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Smart Campus Map

by

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Abstract

The market of maps and application related to the maps is saturated with outdoor maps and services. There are many commercial and non-commercial companies and services on outdoor maps platforms. But in recent years growing of telecommunication network and mobile devices from one hand and increasing urban environment and number of smart buildings from other hand raise the need of indoor maps and indoor services which in this work we name it indoor location-based services (indoor LBS). In this sense the need for some standards and specifications both in technology-wise and geographic-wise aspect is desired. Implementing comprehensive indoor navigation systems not only needs technology platform but also cartographic and well-designed maps especially for mobile devices which in this content we call it smart maps. In present study we investigate scientific background of current standard conceptual models for indoor LBS systems and narrow them to a smart campus map. Respecting developed conceptual model we prepare some sample data of Technical University of Munich main campus both for outdoor and indoor area. In detail we discuss the workflow, problems and solutions for data preparation, and enlighten the path achieving a standard campus map model derived from OpenStreetMap and CAD floor plans. Following 3D model standards we provide a 3D model for university campus and visualize various forms. We explain a complementary project of this thesis so called TUM-Navi that implements a replica of mobile indoor navigation system for campus. In particular we propose a mobile application framework for indoor navigation system of smart campus map which covers four main aspects: 2D smart campus map, 3D visualization, outdoor environment and navigation functionalities. Finally we apply a survey to collect students' opinion on an efficient digital smart campus map and mobile Application.

Keywords: campus map, smart map, indoor LBS, indoor navigation, indoor routing
University map, indoor mobile application, campus mobile application

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Chapter1: Introduction

1.1 Motivation

In recent years along with technology improvements in smart phones and more access to the internet, services which are based on mobile devices in the domain of navigation and location came into consider. Terms such as location-based service, mobile cartography and indoor positioning emerge both in industry and science. As an example Google Maps launched Indoor Google Maps project since beginning of 2012 in USA and Japan and at the moment more than 12 countries it is in progress and in science area you can find many paper and topics on LBS and Indoor Navigation topics. Increasing daily usage of wireless access on smart phone provides much easier indoor navigation services for users. Based on the survey of The Pew Research Center's Internet & American Life Project, April - May 2011, 83% of adults own a mobile phone and 35% of adults are smart phone owners, out of this number 58% of owners use their mobile for location-based direction or recommendations[1]. On the other hand the increasing number of commercial buildings such as airports, shopping malls, sport venues and universities and the time people spend inside motivate us to focus on indoor LBS which in the primary step has a huge need to indoor maps and floor plans. Additionally, based on American Physical Society APS (2008) survey the average North American spends about 89% of their life in indoor environment, 5% outdoor and 6% in vehicles. To be focused more on university and education indoor areas in other survey U.S. Department of Education describes nearly 84 million Americans (including 73.7 million students) spend their days in approximately 124,110 colleges, universities, public and private primary and secondary schools (2007)[2]. Approaching this thesis we decide to focus on university smart campus map, since there is no standard map which representing indoor spaces integrated with the outdoor environment for indoor way finding, from cartographic perspective of view we investigate the criteria of a standard campus

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[1] The Pew Research Center's Internet & American Life Project, April 26 – May 22, 2011 Spring Tracking Survey. n=688 adult smartphone users ages 18 and older. http://pewinternet.org/Reports/2011/Location.aspx, Accessed on 06.2013

[2.] National Center for Educational Statistics- Digest U.S. Department of Education. 2007, http://nces.ed.gov/programs/digest/d07/tables/dt07_001.asp?referrer=report, Accessed on 06.2013

map, data model, the way of communication with a campus map for indoor LBS purposes and visualization approaches.
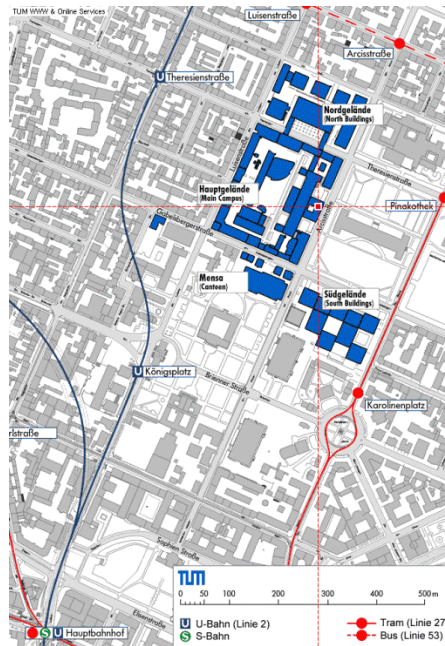
Fig. 1: Technical University of Munich, main campus in the city, www.tum.de

This map is used for room finding tool on the TUM webpage, also showing subway line and entrance. This map is not an interactive map and is not applicable for routing purposes.

Our case study is Technical University of Munich main campus. Figure 1 shows Technical university main campus in the city center. This map is the only map available on the campus web page, and it is not an interactive map. From cartography point of view it is not an aesthetic map and this makes us to work on a campus map for web page application and mobile applications which is appropriate for indoor navigation systems. Figure 2 shows other available maps of university campus (you are here map) which are installed on the university halls and corridors.

This approach is mainly investigating a smart campus map for small screens like mobiles and tablets.
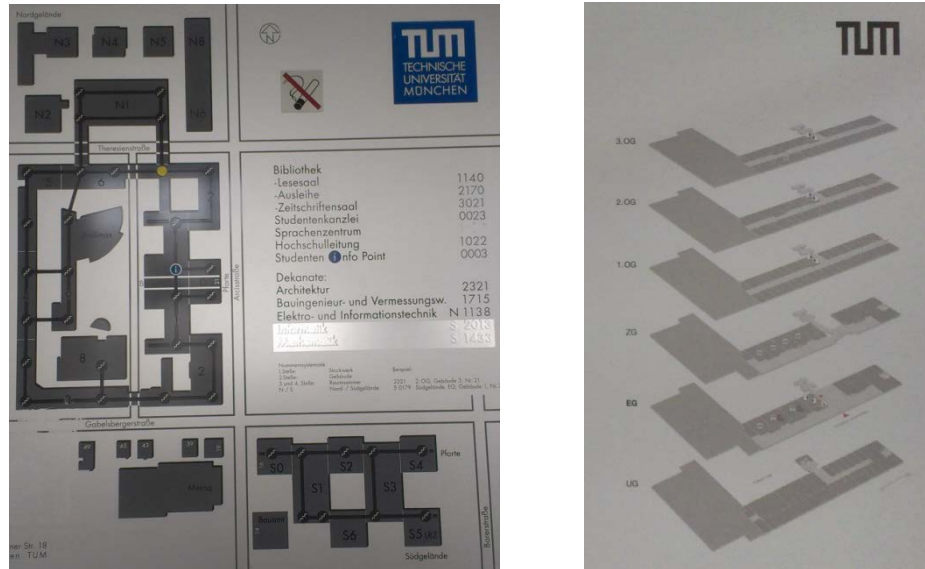
Fig. 2: Technical University of Munich, Main Campus (source: university campus)

(Left image): "you are here map" installed in the university halls and corridors
(Right Image): Another "you are here map" showing building Nr. 5 floors

What is smart and why smart?

Nowadays the word *smart* applies in many aspects in our life. We have smart cities, smart phones, smart cards, smart highways, smart buildings and so forth. Based on dictionaries' definitions smart means bright, intelligent, clever and quick-witted or everyone and everything that has these characteristics. A research project conducted by the Centre of Regional Science at the Vienna University of Technology identifies six main dimensions along which a ranking of 70 European middle size cities can be made. These axes are: a smart economy; smart mobility; a smart environment; smart people; smart living; and smart governance (Caragliu et al. 2009). Talking about smart cities is about their infrastructure, planning and management and people. In these categories there are subcategories such as smart buildings and urban planning, environmental, transportation, education, energy and government (IBM 2012). In this concept we have smart buildings which have sensors and infrastructure for facility management, energy safety, lighting, fire alarm, control water (flow sensing), HVAC[3] (fans, variable air volume, air quality), access and security, elevators (maintenance, performance), PHEV[4] changing (charging of hybrid, electric vehicles) and monitoring (condition monitoring, parking lot

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[3] Heating, Ventilation, Air-Conditioning

[4] Plug-in Hybrid Electric Vehicle

utilization) (IBM 2012). Following these applications for smart term, we define smart map and relating to our work *smart campus map.* So we investigate what makes a map smart and how we can implement a smart campus map especially for mobile devices.

1.2 Thesis Objectives

As mentioned in motivation, establish a work flow and instruction for a smart campus map which is suitable for routing purposes is the base of this thesis. Following this goal we aim to investigate instructions to answer questions of location base services such as "Where am I?", "What is nearby?", "How can I go to?" from indoor LBS perspective in a campus map. The focus is on communication ways with a smart campus map, Campus map from 2D and 3D aspects and does and don'ts in a mobile campus map. We try to answer:

1- Why we need a smart campus map?
2- What are the standards and specifications for a smart campus map for indoor LBS purposes?

The following list describes the objectives of this thesis:

- Investigating indoor LBS and related projects in indoor areas
- Review on current indoor positioning systems
- Campus map conceptual and physical data model
- Data collection and preparation for campus indoor and outdoor
- Campus map standards and specifications
- Using campus map for a mobile application
- 3D campus map for mobile screen
- Collecting student's view over a smart campus map/App

1.3 Thesis Structure

 Following the mentioned objectives after current chapter which is introduction we continue with more general discussion in Location Base services and later on focus on indoor LBS and mobile location services. The below figure (see Fig.3) illustrate the structure of the thesis.
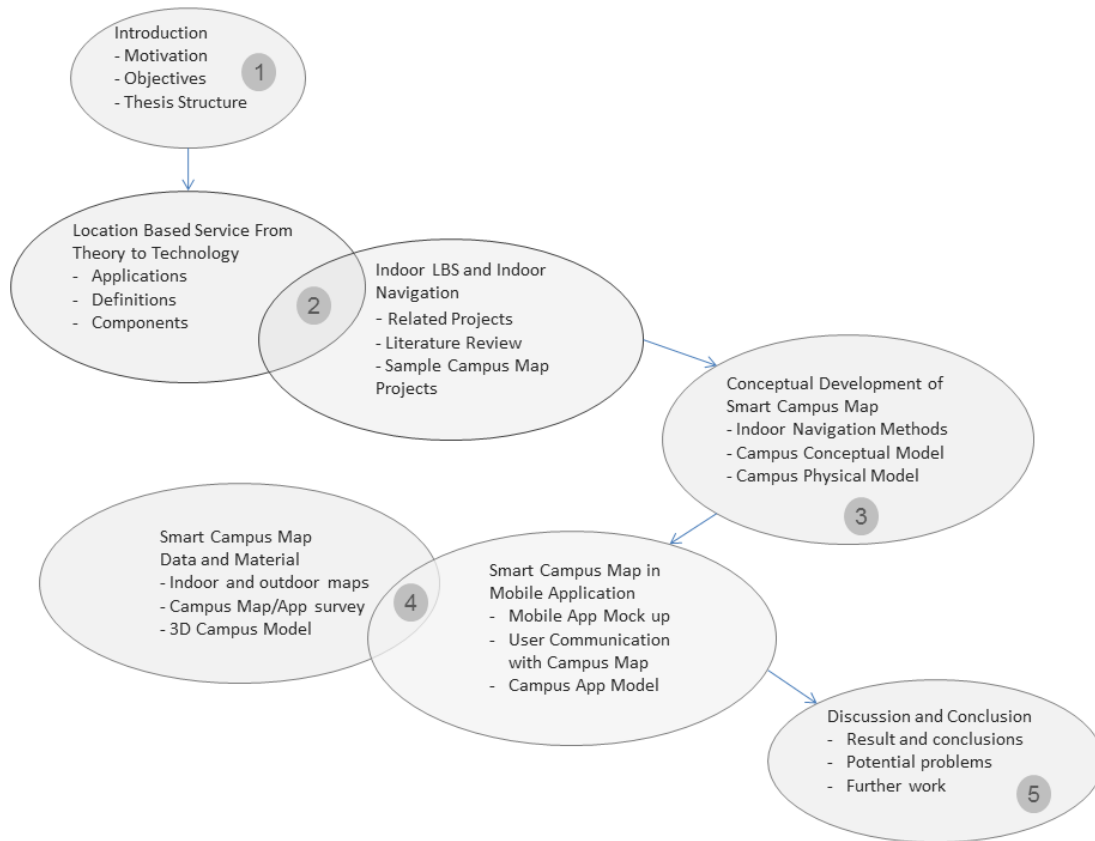
Fig. 3: Thesis Structure

Chapter1: Introduction, motivation, objectives

Chapter2: In this chapter we give a definition for LBS from different literature and investigate components of location base service and how it is useful in daily life. Also consider privacy issues in current location based services especially on the mobile devices and for indoor maps. We go through some literature review and related work in indoor LBS, indoor OSM and university campus map.

Chapter3: In this chapter we focus on the methodology of the work and a work flow for data collection and transformation to make a suitable campus map. Referring to current indoor LBS specification such as OGC, CityGML, BISDM and indoor OSM develop conceptual and physical model of campus map and fill it with sample data of TUM main building.

Chapter4: Besides data part, we perform a survey from some students and staff about the potential campus map and campus App, then we design an application

mock up with the current data model and of course considering the result of the survey. We investigate the way of communication with the campus map and review methods for indoor navigation. We compare different 3D and 2D samples of campus map, and describe current available campus maps/Apps. Then describe a TUM campus App developed in a parallel work Furthermore, we discuss an optimal campus map for mobile devices from symbolization, labeling, coloring, fast loading, routing and reliability perspective of view.

Cahpter5: In this chapter we conclude and discuss the final work and examine further possible plans how to extend campus map and develop a mobile application.

Chapter2: Backgrounds and Literature Survey

This chapter we go through different literature to describe Location Based Services, application and basic component, then we go from theory to some applied examples in technology. To be more focused on thesis topic we narrow the literature review in indoor LBS and indoor navigation related works and projects. Here we mention some example of other campus map from data collection to application implementation.

2.1 LBS from Theory to Technology

2.1.1 LBS Definition

Location based service, location aware service, location related service and generally location service are interchangeable terms (Küpper 2005) which are used in many communities from different fields such as telecommunication, computer science, electronic, Geographic Information System and Cartography. The term LBS has been used many years in telecommunication and from different perspectives there are various definition for location base service. The GSM Association which unites 800 mobile operators in more than 220 countries describes LBS as services that use the location of the "target" for adding value to the service where the target is the "entity" to be located. The entity is not necessarily the user of the service and the added value to the service could be for example nearby Point of Interest (a filter of information), target location (a pointer or blue dot) or kind of push services when user enter an area such as airport and get some information (a definer) (GSM Association 2003, Küpper 2005).

