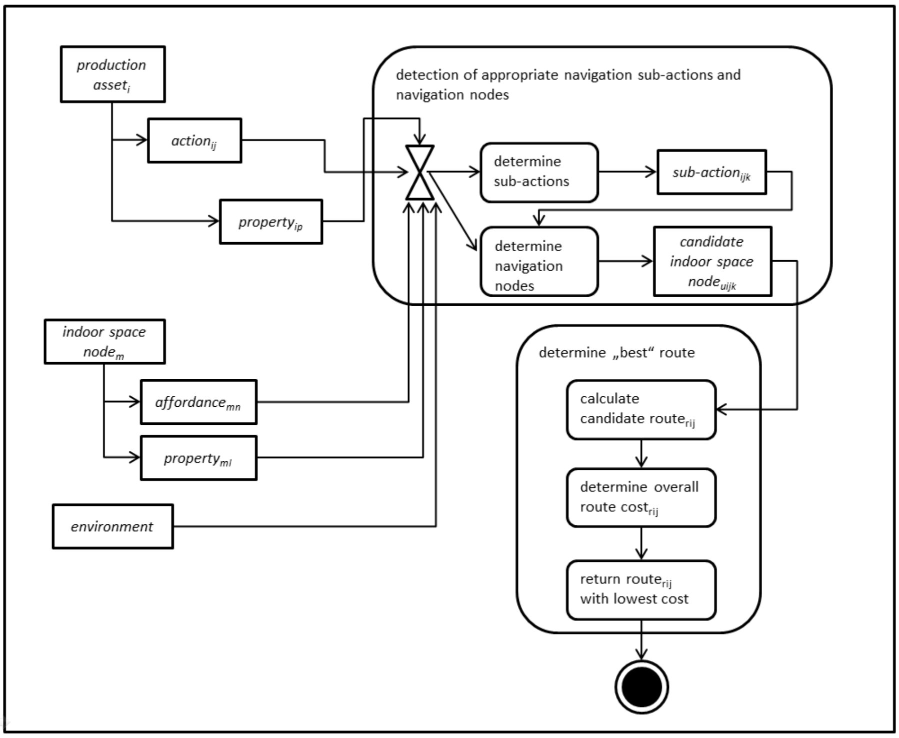

Fig. 5. General approach employed in navigating indoor space based on affordances.

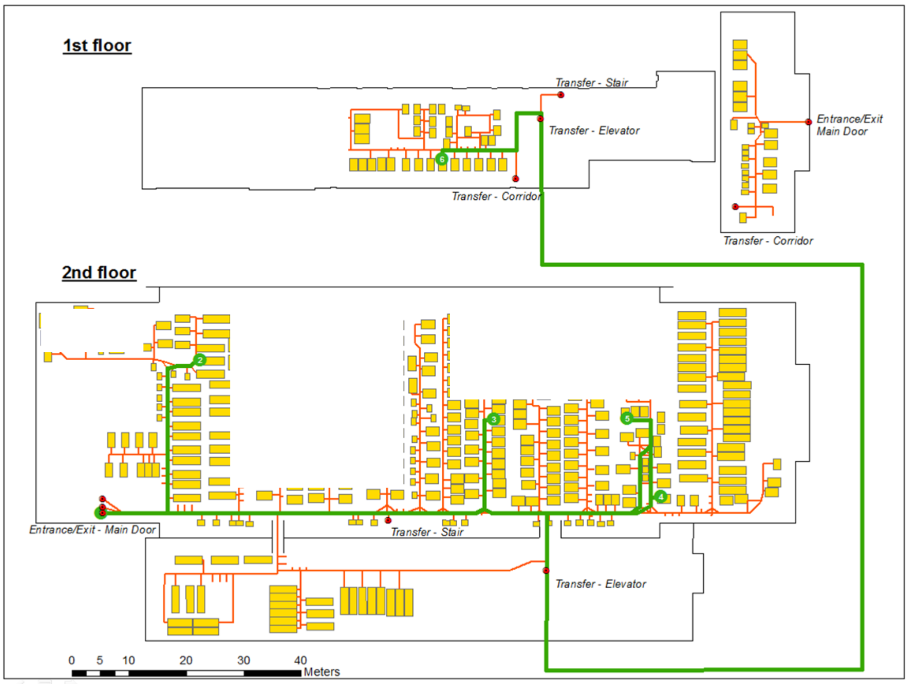

Fig. 6. Prototype application for affordance based routing in an indoor production environment. The red lines represent the traversable graph, and the green lines the route for the production asset. Five actions starting from the main entrance exist that have to be carried out, which are labeled with numbers in ascending order (start node is labeled with 1, final end node is labeled with 6). Of interest is the mandatory transfer from floor 2 to floor 1 by elevator. The white spaces are intentionally to disguise the complete production layout.

6 Conclusion and Discussion

The article elaborates on an ontology for indoor navigation in a production environment – semiconductor manufacturing. The agents moving in the indoor space are production assets that undergo several production processes, which are not aligned sequentially on a conveyor belt. Hence, any production assets should autonomously navigate from one production step to the next with respect to properties of the production asset and the indoor environment. The ontology describing indoor navigation processes is affordance based and includes a description of the indoor space. Based on the results an affordance based routing methodology is outlined and applied in a prototypical application.

The indoor ontology of a production indoor space looks different than current approaches [3] because the indoor space of production environments has different entities than ordinary indoor spaces. Ordinary indoor spaces comprise of rooms, corridors, doors, etc. while the production environment in semiconductor operates in a cleanroom and consists of mainly corridors without e.g. doors or distinct rooms. Due to the fact that production assets should be able to navigate between production equipment, machinery present in the indoor space, barriers (fixed and temporary) impeding movement, and any transfer between different floors are part of the ontology. In addition, the traversable space is modeled as graph that connects elements present in the indoor space. For navigation purposes an affordance based approach is proposed, that identifies required actions and detects nodes that afford the requirements, i.e. transfer from floor 1 to floor 2.

Future research directions include connections between indoor and outdoor space – already mentioned in [3]. In addition, the navigation and movement patterns in an indoor production environment are subject to further research that can be used to evaluate the navigation ontology. To do so we intend to use the concept of Self-organizing Maps [38, 39] and spatio-temporal data mining methods for trajectory pattern mining. Furthermore, we plan to use SOM and analysis of the geographic and attribute space applying the TRI-space approach [37]. In order to focus on the affordance-based routing approach presented in this paper a study highlighting general results of affordance-based routing in comparison to contemporary routing methods.

7 Acknowledgements

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