Another definition by the 3rd Generation Partnership Project (3GPP)[5]: "an LBS is a service provided by a service provider that utilizes the available location information of the terminal" (Küpper 2005). Another definition by the Open GIS Consortium (OGC) describes LBS is "a wireless-IP service that uses geographic information to

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[5] 3GPP: The 3rd Generation Partnership Project unites [Six] telecommunications standard development organizations known as "Organizational Partners" and provides their members with a stable environment to produce the highly successful Reports and Specifications that define 3GPP technologies.

serve a mobile user or any application service that exploits the position of a mobile terminal" (OGC, 2003)[6].

Following mentioned definition we can say "LBSs get benefit of location aware ability of mobile devices to give services either by the user request or service provider force".

2.1.2 LBS Types, Components and Applications

There are different categories for LBS service based on the type of service; GSM Association (2003) classified these services as below:

- **Pull LBS:** This kind of services is triggered and requested by the user. The service provider based on the location of the user reply the query, such as query for the nearest petrol station. Based on (Virrantaus et al. 2001) we consider subcategories for pull LBS which is functionality service where the service is a function such as ticket payment, emergency and security services. Otherwise it is an information service such as weather forecasting. Kupper (2005) introduce *reactive* term for pull services (Küpper 2005).
- **Push LBS:** If the service provider initiate and deliver the value-added service based on the user location this is a push service such as local information about the airport when user enter the airport. This kind of service is mentioned as *proactive* service by the Kupper (2005).
- **Tracking LBS:** When service provider continuously track the subscriber to deliver services, such as a fleet management company which tracks its employee for rout optimization (GSM Association 2003, Ahson 2010).

  The objectives of every LBS system similar to GIS (Geographic Information System) is answering questions such as "Where am I?", "What is nearby?", "How can I get to?"; to answer these questions we need some infrastructure elements (see Fig. 4) as explained below (CartouCHe 2012):
- **Mobile Device (User):** Mobile device is not necessarily a mobile phone it could be a PDA, car navigation unit, Laptop or any tool that request the information.

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[6] OGC (2003): OpenGIS Location Services (OpenLS): Core Services, OGC Implementation Specification, OGC 03-006r1, Open GIS Consortium

- **Positioning:** To deliver the service provider needs the location information which is determined by either mobile network or GPS (Global Positioning Systems).
- **Communication Network:** Mobile terminals which transfer request and responses from user to the service provider.
- **Service and Application Provider:** Service provider deliver the service and is responsible for the process such as rout calculation, searching yellow pages for the information or a specific point of interest.
- **Content and Data provider:** Since the service provider does not maintain all the information therefore geo-location data and map is provided by other authorities such as mapping agencies, yellow pages for industry or business and traffic companies.
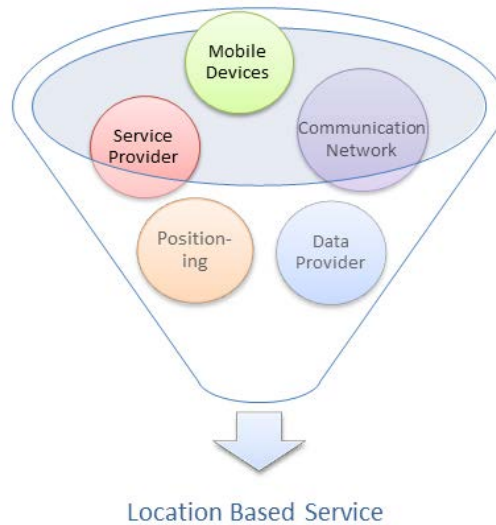
Fig. 4: Location Based Service Components

This image shows fundamental components of a Location Based Service which play role to provide either a pull or push service for the user. These components are mobile devices, communication network, positioning methods, service and data providers.

Another similar classification for LBS infrastructure is *sensor* (devices), *communication network*, *terminal and server* (the hardware which system runs), *the software* (service, client, middleware or application, content component and database) and *positioning* component (W 2006).

2.2 Related Research

During last few years with increasing usage of the mobile devices and smart phones from one side and the other side the increasing number of sensors in the buildings indoor issues came into consider of many disciplines such as computer science, telecommunication, electronic, architecture, energy and environment, cartography and geodesy. Indoor LBS is a cutting edge topic and in recent years there were too much consider in this area from both industry (indoor Google maps, indoor Bing maps, Navteq, indoor OSM) and science. Figure 5 illustrates research areas of an indoor LBS system. However each category and subcategories are depicted separately but all of them are related to each other and performing a research it is not possible unless consider a fusion of different aspects of indoor LBS system.
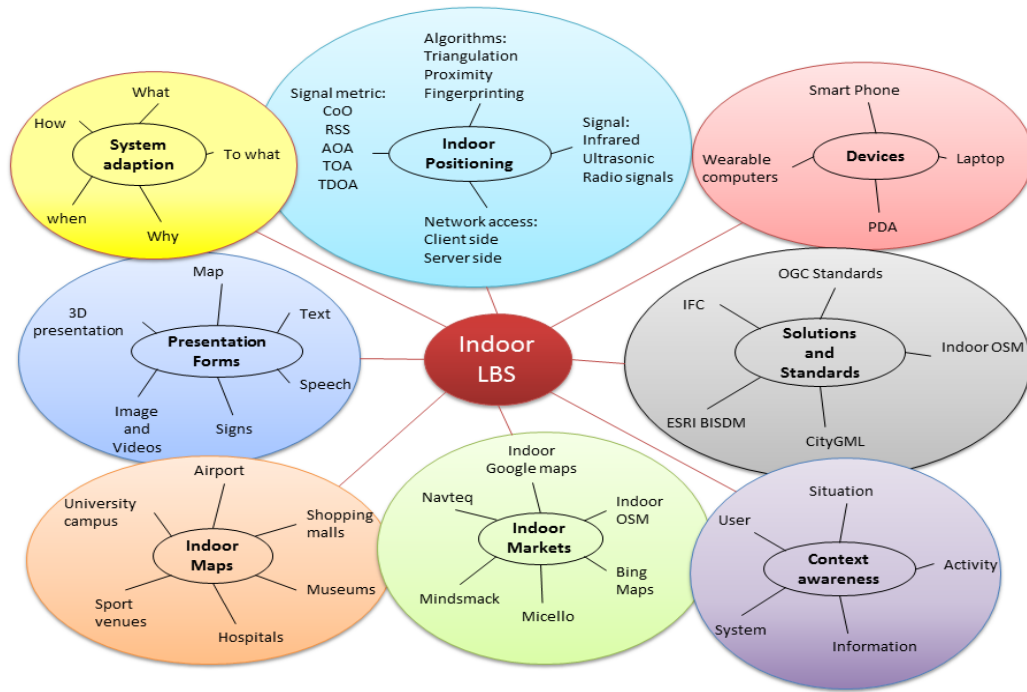
Fig. 5: Indoor LBS research areas.

This image shows research areas of indoor LBS, although these areas are categorized in different classes but an efficient indoor LBS system should consider all of them during design process.

A standard model for LBS system should follows current specification and standards, however indoor LBS is in first stage of development but still there are many researches done in this area. As one of the samples we can mention web campus map service of Lausanne Technical University (EPFL)[7] which represents floor plans on a base map and gives tools for indoor routing, finding point of interests and places. The slider on the page allows user to change between floor plans, in case of routing automatically map shows related plans based on the routing query, and user also can click on the map and get more information about the building. The representation of the maps can be improved. The source of the maps are CAD (computer aided design) and for routing graph a node/link graph composed of corridors, ways, road, path between buildings, rooms, halls, stairs, lifts, doors and point of interest is generated(Gilliéron and Merminod 2003). This map is a good example of indoor LBS was done in 2003 but at the moment with the availability of WLAN network and mobile devices we need application for mobile maps with smart maps. iNAV is an indoor navigation system which is uses an location framework middleware with localization services as plug-in called COMPASS (COMmon Positioning Architecture for Several Sensors) as a means of reliable position data (Kargl and Bernauer 2005, Kargl et al. 2007). The representations formats in iNAV are map, audio and textual and it uses server side solutions for network access. Based on Kargl (Kargl et al. 2007) the drawback of the system in performance is that "both plugins and the translator need to access GeoRDF Services in order to retrieve semantical information like map data".

Another project is called Chloe@University uses a fusion of positioning methods such as WiFi, RFID, CoO and develops a virtual guide simulation with augmented reality. The mobile device is a Sony's Ultra Mobile wearable PC and user uses voice command to give destination and through 3D display will be guided to the destination. The accuracy of the localization is limited to minimum 5 meters and has remarkable consistency for locating the user(Peternier et al. 2007). There are also several projects in the area of indoor routing and modeling was done by the University of Seoul. Hyeyoung (Hyeyoung et al. 2009) describes 2D-3D hybrid model for indoor routing using a spatial data base management system (SDBMS). In this work the author describes having a hybrid model in a spatial DBMS decreases computing cost and increases data flexibility. CAD floor plans are used for 2D models and then using 3D MAX files for 3D visualization. Norwegian University of Science and Technology (NTNU) developed another indoor navigation system for the

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[7] http://plan.epfl.ch/

university campus so called *CampusGuiden (NTNU 2012).* This is an App that guides users outside and inside the buildings with the accuracy of 5 to 10 meter which is not good for indoor environment. The system uses WiFi method for indoor positioning and the authors claim that they have thorough user test from the beginning step of development. NAVIG or augmented reality guidance system for the visually impaired is another project was done by Katz (Katz et al. 2012). However this work is not aiming the indoor areas but the result can be used also for navigating visual impaired people inside the buildings. In this project with combining satellite, image and other sensor information high precision localization is achieved and with image recognition methods and spatial audio rendering detailed trajectories will be presented for blind persons. In recently performed projects Steuer (Steuer 2013) represents a high precision 3D indoor routing on reduced visibility graphs. The author shows using visibility graph for indoor routing significantly decreases computational cost using a customized A* (A*- 3D_building) algorithm for shortest path routing. The assumption is that for each building we can generate a polygon with holes. Goetz and Zipf (Goetz and Zipf 2013) developed a (Mobile) web-based platform for indoor routing with volunteered geographic information (VGI) and specially OpenStreetMap (OSM). The system has two parts, on server side it uses PostgreSQL[8] database with PostGIS[9] extension and on the client side the WMS[10] data can be rendered and visualized by any GIS application. The result is a web-based application which represents floor plans and user can select start (level, room) and target (level, room) from drop down box and compute the rout. The aim of this project is proofing of using VGI from OSM for indoor LBS purposes. In another mobile navigation for outdoor and indoor a combination of floor plans and street maps is used (Nikander et al. 2013). For the floor plans CAD maps were used and employing Adobe Illustrator software and OmniGraffle the accessible path for indoor routing were generated in a semiautomatic process. The application was developed on an iPAD and for positioning they used QR method which needs user interaction for localization. For route planning authors use OpenStreetMap data and all data converted to XML format and the entire map

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[8] **PostgreSQL** is an open source database support PostGIS spatial database, www.enterprisedb.com

[9] **PostGIS** is a spatial database extender for PostgreSQL object-relational database. It adds support for geographic objects allowing location queries to be run in SQL. http://postgis.net/

[10] **WMS** Web Map Service is a Standard Interface defined by OGC and provides a HTTP request of the geographic layer(s) and area of interest from distributed geospatial databases. http://www.opengeospatial.org/standards/wms

converted to image tiles for representation. The significant challenge in this work based on author is processing and preparing CAD data for the indoor LBS purposes.

There are many other samples under progress, for instance in the area of CityGML and indoor OSM many projects from different perspective of view (refer to Fig. 34) is going on. Other commercial examples in indoor area are Navizon[11], S[12] and some startup companies (Micello[13], Mindsmack[14], infsoft[15]) which are preparing indoor maps and give indoor LBS service.

2.3 Google and OSM Trends in Indoor Mapping

Goetz and Zipf (Goetz and Zipf 2011) in a research on extending OSM to indoor environment give statistics about progressing trend for the indoor mapping. Since OSM provided facility for the contributors to specify buildings, indoor areas and the height of buildings in their inputs, therefore the number of buildings and indoor spaces is dramatically increased in recent years in OSM. Adding key-value such as *building=yes, indoor = yes, level=yes* give this option to the VGI contributors to enhance their geographic information during mapping on OSM. Based on this research currently there are 26 million buildings and about 645.000 of them contain height information. The below graph (see Fig.6)shows the increasing usage of the keys *buildings* and *indoor* between 2007 to 2010 during OSM mapping (Goetz and Zipf 2011).
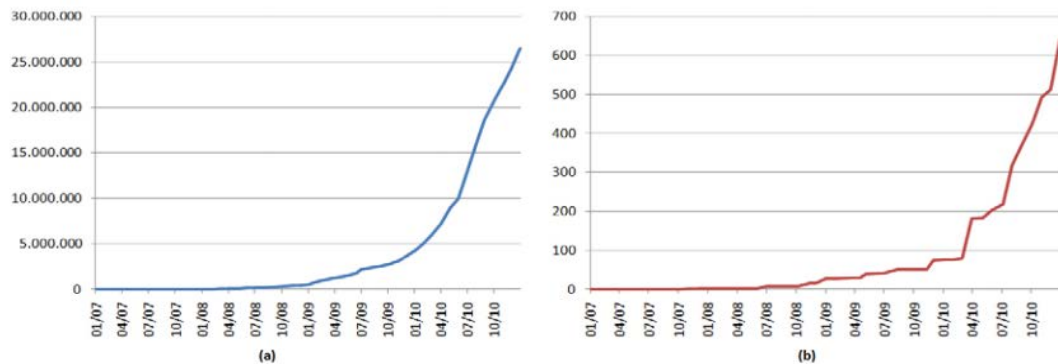
Fig. 6: Indoor OSM trends between 2007 and 2010 (Goetz and Zipf 2011)

(a) Usage of the building key and (b) usage of the indoor key

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[11] http://www.navizon.com/
[12] http://www.skyhookwireless.com/
[13] http://www.micello.com/
[14] http://www.mindsmack.com/
[15] http://www.infsoft.com

Another trend is derived from Google search engine during years during 2005 to 2013. In this trend we investigate for keywords containing indoor plus map concept such as campus map, university map, museum map, airport map, indoor map. However the search engine with English keywords is mainly used in English speaker companies but still it gives a comparison between demands for different indoor maps and the trend expand during years (see Fig. 7). This trend shows the query for the keyword *airport map* is more than *university* or *campus map*. The graph represents a fluctuating trend during years 2007 and 2013. The map shows the country which applied mentioned keywords for their search which is mainly English speaker countries (Canada, US, UK, Australia).
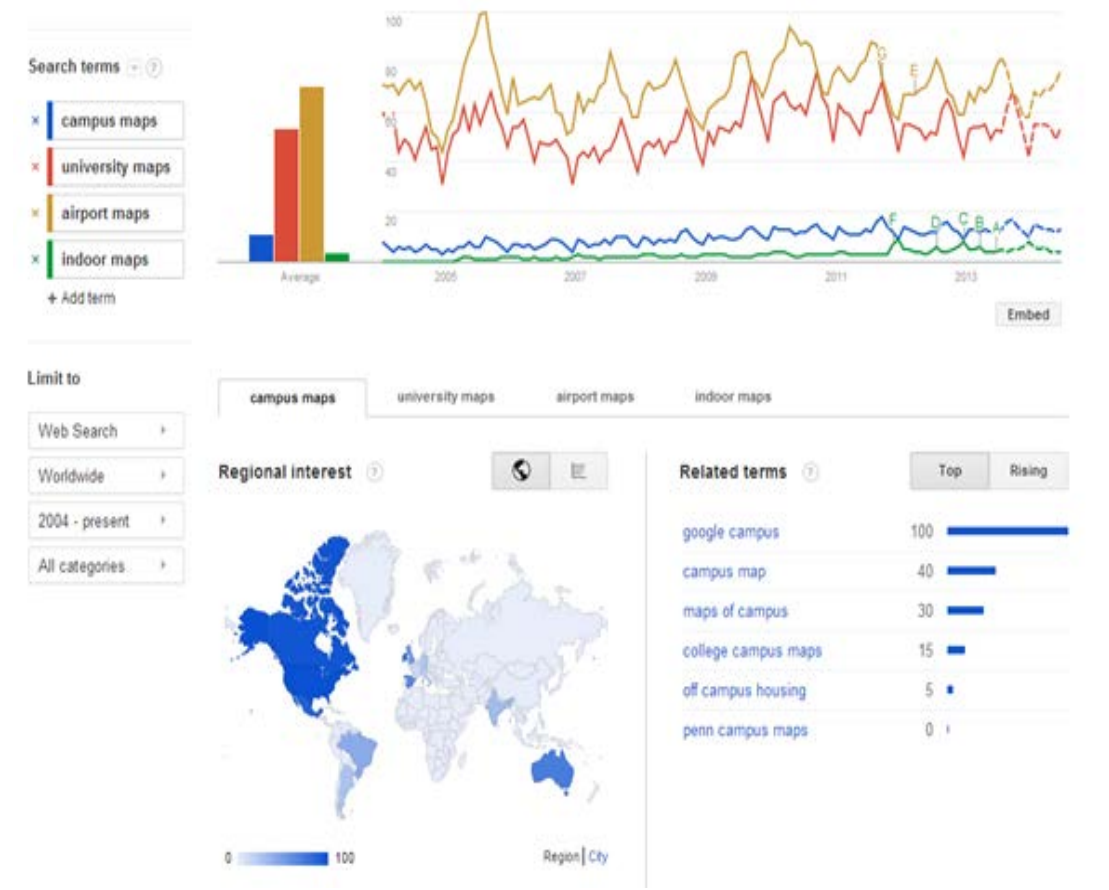
Fig. 7: Google search engine trend (www.google.com/trends/)

Shows frequency usage of keywords such as university map, airport map, and indoor map during the years 2005 to 2013. The graph shows search for *airport maps* is at the more than other indoor maps. The demand for the indoor maps has a fluctuating trend.

Chapter3: Conceptual Development of Smart Campus Map

3.1 Indoor Navigation Systems

One of the challenges in indoor LBS is localization and indoor positioning. Since GPS signals cannot penetrate solid objects such as buildings, for indoor localization we need other approaches which in recent years developed too much. Indoor positioning methods vary based on cost, accuracy and technology. Huang and Gartner (Huang and Gartner 2010) in a recently survey on mobile indoor navigation systems, investigate indoor positioning systems from different perspective of view and used methods between the year 1997 to 2008. in this survey indoor navigation systems are evaluated from various aspect such as indoor positioning, context aware adaption, route presentation and communication, network access, client platform and other aspects. Here we briefly explain available indoor positioning systems. For indoor navigation we need both the update position of the user and also a graph for routing inside the buildings. In contrast with outdoor positioning that user employ 2D or 3D map, textual and verbal instruction, in indoor areas user has more communication forms to use the system such as map , textual and verbal instructions, augmented reality, sign, rotating campus, vibration, image and video (Huang and Gartner 2010). In this survey authors claim that for indoor navigation still maps are the most popular communication tool because of physical guide usage such as "You Are Here Maps" installed in indoor areas. An evaluation framework for indoor navigation systems proposed by Huang and Gartner (Huang and Gartner 2010) is shown below (Fig. 8).
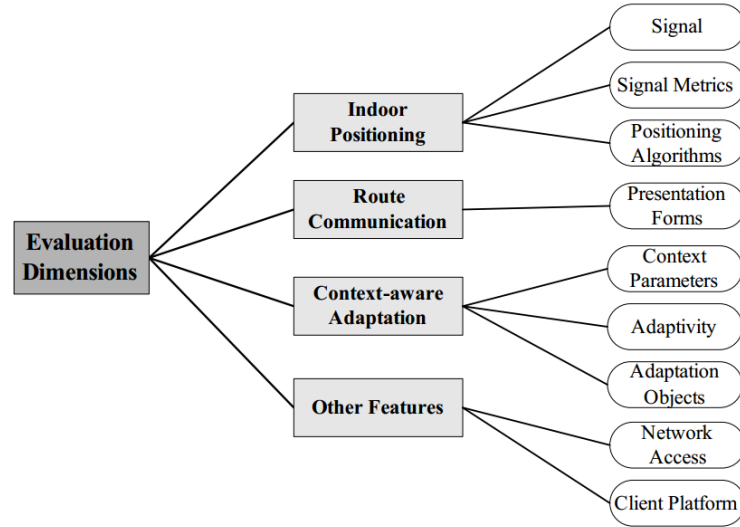
Fig. 8: Evaluating indoor navigation system framework (Huang and Gartner 2010)

Huang and Gartner (2010) used this framework for their indoor navigation survey evaluation, 4 main aspects of indoor LBS systems are discussed in this survey.

In our work we focus more on indoor positioning system in campus area and route communication ways for campus map in a mobile application.

Three most promising technologies of indoor positioning are WLAN fingerprinting, RFID positioning and indoor positioning with GPS.

3.1.1 WLAN Positioning

WLAN (Wireless Local Area Networks) is a cellular network installed in buildings where each cell served by a base station so called *access point (Küpper 2005).*The coverage of an access point is called Basic Service Area. In WLAN systems we consider two layers, one representing air interface which is physical layer and the other one is medium access layer (MAC) used for multiple access coordination. All these specifications and WLAN standards are described and standardized by IEEE 802.11 specification series.

Measurement of the received signal strength (RSS) and received signal to noise ratio (SNR) or proximity sensing are the principals of every WLAN positioning system. RSS and SNR observations are based on beacons which are broadcast either in the uplink or the downlink leads to following three basic positioning methods:

- **Proximity sensing**: The position of the terminal is derived from access point position which is scanned by strong signal.
- **Lateration**: The distance between access points and terminal is determined by the path loss a beacon experience during transmission.
- **Fingerprinting**: For every WLAN network there is predetermined RSS pattern table for different positions, looking up in this table and compare to observe RSS pattern from several access points the best fit position will be adopted (seeFig. 9).

Fingerprinting has three modes (a) Terminal assisted mode, (b) Terminal based mode and (c) Network based mode. A significant drawback of fingerprinting is time consuming process of measuring close grid of coordinates to cover a building (Küpper 2005).
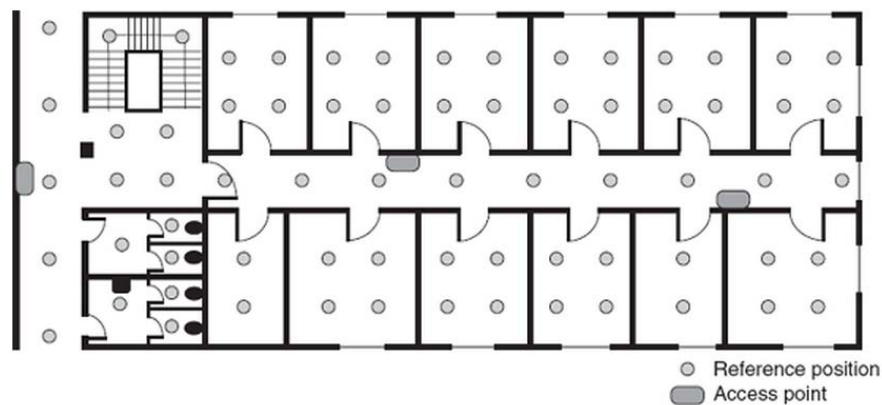
Fig. 9: WLAN fingerprinting environment (Küpper 2005)

The observed RSS patterns originating from or received at several access points are compared with a table of predetermined RSS patterns collected at various positions and the best fit is adopted as location.

3.1.2 RFID Positioning

Radio Frequency Identification (RFID) is using radio signals transmitted between RFID reader and tags (transponder). In contrast to WLAN positioning for fingerprinting we need some devices such as readers and tags for the system user. Reader which is more expensive than tags comprises of antenna, transceiver, processor, power supply and interface for connecting to the server using a serial port and the tag has the same parts as well as memory, some of them has power supply an others just use the transmitted radio signals energy as power. RFID tags without power supply have limited range of receiving signals about few meters and are named as passive while the other tags are active and have tens of meters bridge distance. We can classify RFID positioning as proximity sensing schema. RFID positioning depend on the navigation environment can be implement in a network based or terminal based platforms while in the former the readers are mounted to walls, corridors and entrances in a building connecting to a location server and the latter is integrated in a mobile device (smartphone, PDA) and catches location data from the tags in the infrastructure when passing them (Küpper 2005).

3.1.3 Indoor GPS Positioning

GPS (Satellite Global Positioning) uses signals of at least four satellites which received by the receivers located in open air for accurate positioning, since these radio signals cannot penetrate solid objects, for indoor positioning conventional GPS receivers which use signals with a strength of at least -130 dBm are not properly detected and interpret GPS signals. GPS receivers for outdoor positioning use *code phase ranging* technique as time measurement, when they have already detected two to four satellites. For identifying the signals of a certain satellite the correlators embedded in the GPS receivers must detect the Coarse/Acquisition codes. The challenge in indoor environment is that these signals are too weak to be discriminated from noise in the environment. As a solution for indoor positioning the dwell time of the correlation is increased, this improves the data delivery and *signal-to-noise ratio* (SNR) as well.

One drawback of this approach is that the acquisition time would dramatically increase. Consequently for indoor positioning the idea is to equip GPS receivers with a high number of parallel working correlators to increase the sensitivity. With this solution it is possible to receive signal with strength of -160 dBm and less acquisition time. Other radio technologies such as WLAN and Bluetooth operate with RSSs of between -20 dBm and -80 dBm.

3.1.4 Positioning Algorithms

In indoor areas because of several problems such as line of sight path, low probability, moving object and reflecting surfaces modeling the radio propagation is difficult (Hui et al. 2007). Therefore at the same time we need more than one positioning algorithm. Here we discuss some cellular positioning methods which also are used for indoor environment.

- **Proximity Sensing:** This algorithm usually relies on a dense grid of antennas with a specific position. When a terminal or mobile target is scanned or detected by a single antenna it will be collocated to that antenna, meantime if another base station (antenna) detects the mobile then the collocation depends on the strongest signal. Infrared radiation (IR), RFID, cell identification (Cell-ID) also called POA (Point of Access), and cell of origin (COO) are the methods using proximity sensing (see Fig.10).

- **Triangulation:** This is a geometrical method based on triangle properties to locate the target. It has two derivations: *(1) lateration* and *(2) angulation*, where the former uses distance (range) of the object to the multiple reference points for positioning and the latter (angulation) uses the angles between the target and the number of base stations.

(1) *Lateration* method uses received signal strength (RSS) instead of distance and also *time of arrival* (TOA) or *time difference of arrival* (TDOA) to derive the distance by the attenuation of the emitted signal strength. Another classification for lateration is *circular lateration* and *hyperbolic lateration*.

    (a) In TOA technique the distance of the mobile target to the measuring unit is directly proportional to the propagation time (see Fig.10).

    (b) In TDOA technique instead of the absolute arrival time of TOA it uses the relative position of the mobile transmitter by examining the difference in time of signal arrival in multiple measuring units (see Fig.10).

    In TOA and TDOA methods the drawback for indoor areas is finding line of sight (LOS) between transmitter and receiver. Since in indoor area radio signal will be affected by several items, the time and angle consequently will be disturbed and the accuracy could be decreased.

    (c) As a solution another technique in Lateration is *RSS-based* (or Signal Attenuation-Based). In this method by calculating the signal path loss

(due to propagation) between transmitted and received signal strength into a range estimate and comparing with some empirical and theoretical models the position will be calculated.

(2) **Angulation** technique is called Angle of Arrival (AOA) or Direction of Arrival (DOA) as mentioned above uses the intersection of several pairs of angle direction lines generated by the circles with the centrality of base station or a beacon station and the radius to the mobile target (see Fig.10). The advantage of AOA is the positioning is possible with the minimum number of measuring units (three for 3D positioning and two measures for 2D positioning) (Hui et al. 2007) and (Küpper 2005).

- **Scene Analysis:** In this kind of algorithms, first collect fingerprints in the environment (Scene) and then match them with the closest *a priori* location fingerprints. These fingerprints are signals properties based on their location. These properties can be strength and source of the signal. There is two stages for location fingerprinting offline and online. RF-based systems which use fingerprinting are: probabilistic methods, k-nearest-neighbor (kNN), neural networks, support vector machine (SVM), and smallest M-vertex polygon (SMP). As a drawback, scene analysis methods suffer from signal strength affection by diffraction, reflection and scattering in indoor environment.
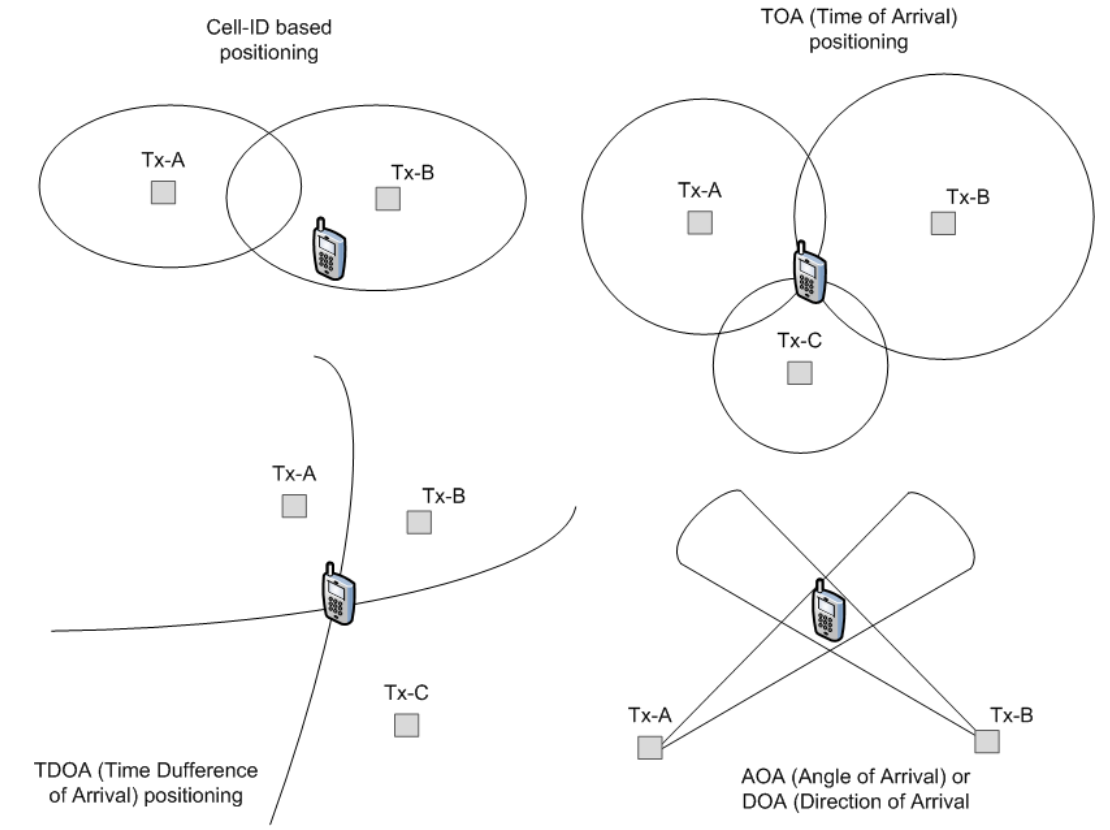
Fig. 10: Positioning Algorithms

The illustration gives examples of triangulation and proximity algorithms.
TOA and TDOA are examples of lateration (using triangulation) and AOA/DOA is an example of angulation (using triangulation) and Cell-Id based uses proximity sensing algorithm.

As a conclusion we should say for a good result of localization in indoor area systems cannot rely on just one method and generally they use a combination of different algorithms based on the environment, equipment, demand and cost. To have a continuous positioning from outdoor environment to indoor systems should be intelligence in applying different positioning algorithms in this contain a hybrid system is applied by many projects. For instance CyberGuide, IRREAL and BPN use infrared and ultrasound as positioning signal, CoO (cell of origin) as signal metric and proximity for positioning algorithms; iNav uses Compass, Chloe@University uses WiFi, RFID, RSS, CoO and fingerprinting, Open-SPIRIT uses Bluetooth, CoO and proximity. Huang and Gartner (Huang and Gartner 2010) in a thoroughly survey on indoor navigation system conclude that all indoor navigation systems are in the primary development stage and there is different challenges for positioning accuracy, finally sensor fusion could be a solution.

3.2 Spatial Data Model (Indoor and Outdoor)

. In this part we focus more on developing a model of physical spaces in the building. In last section we discussed practical part of data preparation from CAD and floor plans, now we aim to make a spatial model for building features. This model describes and simplifies not only the elements of an indoor area but also their relationship.

3.2.1 An Overview on Existing Indoor Spatial Models

Why we need a model?

Based on the definition of OMG[16] (Object Management group) modeling is the designing blueprint for making any plans (site maps, elevations, physical model) and software development before get into coding (OMG, 2005). As a general definition a model visualize the real world and help to construct the system structure and decision process. By the growing use of spatial data the need of developing, storing and distributing of spatial data is also becomes necessary. Hence, documentation and data dictionary are key component of geospatial repositories (Brodeur et al. 2000) and (Friis-Christensen 2000). Regarding spatial models there are many researches to clarify how spatial objects are related and attributed. There are three main level of models: (1) Conceptual model, which for geographic phenomena is the idealization of the world (Friis-Christensen 2000) and defines the highest level of relationship among system components such as geometry, topology and entity names; (2) Logical model, describes the details of conceptual model for implementation, and explains the relational model by primary keys and foreign keys; (3) Physical model, describes how the data physically is implemented in the database such as indexing and specifies table structures and data types. (Filho and Iochpe 1999) from a conceptual framework perspective describes that a geographic phenomenon has three components: space, time and attribute. Based on this category any object in the reality can be abstracted via a conceptual model. In object view classes are generated by the *spatial object* class for the specification of the spatial component representation, these spatial objects are point, line, polygon, cell and complex spatial object (Filho and Iochpe 1999). In another research (Yvan et al. 2002) investigates modeling multiple representation into spatial data warehouse. This representation varies in different level of details based on user's need. The

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[16] The Object Management Group (OMG®) is an international, open membership, not-for-profit computer industry standards consortium founded in 1989. http://www.omg.org

author proposes a spatial data modeling solution called *perceptory* which is a visual modeling tool for designing conceptual object class models based on UML (Unified Modeling Language). "Perceptory is a CASE tool that comprises a UML based conceptual schema building tool for geospatial conceptual models and an object dictionary database "(Brodeur et al. 2000).

The four basic geometries of the spatial PVL (Plug-in for Visual Language) which is a pictogram embedded in a font can be used to describe a simple geometry (see Fig. 11). Later he specified four occurrence of a spatial object class: (1) a simple geometry, (2) a unique geometric aggregate, (3) an alternate geometry, (4) several independent geometries, where usually only one is used at a time. This solution supports semantic and temporal multiple representations and generalization of spatial data. However this solution is applied for scaled structure of geographic data for instance to represent different level of cartographic scales (20k, 100k, 250k, 1m, 8m)(Yvan et al. 2002).

▣	0- Dimensional Geometry, Point
◪	1- Dimensional Geometry, Line
▣	2- Dimensional Geometry, Polygon
◷	0- Dimensional Temporality, Punctual Time
◕	1- Dimensional Temporality, Durable Time
▣	Visual Info – Photo
▣	Visual Info - Video
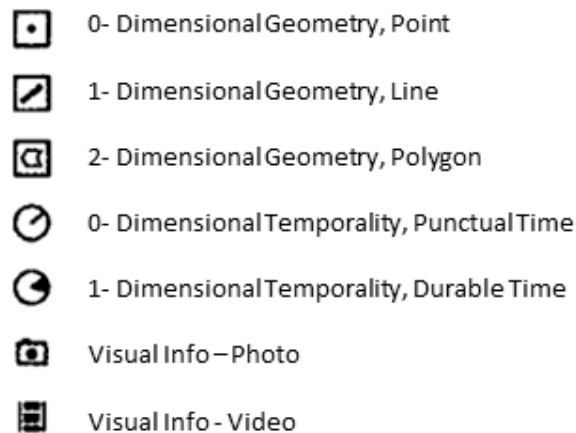
Fig. 11: Plug-in for Visual Language (VPL) pictograms (Brodeur et al. 2000)

Based on Perceptory definition it uses spatial and temporal PVL graphical notation depicting geometries, temporal and visual properties of objects and attributes.

Focusing from spatial data models to one detail level which is indoor spatial data, we have to dealing with positioning algorithms, sensors, signals and signal metrics (Huang and Gartner 2010). OGC Standards published a discussion paper on requirements and space event modeling for indoor navigation in 2010. In this article the authors specify below minimum requirement for a flexible indoor data model(Gröger et al. 2008) :

- Support multiple localization methods (such as indoor sensors technologies and selection of the end user device)
- Support different navigation context (such as navigation constraints, locomotion and temporal constraints)
- 3D topographic representation of the interior built environment (required for rout planning)

Based on these requirements every indoor navigation system not only has to support the physical built spaces for navigation but also consider the moving object in logical navigation constraints (security zones, opening hours, under construction areas). Here we can define three modeling requirement for interior spaces (Nagel et al. 2010). Firstly, indoor navigation model should be compatible to existing 3D building models. Existing data models for buildings are OGC CityGML (Kolbe et al. 2005, Gröger et al. 2008), IFC (Industry Foundation Classes)[17], X3D[18] and ESRI BISDM (Building Interior Space Data Model)[19]. In this work we referred more to CityGML and ESRI BISDM models. Secondly, many of building models have a hierarchical grouping of spaces. It means that they decomposed indoor physical spaces into small parts like floors, rooms, passages and then in more detail rooms also can be decomposed into subdivisions considering the moving objects for instance for robots or wheelchairs. These kind of hierarchical models consider the geometric and semantic aspects of routing, mobility, visibility and signal propagation. However it is too complicated to consider all aspect of indoor navigation in one building model, consequently sometimes we can see multiple building models for the same interior built environment. The third requirement for designing an indoor model is mathematically sound framework. From network topology perspective, navigation models try to describe connectivity and adjacency between interior spaces. A mathematical sound framework by the OGC tries to specify some standards for topological graph structure (adjacency and connectivity).

Following mentioned requirements for building models, Becker (Becker et al. 2009) proposes a model based on a multilayer space-event representation. The author tries to separate different space models in this framework, e.g. topographic space and sensor space. In this model by decomposition of a specific space to subdivisions other spaces are not influenced. Fig. 12 illustrates the proposed model; the vertical black planes divides the space considering the Euclidian and topological aspects

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[17] http://www.buildingsmart.org/standards/ifc
[18] http://www.web3d.org/realtime-3d/x3d/what-x3d/
[19] http://www.esri.com/industries/government/facilities/bisdm-group

while horizontal black plane indicates the primal and dual space. Respecting alternative space concept the multiple vertical black planes divide the space based on sensors, topography and other layers (such as movement space, activity space, visualization space). Primal and dual spaces are transition diagrams, for example the topological adjacency relationships between 3D cells are transformed to edges which are one dimension, linking pairs of nodes in dual space.
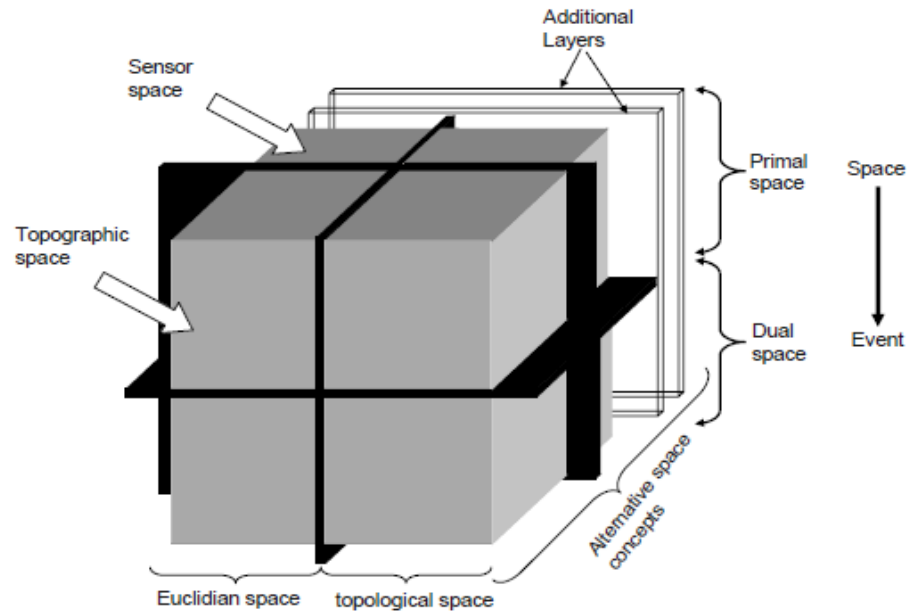
Fig. 12: Multilayer combination of alternative space concepts (Becker et al. 2009)

The proposed model by Becker (2009) describes a novel framework for a multilayer space-event representation which allows the decomposition of a specific space into smaller units according to respective semantics, without influencing other space representations.

In next part we go into detail and try to define a building model for campus map based on mentioned example, in our proposed model we focus on the topology relationship of the entities in a campus map and do not discuss sensor space regarding moving objects and propagation signal. The proposed conceptual and physical model is structuring indoor campus regarding geometric calculations such as point-in-polygon, adjacency and boundary strategies.

3.2.2 CityGML and BISDM

Kolbe (Kolbe 2009) in a paper about representing 3D city models with CityGML explains the aim and application of CityGML for 3D city models and discusses the

necessity of a standard for 3D building 3D models. "CityGML is an international standard for the representation and exchange of semantic 3D city and landscape models adopted by the OGC (Open Geospatial Consortium)"(Kolbe 2009). CityGML uses data model based on the ISO 19100 standards and OGC's Geography Markup Language (GML3) as application schema implementation. "CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models."(Gröger et al. 2008)

Based on OGC definition (Gröger et al. 2008) CityGML is an open XML-based format data model for the storage and exchange of virtual 3D city models. The aim of CityGML is to define a common standard for basic entities and relationship of a 3D city model. CityGML is not only the graphical representation of city models but also semantic, thematic, taxonomies and aggregation representation. CityGML supports different Level of Details (LOD) to reflect independent data collection processes with differing requirement. It defines 5 level of details enabling the analysis and visualization of the same object with regard to different degrees of resolution where LOD3 represents architectural outside models and LOD4 deals with architectural interior models (Gröger et al. 2008).

 Spatial properties of CityGML for 3D geometry representation are according to the *Boundary Representation* model. This geometry model based on GML3[20] consists of primitive geometries dimension, a 0D object is a Point, a 1D is a _Curve, 2D is a _Surface and 3D is a _Solid. For example a solid is bounded by surfaces and a surface by curves. Fig. 13 illustrates the geometry model for complexes and aggregates. Based on the UML diagram combined geometries can be aggregates, complexes or composites of primitives. In Aggregate the spatial relationship between components can be disjoint, overlapping, touching or disconnected. In contrast to aggregates which are not restricted a *Complex* is topologically structured, it means that its parts must be disjoint, must not overlap and are allowed to touch, at most, at their boundaries or shape parts of their boundaries (Gröger et al. 2008).

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[20] GML3 represents 3D geometries based on the ISO 19107 model
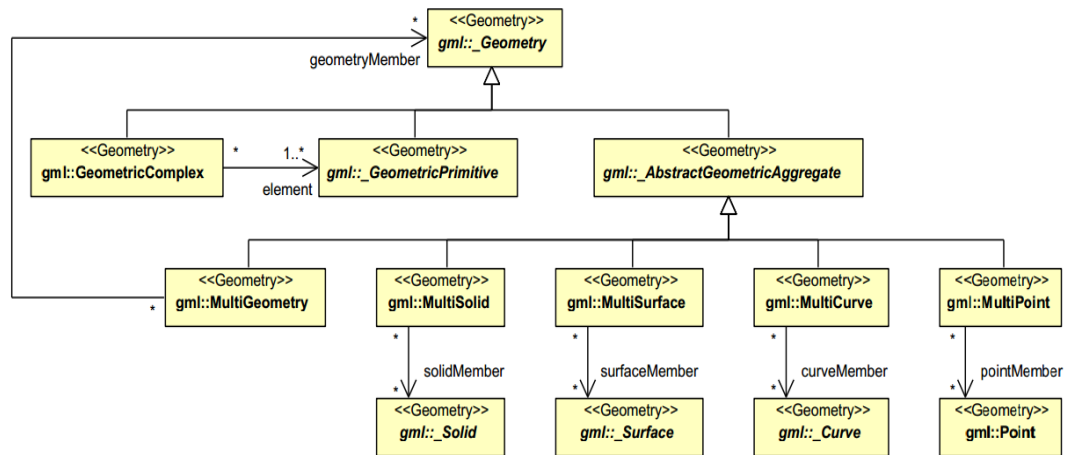
Fig. 13: UML diagram of CityGML's geometry (Gröger et al. 2008)

Combined geometries can be aggregates, complexes or composites of primitives.

Another spatial data model for indoor spaces and buildings is proposed by ESRI so called BISDM (Building Interior Space Data Model). The purpose of this data model is providing a GIS-based data model for managing and reporting from different aspects of interior spaces such as architecture, construction, landscape planning, facility management and so forth. Fig. 14 shows small part of this data model, relation and attributes are designed in UML diagram.

The last version of this data model is BISDM 2.0 which includes a sample campus map of ESRI Campus in Redlands, California, data models and documentation. The general pattern that is suggested in the BISDM Framework document and template data model is that feature classes have minimal attributes except for a Key to a related table. For example, *Building_Footprint* and *Building_Info* is one example of this pattern (see Fig. 15) (ESRI 2012).
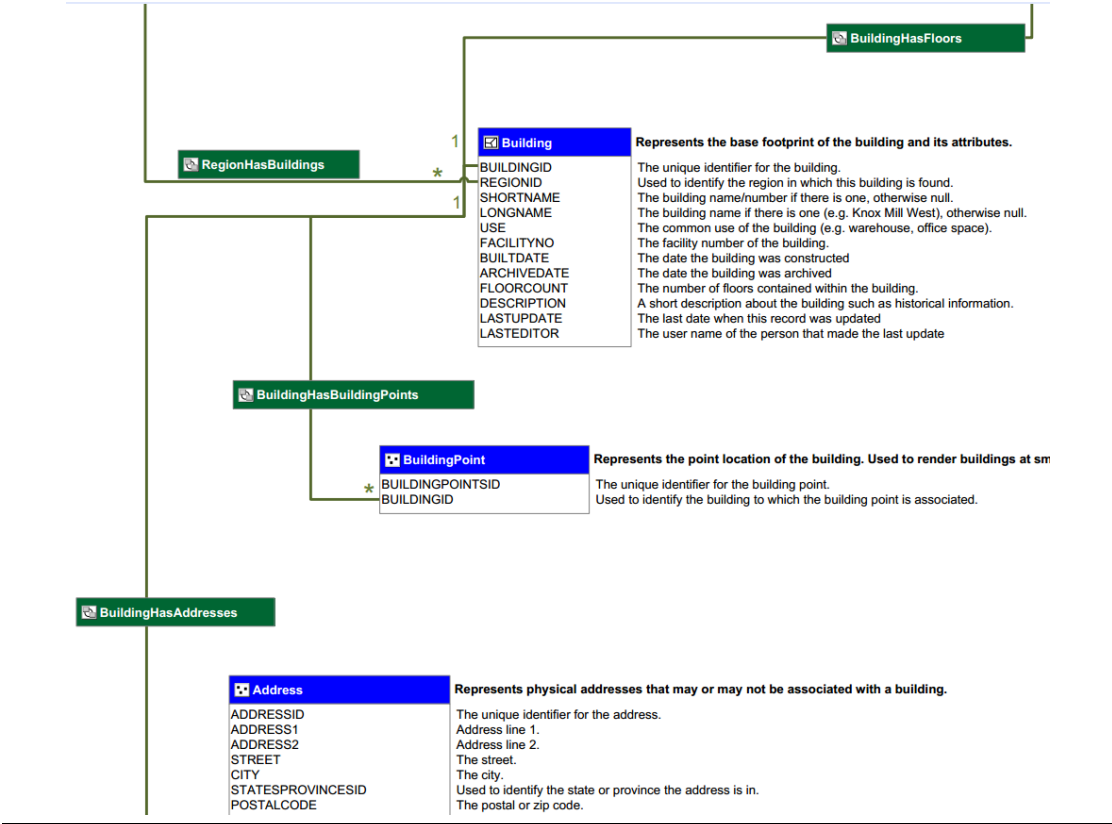
Fig. 14: Part of Building Interior Space Data Model (BISDM2) by ESRI
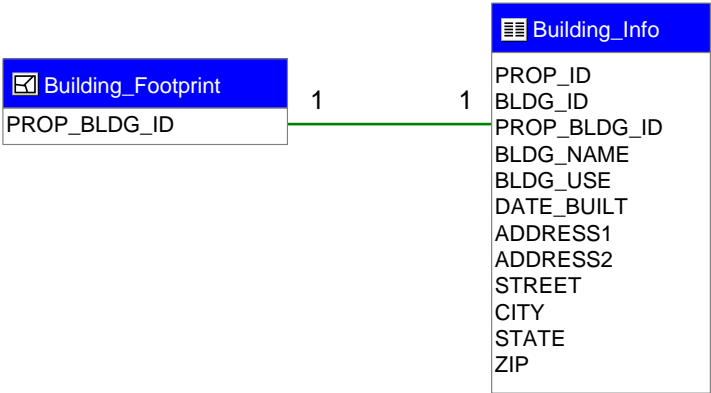
Fig. 15: Minimal Attributes and Relational Tables in design (BISDM by ESRI)

The basic rationale behind this approach is that the _Info table will be updated from another source, but it is anticipated that getting the attribute data into the same Geodatabase will ensure good performance in ArcGIS.

BISDM has two conceptual data models, one Core and the other one is Asset. Asset data model adds additional features to the Core data model and includes proposed assets class names such as Conveyance, electrical, fire protection, HVAC, Plumbing and Structural. This asset data model uses Industry Foundation Classes (IFC) which is developed for Building Information Model (BIM) standards.

3.2.3 Campus Conceptual Model

As discussed in section 3.2.1 a conceptual model is the first model of developing a system which for geographic phenomena is the idealization of the world (Friis-Christensen 2000) and defines the highest level of relationship among system components such as geometry, geometry, topology and entity names. In this work we try to follow principals in CityGML and ESRI BISDM (Building Interior Space Data Model)[21] models to develop a new model based on TUM Campus Map.

In this data model we mainly focus on topological relationship between the features that will be explained in section 4.1.2, the aim of this data model is providing a specific model for TUM campus buildings and indoor spaces. For the outdoor area we can use standard models proposed by ESRI and CityGML which discussed before. In this model we use UML (Unified Modeling Language) Static Structure, and use links to specify multiplicity and geometry relation between features (see Appendix E). The core objects of the data model are building and floor objects. We try to generalize multiple features in one feature to make the data model simple however still the similarity to the real world is maintained. This data model is usable for three campuses of the Technical University of Munich which are main campus (Stammgelaende), Garching and Weihenstephan. For example in Wiehenstephan campus buildings are distributed in a large area while in Stammgelaende buildings are gathered in a small area in the city center. The data model should be extendible for connection to outdoor data models for the cases of connection outdoor and indoor routing. For instance user of the indoor navigation system should be able from metro station which is 2 intersections away from university entrance navigate to a lecture room inside the building. In this work we do not claim that our work covers also outdoor issues but generally every indoor navigation system and data model should consider outdoor data and routing.

TUM campus spatial data model has in the center building and floor, where one building is composed of many floors (1 to 1…* multiplicity), then each core objects connected to detail parts of objects based on the geometry (see Fig. 16).

In this data model we define each floor with interior spaces that are polygons and these polygons have topological relationship, for instance adjacent rooms share the same line, doors are points which located on the room border. Corridors are specified by polygons but also they have centerline for navigation purposes and routing graph generation. Stairs and lifts are specified by start point and endpoint in every floor and also some mid points in stair cases. Using this approach we can connect floors and navigate between floors by stair centerlines and their id in each floor. In the attribute table of each stair it should be defined which floor it belongs to. In case of lifts that just stop in odd floors or even floors, attribute filed "*ConnectedFloors*" which is a string of connected floors solve the problem. Another problem in buildings topology is congruent geometries. Congruent geometries are objects that are duplicated in several floors in the same position and shape which is normal in architecture design of buildings. In these situations each object not only has a unique Id when it is generated is assigned to it, but also "*FloorId*" is used to specify the unique object for querying and routing.
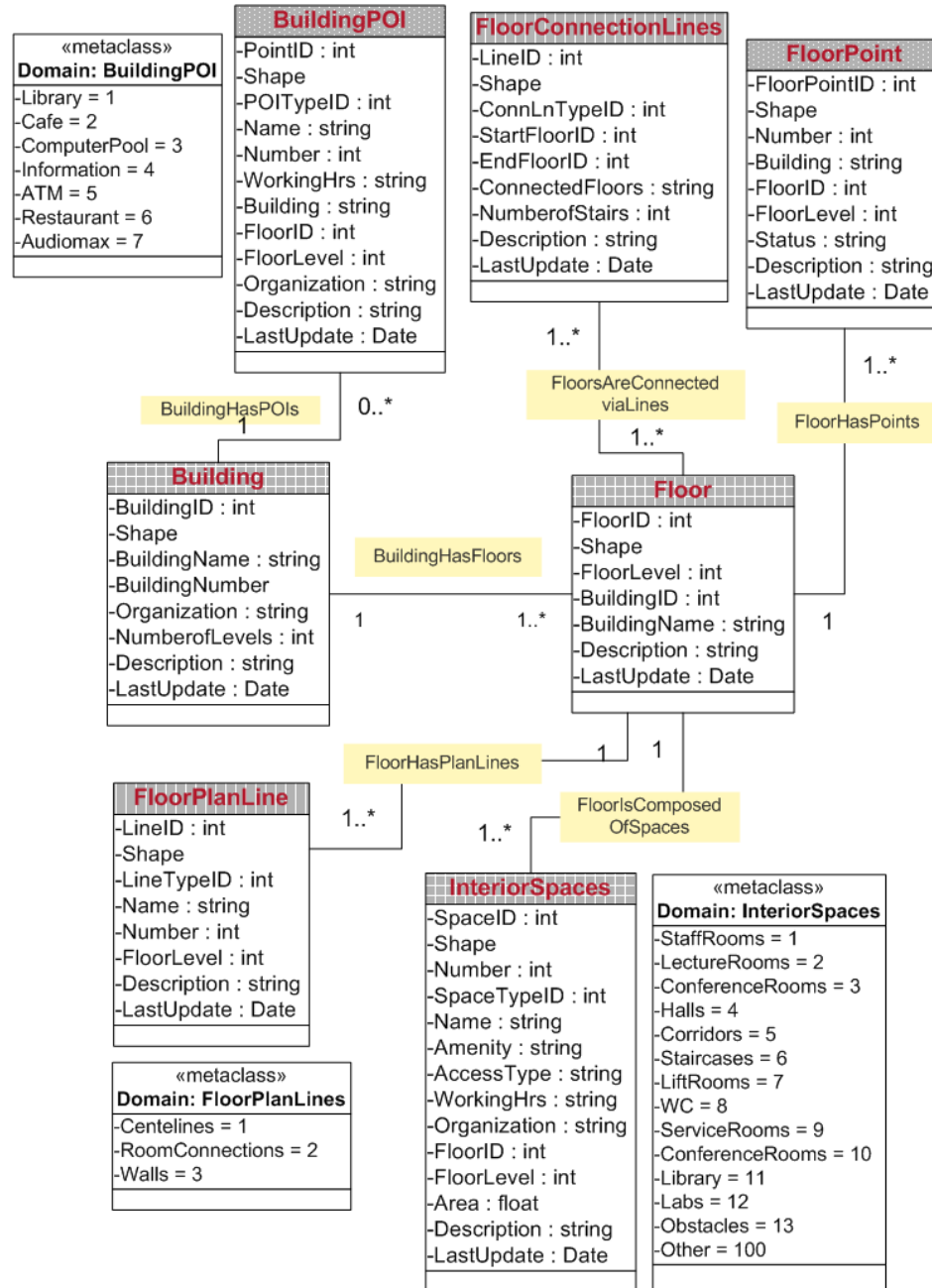
Fig. 16: Part of TUM Campus Indoor Data Model

TUM buildings are represented in the model mainly by *InteriorSpaces* (polygon), *FloorPlanLine* (line) and *FloorPoint* (point) classes. The topological relationship and attributes of objects is explained in a detail data model (Appendix E)

The classes and their relation of campus data model are explicated in below:

Building: Represents university buildings, defined by name and number, has floors

Floor: Represents building floors, composed of interior spaces.

BuildingPOI: Represents Point of Interest such as restrooms, library, restaurant, has floors Id, organization. Some of these POIs are in reality one point, such as soft drink automats or bank ATMs, but some others representing an indoor space which is a polygon such as registration office, restrooms, library, restaurant or café.

BuildingConnectionLines: Represent passages, bridges and stairs connect buildings

Parking: represents indoor or outdoor parkings, can be part of Floor class.

FloorConnectionLines: Represent non horizontal and vertical passages, stairs, elevators, escalator for to connect floors, mainly generated from start point and end point in each floor with centerline, has ConnectedFloor attribute of string to specify which floor are connected.

InteriorSpaces: Represent indoor physical spaces of building by polygons object, Obstacles are also represented in this class, also access type should be specified for interior spaces such as public, private and so forth. Interior spaces (such as lecture rooms, conference halls, labs, library, restaurants and café, rest rooms, study rooms and etc.) form floors. Floor has *1 to 1…* multiplicity* by this class.

To avoid *congruent geometry* which are shapes that duplicated in the floors with the same coordinate and geometry such as restrooms, stairs, lecture rooms or labs we characterized objects of this class in each floor by the floor Id and floor number.

FloorPoint: Represent point such as doors, start and end of stairs, each floor entrances, building entrances. For instance start of a stair centerline should be located on the start point (multiplicity 1 to 1) or one point can be located on the intersection of many lines (1 to n multiplicity).

FloorPlanLine: Represents horizontal passages and lines, centerline of corridors and ramps in a floor. In case some routes are temporarily blocked because of construction or in emergency cases this class will be attributed and visualized on the map and should be updated in the database for routing purposes.

Photo: Represent the photo of indoor areas. The location of the camera should be indicated for linking to the real object. The location of the photo is saved in another table with point geometry. Date taken and URL is also other attribute of this object.

PhotoLocation: Represents the location of each photo that taken, also these locations can be used for augmented reality. It means that if user navigates to this location can see extra information on the application screen on the image or map.

GeoRaster: Represents the location of the building in outdoor environment, so each building polygon should be georefrenced to the orthoimage or satellite image.

Since every topographic object of building space should be defined by a primary geometries such as point, line, polygon, curve and etc. and moreover should have an extent and position that can be measured and modeled (Nagel et al. 2010), in this model also we define our model as a subset of *Euclidean Space*. Metric space with Cartesian coordinate system is used for measurement in Euclidean Space. The distance between two points or vectors in this metric space is defined by Euclidean norm   of the difference between these points. If

In next section we explain the classes in a physical model using ESRI ArcCaralog and also provide Geodatabse with some sample data of indoor and outdoor campus data.

3.2.4 Campus Physical Model

In section 3.2.1 we explained that *physical model*, describes how the data physically is implemented in the database such as indexing and specifies table structures and data types. In this section we define a physical model based on previous designed conceptual model of the campus. Then we fill this physical model with some data that will be prepared in section 4.1.2, moreover we define relationships between data model components and set some topological rules for geometries. This data model is extendible for all three TUM's campuses and covers not only indoor features but also outdoor environment. This data model includes feature datasets both raster and vector and some non-spatial data (such as domains and enumeration) are represented by attribute tables. We use feature dataset for building because all the object of the building has the same coordinate system and features thematically are related to each other. Coordinate system for indoor data is the same as outdoor data and here we use *"WGS_1984_Web_Mercator_Auxiliary_Sphere"*.

Components of this physical model are described in below:

Feature Classes: All the classes in the conceptual model with specified attributes are defined here, such as *Floor, FloorPoint, FloorLine, BuildingPOIs* and etc. Fields data type and domains are defined and for long names an alias is assigned. Coordinate system for each feature class is inherited from feature dataset coordinate system. Relationship are defined by the relationship class and added to the feature class attributes. For indexing we use *ObjectID* of each featureclass. For the classes that in the conceptual model we defined enumeration and domain we assigned them here. for example the domain for the POI is attributed by *POITypeId* or for *InteriorSpace* class the interior spaces domain are characterized by *SpaceTypeId*, for instance *StaffRoom*=1, *LectureRooms*=2. The same approach we define *FloorConnectionLines* which are non-horizontal passages and *BuildingConnectionLines*. These domains are defined in separated tables out of feature classes and link to the feature class via *ObjectId*.

Relationships class: Relationships also are defined in the building feature data set and clarify the table relation between classes by defining the primary and foreign

keys and cardinality between members. For instance *FloorHasInteriorSpace* indicates the relation between floor class and interior spaces, as mentioned before each floor is a composition of interior spaces and the relation is 1 to M (1 to Many) where 1 floor can have 1…* interior spaces (see Fig. 17). It is not possible zero member for interior spaces class. In very exceptional case one whole the floor is covered by one interior space.
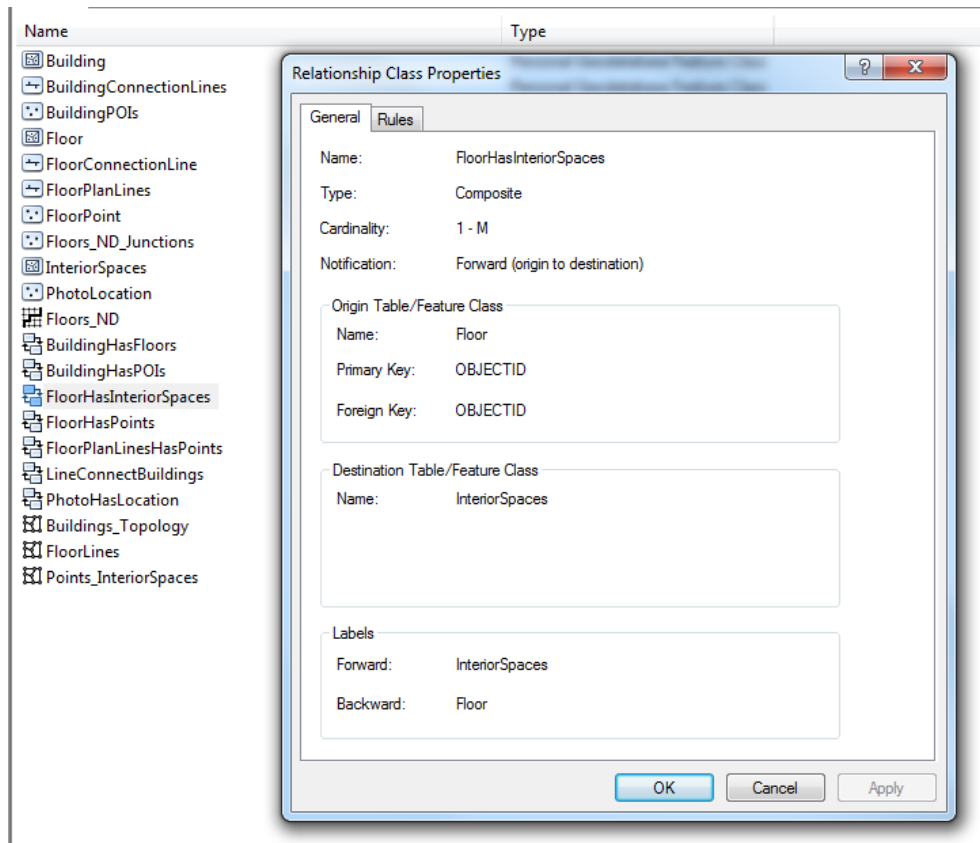
Fig. 17: Sample of class's relationship in physical model

The figure illustrates the class "*FloorHasInteriorSpace*" , the relation between floor class and interior spaces, each floor is a composition of interior spaces and the relation is 1 to M (1 to Many) where 1 floor can have 1…* interior spaces.

 The other important part of this physical model is topology rules which define topological rules that should be imposed on the objects. For instances for the same objects *Floors* and *InteriorSpace* we define the rules "*InteriorSpaces Must Not Have Gaps*" or "*Floors Must Covered by InteriorSpaces*". Similar rules define for line objects and points. For example "*FloorLines Must Not Have Dangles*", or *FloorPoints* "*Must Be Coincide With…*", "*Floor Boundary Must Be Covered By…*", these rules should be considered during data preparation process.

In this model we do not assign different class for navigation graph since routing graph mainly coincident with the class of FloorPlanLine. In next chapter we discussed about indoor routing and graph generation method.

Outdoor Feature Dataset: In the current data model we also include properties for outdoor data and fill it with some sample data of TUM campus geodatabse. this outdoor feature dataset contains feature classes of different geometries such as polygons of buildings, university boundary, university environment, parking, and other main layers with schema of their attributes, line classes are street centerline in different classification of highway, cycle way, footway, and the last class is point class such as café, cinema, fast foods, restaurants, benches, trees and any point feature in university environment.

Operational Information and Domains: These are classes that are defined as non-spatial information and tables such as the Photo table which indicates the interior and exterior images information, this table is linked to the *PhotoLocation* table which is explained before. Moreover domains for *POI*, *InteriorSpaces*, *FloorPlanLines* and other *metaclasses* which are defined in conceptual model here should be defined and linked to their coincident geometry. For instance POI are defined by the *POITypeId* and linked to the class *BuildingPOI*. Address table is also another attribute table for buildings descriptive location which will be linked to building table for geocoding purposes.

GeoRaster: This feature dataset contains orthoimage and satellite image of the university environment, for the user to be able to change the view from map view to image view. We will explain in sections 4.1.1 and 4.1.2 that building polygons are used to be georefrenced and then interior buildings and floors also should be georefrenced based on the world coordinate system.

In Next chapter we explain campus map specifications, fill these prepared data models with real data of the campus and discuss more practical part of a campus map for mobile application.

Chapter4: Campus Map Material, Data, Applications

4.1 Data Collection and Preparation

Data preparation which is including collection, modification and analysis is divided to two main parts: *indoor data* and *outdoor data.* Outdoor data covers campus environment such as connection streets, bus and subway stations, commercial and residential buildings and we try to cover an area about half a kilometer around the university. The main source data for the outdoor environment is Open Street Map.

The indoor map which represents indoor physical spaces and features mainly generated from CAD floor plans, and later on necessary attributes are linked to the data.

4.1.1 Outdoor Data

To develop a Smart Campus Map, we need to start from mapping the environment and then link it to the indoor parts this approach should be considered for all steps from mapping to navigation. It means we need both outdoor and indoor data to be able to map, locate and navigate the user from out of the campus to the end point inside the buildings such as lecture rooms or library.

In this work we start with getting "Open Street Map" data using JOSM[22] , since this data is in OSM format we need to convert the data to shapefiles to make outdoor maps. There are different solutions to convert OSM data to shapefiles such as *QGIS[23], PostGIS[24]* using *osm2pgsql[25]*, using *Global Mapper[26]* or some Arc GIS plugins

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[22] **JOSM**: is an extensible editor for Open Street Map written in Java; http://josm.openstreetmap.de/
[23] **QGIS**: Quantum GIS (QGIS) is an open source Geographic Information System (GIS) license under the General Public License (GNU); http://www.qgis.org/

[24] **PostGIS** is a spatial database extender for PostgreSQL object-relational database. It adds support for geographic objects allowing location queries to be run in SQL. http://postgis.net/

[25] **osm2pgsql** is a command-line based program that converts OpenStreetMap data to postGIS-enabled PostgreSQL databases. http://wiki.openstreetmap.org/wiki/Osm2pgsql

[26] **GlobalMapper** is commercial GIS data processing software developed by Blue Marble Geographics Company. http://www.bluemarblegeo.com/products/global-mapper.php

such as *OSM Loader* or *OSM Editor* for ArcGIS. More details about getting OSM data and convert them to shapefiles there is in *wiki.openstreetmap*[27] webpage.

Also OSM data are provided as shapefiles format by *Cloudmade*[28] and *Geofabrik*[29] companies, but this data is raw data and some details geometry which we can find in OSM online map are not available in these websites.

After getting OSM data for the campus and surrounding area we convert them to individual layers in shapefiles format, the criteria for split layers is feature description attribute field in OSM data. Using this attribute data we make many layers in three main basic geometries which are polygon, line and point. As an example we use the attribute "area_amenity_university" to make university buildings layer. The same process is used to make all the point, line and polygon layers which is used for outdoor university campus. Table1 shows the list of layers and properties which we used for the Technical University of Munich, main campus (Stammgelände), detail of layers are in Appendix A.

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[27] http://wiki.openstreetmap.org/wiki/Shapefiles

[28] **CloudMade** provides OEMs and application developers with a range of innovative tools and APIs. http://cloudmade.com/

[29] **Geofabrik** is a German based company founded in 2007 which creates shape files, maps, map tiles and full-blown web mapping solutions and dealing with OpenStreetMap. http://www.geofabrik.de/

Campus Map Material, Data, Applications

Simplified Data Dictionary of Layers in Main TUM Campus Map

Scale Level	Layer name	Feature Type	Visibility Scale	Source
1: 1000	point_railway_subway	Point	Range 1:250 – 1:1400	OSM, Sattelite Image
	point_railway_tram_stop		Range 1:1400 – 1:2500	OSM
	point_shop_supermarket		Range 1:250 – 1:1400	OSM
	point_amenity_cinema		Range 1:250 – 1:1400	OSM
	line_building_stairs_prj	Line	Range 1:250 – 1:1400	Auto CAD Map
	line_highway_street_Merge		Range 1:250 – 1:1400	OSM, generalised
	line_highway_service		Range 1:250 – 1:1400	OSM
	line_highway_footway		Range 1:250 – 1:1400	OSM
	area_amenity_ConnectionBiulding_uni	Polygon	Range 1:250 – 1:1400	OSM
	area_highway_pedestrian		Range 1:250 – 1:1400	OSM
	area_boundry_university		Range 1:250 – 1:1400	OSM
1: 2000	point_railway_subway_entrance_2000	Point	Range 1:1400 – 1:2500	OSM, Sattelite Image
	point_railway_tram_stop		Range 1:1400 – 1:2500	OSM
	point_amenity_fastFood_Cafe_Merg		Range 1:1400 – 1:2500	OSM, generalised
	point_amenity_cinema		Range 1:1400 – 1:2500	OSM
	line_highway_street_Merge	Line	Range 1:1400 – 1:2500	OSM, generalised
	line_highway_service		Range 1:1400 – 1:2500	OSM
	line_highway_footway		Range 1:1400 – 1:2500	OSM
	area_amenity_ConnectionBiulding_uni	Polygon	Range 1:1400 – 1:2500	OSM
	area_leisure_playground		Range 1:1400 – 1:2500	OSM
	area_boundry_university		Range 1:1400 – 1:2500	OSM
1: 4000	Text_4k	Point	Range 1:2500 – 1:6000	Author
	tree_sc2000		Range 1:2500 – 1:6000	OSM, Sattelite Image
	point_amenity_entrance		Range 1:2500 – 1:6000	OSM
	line_highway_street_Merge	Line	Range 1:2500 – 1:6000	OSM, generalised
	line_highway_service		Range 1:2500 – 1:6000	OSM
	line_highway_footway_4k		Range 1:2500 – 1:6000	OSM, generalised
	area_amenity_university_4k	Polygon	Range 1:2500 – 1:6000	OSM, generalised
	area_highway_pedestrian		Range 1:2500 – 1:6000	OSM
	area_boundry_university		Range 1:2500 – 1:6000	OSM
	Clip	Polygon	All scales	Author

Table 1: Part of Data Dictionary of Layers in Main TUM Campus Map
These layers are mainly from OpenStreetMap and generalized in three scales. Floor layers from CAD maps also are available in scales of bigger than 1:1000. For a complete table refer to Appendix A.

We designed the outdoor campus map in ArcGIS v.10 for three zoom levels:

- **Scale 1:1000** (1:250 – 1:1400) in this zoom level we show detail of indoor spaces for base floor, room numbers, street centerlines, point features such as trees, benches, statues and so on.
- **Scale 1:2000** (1:1400 – 1:2500) for this scale we generalized some features for instance point features, roads and some buildings, also the annotations are decreased to clarify map presentation. Some generalization methods in each zoom level are applied to make a comprehensive map, for instance *classification* to decrease classes of roads, and buildings; *dimensional collapse* to use centerline in small scale instead of double road lines.
- **Scale 1:4000** (1:2500 – 1:6000) the final zoom level which has an overview on the campus environment. In this level we aggregate individual buildings to make building blocks and use selection method for point features. Providing outdoor map in different zoom levels gives this option to the user that with zoom in and out get different level of details of the campus environment.

Figure 18 shows main campus map. For a good resolution of this map, and also maps of other TUM campuses (Garching and Weihenstephan) refer to Appendices B, C and D.

Regarding attribute data we try to simplify information and remove extra details and blank field, instead add some necessary fields per feature type. So user in each zoom level by clicking on the map and objects get necessary information.

- Link PDF map of construction details for each building in zoom level 1:1000
- Link image of each building in zoom level 1:1000
- Hyperlink website of departments and university to related objects
- Add fields which shows last update, author and source of data for each layer
- Provide some blank fields which are needed to fill later such as type, name and other fields.

Fig. 18: Smart Campus Map layout for Outdoor

This image shows Campus Map environment which is prepared in ArcGIS using an integration of Open Street Map data and CAD maps for buildings details in large zoom levels. Since beginning of this work there is now basemap and geodatabse for campus environment this map is the first step of data preparation for next steps.

Since this map is just usable for desktop and printable versions, we made another map which is available online using ArcGIS online service. This is the first version of this map which is progressing in the future along with ArcGIS online improvement. In this version we try to upload the same data and make a map in different zoom levels, however still there are some restrictions in labeling and symbolization. Steps to generate an online map in ArcGIS online are user-friendly and fast. In below shortly we mention these steps:

- Upload layers
- Design Map
- Edit Layers
- Save and Publish

After upload ArcGIS desktop layers and design online map we can share it to be available for public access, we should mention that for ArcGIS Online map we do not use all the layers, and also symbolization is different (see Fig. 19). This map at the moment is available on ArcGIS Online server under the name of "TUM Department of Cartography". The benefit of ArcGIS Online map is that we can use different maps such as OSM, Topography map, satellite image, street map as the base map. A detail report of the whole work about the data collection and conversion from OSM and CAD files, detail list of layers and properties and cartography workflow there is in TUM Smart Campus Map report (Nikoohemat 2012).
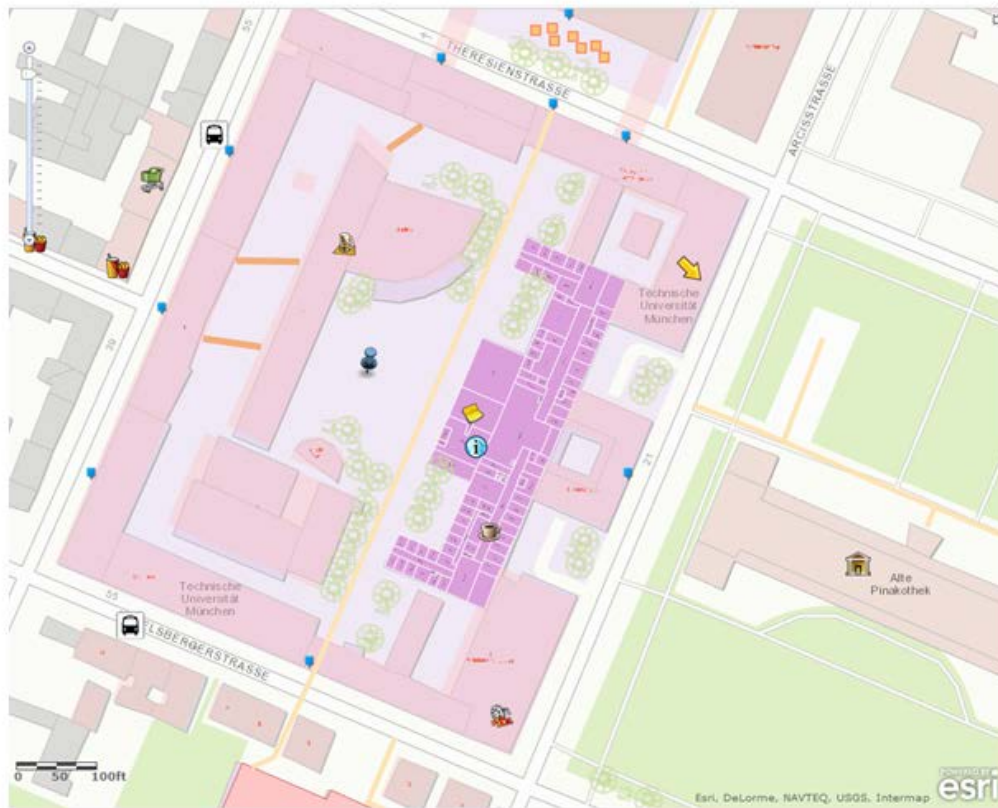

Fig. 19: Smart Campus Map on ArcGIS Online

This image represents TUM Campus Map on ArcGIS Online; this is an interactive map, when user clicks on features would be able to get attribute information. Through zoom in indoor spaces of buildings will show up.

4.1.2 Indoor Data

Another important step to provide smart campus map for LBS purposes is mapping indoor areas. Definitely, the first map source for indoor spaces is CAD maps (Computer Aided Design); CAD maps are used for construction, maintenance of buildings and utilities such as water and networks. These maps have different features and object formats which needs to much manual work to be prepared for LBS purposes. In CAD maps there are objects such as 3D faces, 3D polylines and dimensions to represent indoor spaces such as rooms, corridors, stairs, doors and lifts. "However to propose a smart itinerary to a pedestrian, a deeper knowledge of the map objects is required, along with more information about their topological relationships"(Gilliéron and Merminod 2003).On the other hands there are some topological and geometry problems in the CAD files which before editing and converting to other formats should be modified. Here we discuss the process.

1- First we get rid of unnecessary layers and just keep layers which construct the indoor spaces of floors. Removing unnecessary layers should be done carefully, not to remove any line or layer that makes physical spaces which are needed for indoor navigation process.

2- Then we make text smaller and try to locate them in the right position of the room or building. Later we use these texts such as names and room numbers to link attribute data to the indoor areas.

3- As mentioned before there are some geometry errors in CAD files such as *undershoot* and *overshoot.* Table 2 shows different kinds of geometry errors which should be modified before next step.

4- Clean up tool in AutoCAD Map 3D gives this opportunity to apply an automatic cleanup process on geometry errors of the floor plans. If we do not do this process carefully most likely we miss some rooms and areas because of unclosed polygons (see Fig. 20)

5- Since the CAD maps are not in geo-referenced position and have different scales we need to geo-referenced them and scale them to match them with the outdoor map location. To do this we can either use *Spatial Adjustment tool* in ArcGIS toolbox and scale, rotate and geo-referenced the floors to the base map which we have already made or we can use scale, rotate and *Rubber Sheet tool* in AutoCAD and geo-referenced floors and modified them again. This step needs too much patient and probably reiteration of the process to get desired result.
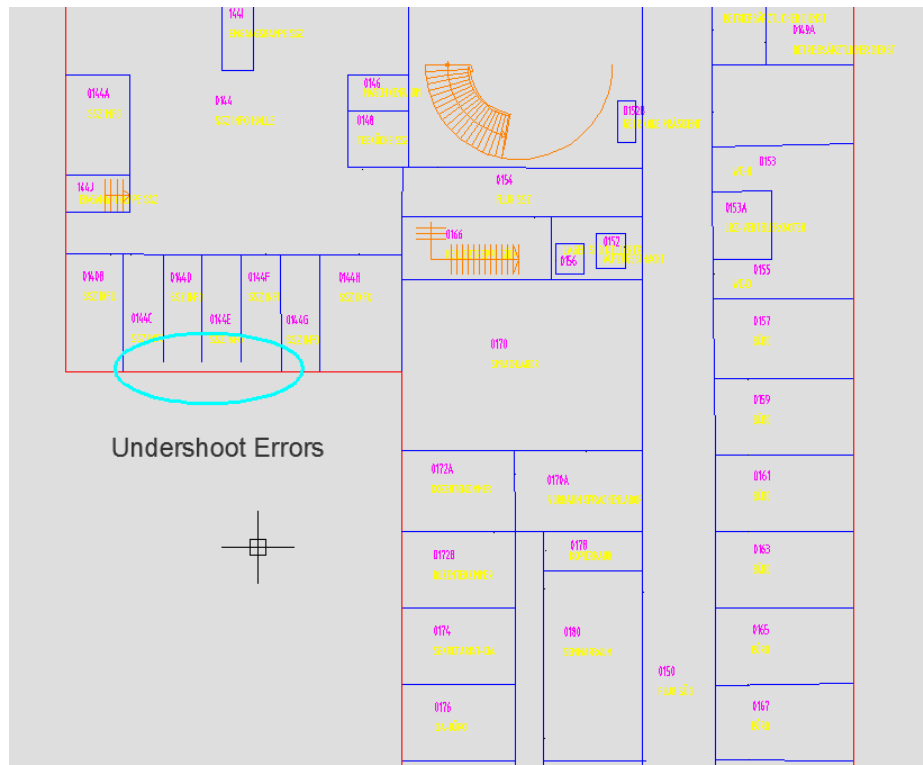
Fig. 20: Sample CAD floor plan with undershoot errors

This CAD floor plan shows some rooms are not closed areas because of undershoot errors, hence before using the map from GIS point of view we should cleanup the map from geometric errors.

In these CAD maps we represent indoor spaces such as rooms, corridors and lift rooms as polygons, since we do not have polygon object in CAD structure we represent them with closed lines and make sure there is no gap or undershoot in snap points therefore neighbor spaces share lines. Text and number of rooms are represented as points; doors also characterized by points which topologically should be snapped to walls in the same position of architectural plan, stairs represented by centerline with the start and endpoint in each floor (see Fig.21). Furthermore we can generate centerline of corridors and connection lines for routing graph.

Rooms, lift rooms, stair cases, corridors: closed areas which sharing walls

Stairs: centerline with start and end point

Doors: points snapped to the walls in the same position

Texts and Names: in the right position with insertion point

The reason why each object should have which geometry and which kind of topology relationship will discuss in conceptual model (3.2 Conceptual Model).
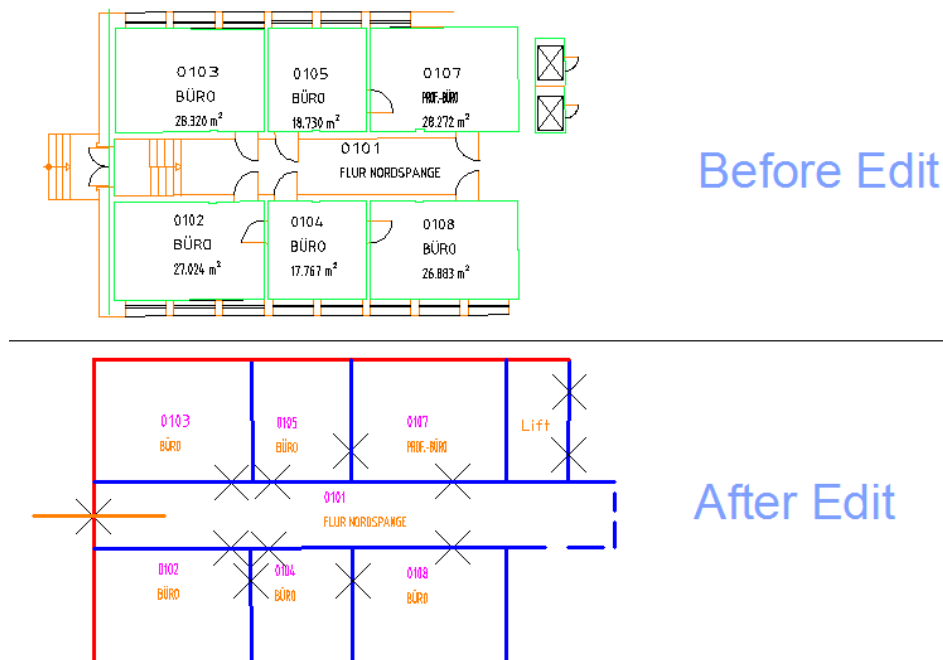
Fig. 21: Part of CAD floor plan

Representing different elements before and after editing process (doors, rooms, lifts, stairs, corridors, texts)

This CAD floor plan shows different floor elements, here we represent doors as points which are marked by X symbol. Doors should be located in the right position of architecture plan and snapped to the wall. Rooms, corridors, lifts and other physical areas are closed by lines. Neighbor rooms share lines. Stairs are represented by the centerline. Windows and spaces between walls are removed from result edition.
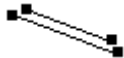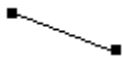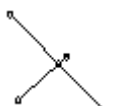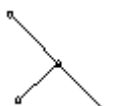
Geometry Error	Modified Geometry	Description	Modify solution
		Duplicate Objects These objects share the same start and end point, it applies to all basic geometries such as point, line, polygons, text	Delete Duplicate
		Undershoot Undershoot happened when lines are not snapped precisely one of the most important effects of this error is unclosed areas and missing polygons.	Break Crossing Object
		Crossing Objects This error happens for features that cross each other but do not have node at crossing point.	Extend Undershoot
		Dangles or Overshoot Dangle objects are unnecessary segments which should be removed.	Erase Dangling Objects
		Pseudo Nodes Pseudo nodes are unnecessary nodes in a geometric link that is shared by only two objects.	Dissolve Pseudo Nodes

Table 2: Table of Geometric Errors

This table illustrates some of the main geometric errors in the CAD maps which we need to modify before using floor plans. For example undershoot errors cause unclosed areas. (AutoCAD Map 3D, 2013)[30]

[30] AutoCAD Map 3D online Help, Clean up Action, 2013;
http://docs.autodesk.com/MAP/2013/ENU/index.html

After performing these steps we almost prepared floor plans, we apply this process for different floor plans of campus building, for instance building 1 has five floors and in total we have more than 15 buildings including north building.

Another approach for making floor plans and exporting them to desired formats such as SVG[31] is the work which is done in another work by Cirlugea (Cirlugea 2013). In this work which is done for all CAD files of TUM Campus, instead of DWG format of CAD maps he used PDF format of architectural plans and using Adobe Illustrator (or Inkscape) with drawing tools generate closed polygons for each physical space. However in this work there is a gap between pair rooms or corridors, and doors are represented as polygons. Thus in the final result rooms are not topologically neighbors and there is a gap between them which are connected by door polygons (see Fig. 22). Room numbers also are linked as an attribute to polygons. Later on these maps are exported as *SVG* file and imported into the *SketchUp* as surfaces using a plug in.

Fig. 22: Indoor rooms and corridors, TUM campus building (Cirlugea 2013)

This map represents an imported SVG file in SketchUp. As it is shown physical indoor areas are connected by doors which are small polygons, and there are gaps between rooms and corridors. In this kind of maps, indoor spaces do not share walls.

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[31] **SVG**: Scalable Vector Graphic is a two dimensional xml-based language to define vector-based graphics for the web

There are some disadvantages for this approach considering the too much manual work and topological issues. Since there are many CAD files it is not a good workaround to digitize files manually in drawing software such as Inkscape or Adobe Illustrator, here there would be two objections. First, the process is very time consuming and second it is not that much precise regarding connected lines and closed areas. Furthermore the doors are represented as polygons which topologically have no logic behind that. However still they are useful for some application and more static mobile applications. In addition for 3D visualization still they are applicable. In next section when we discuss indoor navigation methods and applications we explain one mobile application prototype which uses these maps for campus map.

4.2 Smart Campus Map in Mobile Applications

4.2.1 Available Campus Map in Application

There are several campus maps designed for TUM campuses and available on the TUM website[32] and some simple "You are here map" installed on the university buildings and corridors (refer to figure 1 and figure2 in the introduction). Although these maps are not cartography designed but they are the only maps at the moment available for the campus.

For TUM campus there is a mobile app which mainly is designed for informing the students about the general information such as events, news, restaurant menus, city transportation schedule and also a map plan of the university campuses which is a very basic map in image format (see Fig. 23). Also several other test applications for research purposes are developed by different departments. Moreover there is a room finder webpage which gives very primary information over lecture rooms with very basic functionality on the same simple maps (see Fig. 24).

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[32] http://portal.mytum.de/campus/index_html_en/
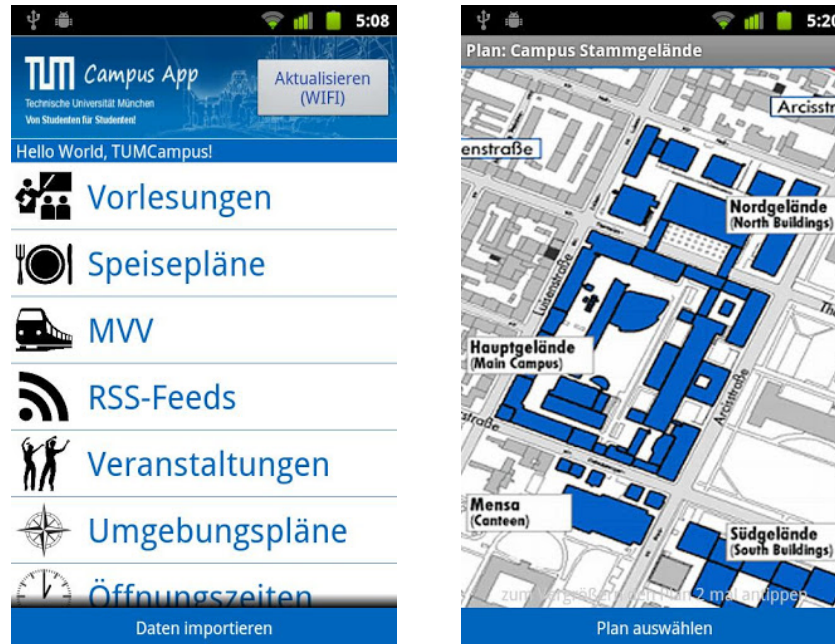
Fig. 23: TUM Campus App (www.tum.de)

This Campus App is designed by TUM Informatics' department mainly for giving general information about the lectures, restaurant daily menu, transportation schedule, news and events in the university. Also it has a map representation which is an image. This map is not designed for indoor navigation purposes.

These maps are not cartographic designed and not proper for indoor navigation system. For this reason one of the purpose of this work is pushing the smart campus map project for multiple applications mainly mobile Apps. In a parallel work of another student in TUM department of cartography a sample app for several buildings was developed. However this App is in the first implementation stage and is developed just for some static routs but is a good start. In further work with the cooperation of extended models and methods in this work we lead to more complete App with LBS purposes. In next section we briefly explain the implemented application.
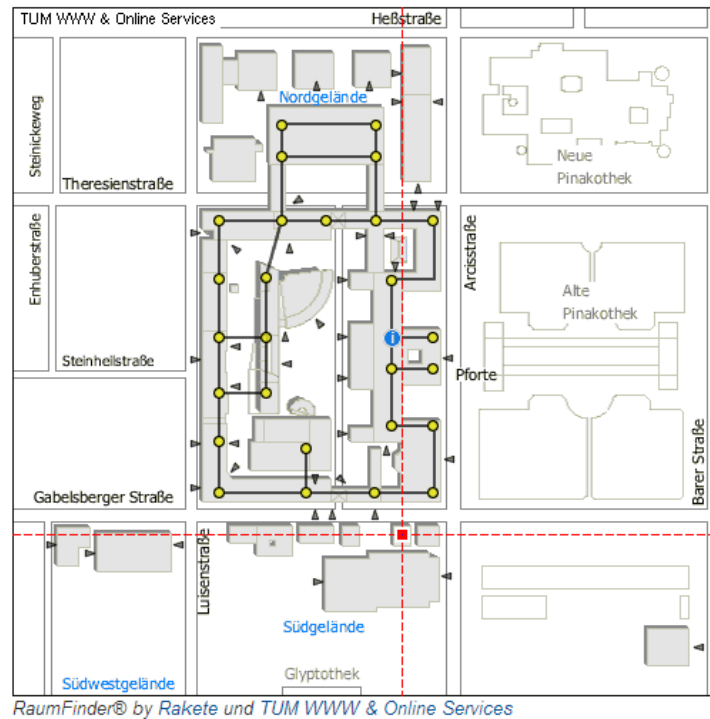
Fig. 24: Roomfinder tool available on the TUM website[33]

This application just represents the searched room number with a red cross on the base map as shown in the image. The map is not interactive.

4.2.2 TUM Campus Mobile App (TUM Navi)

The main goal of mobile cartography approach is to offer geographic visulalisation with the greatest relevance to the mobile user (Reichenbacher 2003). In this contain the user is object of relevancy it means that the context and dimensions (location, time, activity, information, system, etc.) that user is involved in it conveys the relevancy. For university mobile application this is university campus and students and staff. Therefore each mobile application should aim to meet the student's queries and demands in the context of university and campus map. In this regard we classify student's requests to two main categories; those that are location based and

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[33] URL: http://portal.mytum.de/campus/roomfinder/search_room_form

those which are just informative. Location base demands as discussed so far are clear queries such as routing, find lecture rooms, locating POIs and find friends. Informative requests are checking events, hot news, checking lectures schedule, get information about the exams and checking daily university restaurant menu and some others demands. However many of these informative services can be integrated into the campus map and somehow related to the location. For instance students after checking the events can be informed about the location on the map. A smart campus map for the mobile application should be interactive to able the student get information about the represented features on the map.

In following work we briefly explain the applications that developed by Fackler (Fackler 2013) as a replica of more completed application. The current App so called *TUM Navi* is in the test developing stage and uses some static and predefined routs for navigation in two buildings of the TUM main campus. Here is the characteristic of application environment:

Device: Windows 7, HTC

Platform: Windows Phone 7.8

Programing Language: Visual Studio, C#, Win. SDK 8

Map functions SDK: ArcGIS Runtime SDK for Windows Phone

Map platform: SVG, SketchUp, DirectX

App Language: German

As we can see in figure 25, the start page of the App gives the user start and destination point entries, and then user is able to select routing or just go to the map.

Fig. 25: TUM Campus App for windows mobile (Fackler 2013)

TUM-Navi mobile application routing functionality gives the user start and destination point entries, and then user is able to select routing method or just go to the map.

As mentioned before routing is set for some fixed routs from two neighbor buildings. For routing there are two options, minimalistic routing and explicit routing (see Fig. 26-left). Minimalistic rout just shows the start point and with arrows heading to the destination guides the user to the target. There is no positioning in this step. However this option can be improved by adding localization on the screen. In minimalistic rout the user get benefit of some room numbers and landmarks on the map to confirm his location and correct routing, then user can change the floor plans and using arrows directing to the target to reach the destination, meantime the information about the start, destination and represented map floor are shown on the mobile screen (see Fig. 26-right).

Fig. 26: TUM-Navi routing's tools (Fackler 2013)

Fig. 26-left: Routing options in TUM Navi, explicit routing and minimalistic routing

Fig. 26-right: Routing using minimalistic option. The red surface is destination and the arrows direct the user from start to the target. Some room numbers and symbols used as localization and routing confirmation by the user. With − and + buttons user change the floor maps.

Another routing option is explicit routing which get benefit of predefined routs and guide the user to the target (see Fig. 27-left). Internet connection for none of the routing options is not necessary, however if the App in next developing stage uses add indoor positioning service then internet connection would be useful. Also the App is able to connect via internet connection to the room finder tool of on campus web page and show the result on the room finder map which previously explained. Moreover as a connection to the outdoor environment the app uses ArcGIS online map through internet connection and by GPS positioning shows the user position outside the buildings in the campus environment and user can navigate from point A to point B using ArcGIS API for routing (see Fig. 27-right). The benefit of outdoor positioning is that we are able to embed customized campus map containing more attributes, symbolization and floor plans to current online map services such as Bing, OSM and ArcGIS online. However this purpose as the moment just available for the base map of ArcGIS Online.

Fig. 27: Explicit and outdoor routing in TUM-Navi (Fackler 2013)

Fig. 27-left: Explicit Routing using predefined routs for routing from A to B
Fig. 27-right: Outdoor Routing using GPS and ArcGIS Online map service

Augmented reality also is implemented in the App. For this purpose the user should be locate to the observation point which are shown on the map and then with the Augmented reality option can get the name of the buildings using mobile camera. This is a very useful method when equipped with speech tool on the mobile for impaired visual users. The downside of this tool in *TUM-Navi* is that user should locate into the observation points (of course with a tolerance of few meters) to be capable of using this service.

One of the interesting options in the map representation is that the map is a float map on the screen which rotates and change its perspective based on the gyroscope axis angles and rotation matrix. This functionality works with a combination of gyroscope and compass sensors. As a negative point too much rotating and shaking of the map on the screen make it unreadable for the user, probably this visualization option could be progressed by decreasing sensor's sensitivity and an option for the user to fix the map.

Finally a user test was implemented on the App for familiar and unfamiliar users in the campus. The result and detail documentation on this project is available in the Fackler's thesis (Fackler 2013).

4.2.3 Proposed Indoor Navigation System Framework

After data preparation step and providing campus map data models (refer chapter 3), now we need to put all together in a mobile application. To do so we propose an application framework to smooth the path. In this framework we consider all probable options which are on demand for a campus mobile App while try to keep it simple and applicable. This framework shows the indoor navigation system components integrated with 3D visualization and outdoor navigation in a mock up user interface.

This framework composed of 5 main components where each of them contains subcomponents.

1. Main User Interface:
2. Advanced Visualisation
3. Index Structure
4. Indoor Navigation Function
5. Outdoor Environment

1. **Main User Interface:**

   Main user interface contains the 2D map representation with the options in the left and right to enable outdoor map, 3D map and change between floors in the same screen (see Fig. 31). User can use a slider to change between floors, since this 2D map just shows indoor environment, user can change to outdoor environment for better orientation which shows user's position and building where user is inside. 2D map is an interactive map which user is able to get information by clicking on the features (see Fig.28). When user change floors the same screen in a 2D view will change, but if user selects 3D map or outdoor map then application locate to another page and show other maps. 3D map option is mainly for visualization of user enquiries and result of routing in a 3D environment and just give user an advanced 3D perspective, it is not for the purposes of the routing. All calculation and queries applied in the 2D map. Since LBS services are context-aware systems it shows bluedot user location and depends on the user location gives relevant information on the map. The info screens are pop up screens and balloons on the 2D map screen. A good route presentation form should have the minimum cognitive load for the user. The available solutions for presentation forms in addition to map is signs (electronic),

textual, verbal instruction, images, videos and 3D presentation (Huang and Gartner 2010).
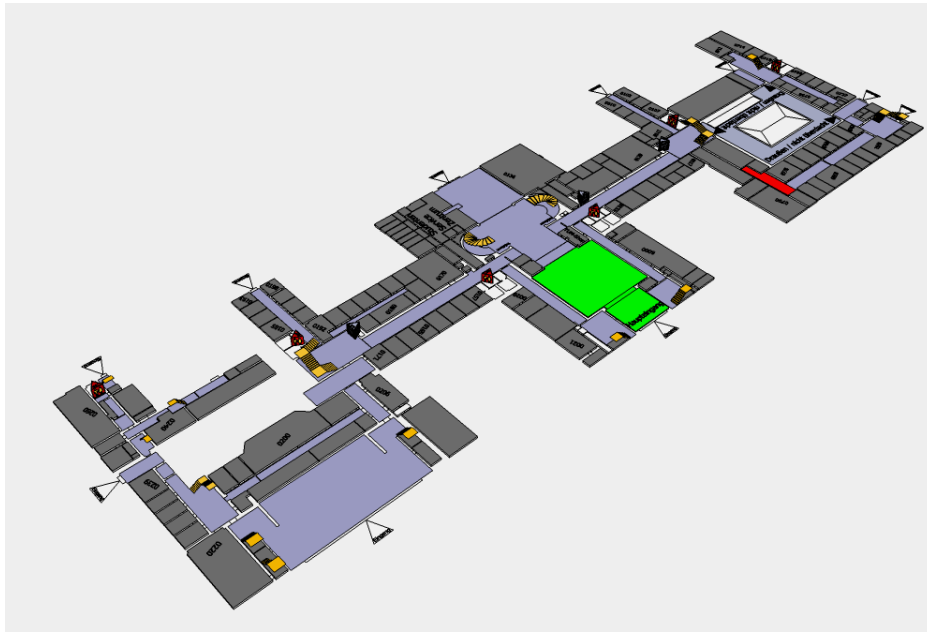
Fig. 28: Sample 2D map for routing representation (Fackler 2013)

The dark blue areas show corridors and the green areas is showing the current location of the user in main entrance, all rooms are not labeled to avoid overloading information, just some rooms and symbols help the user as landmarks for way finding.

2. **Advanced Visualization:**
    User has possibility to enable this service through the main interface and then the screen change to 3D map representation. 3D map contains floors in perspective view with 3D symbolization and texture (see Fig. 29). Also routs, stairs and passages between buildings are represented in a 3D format (see Fig. 30). The core element of the mobile cartography concept is adaption (Reichenbacher 2003). In this sense the application visualization should be adaptive to user's activities and current information in demand. Advanced visualization should be an available medium adapting to the user's goals and activities. The software environment for 3D map should be discussed it can be CityGML, VRML (Virtual Reality Modeling Language), Sketch Up 3D models and convert them to readable formats for mobile platform. Whatever we use for 3D visualisation depends on mobile devices, programming language platform, positioning system and server/client structure. Since generally 3D models need

huge amount of rendering, hence during development computation costs and fast loading should be considered.
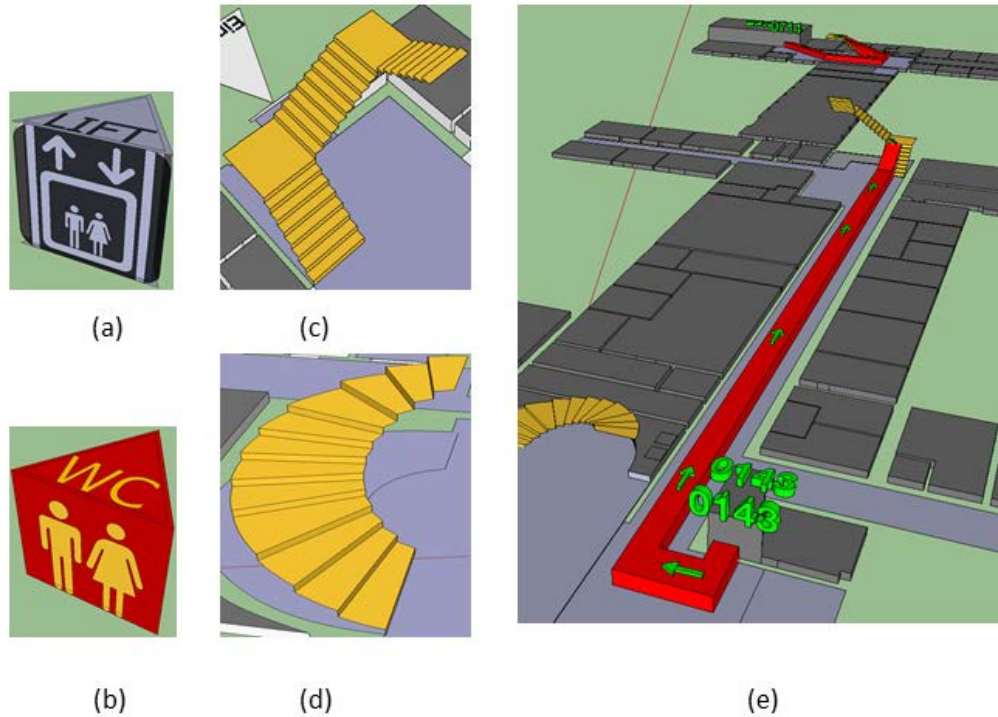
Fig. 29: TUM campus main building, first floor (Fackler 2013)

This images representing 3D rout by arrows, stairs and 3D symbols
Fig. 29a, b: Show 3D map symbols
Fig. 29c, d: Show 3D stairs representation
Fig. 29e: Shows 3D rout and labeling representation
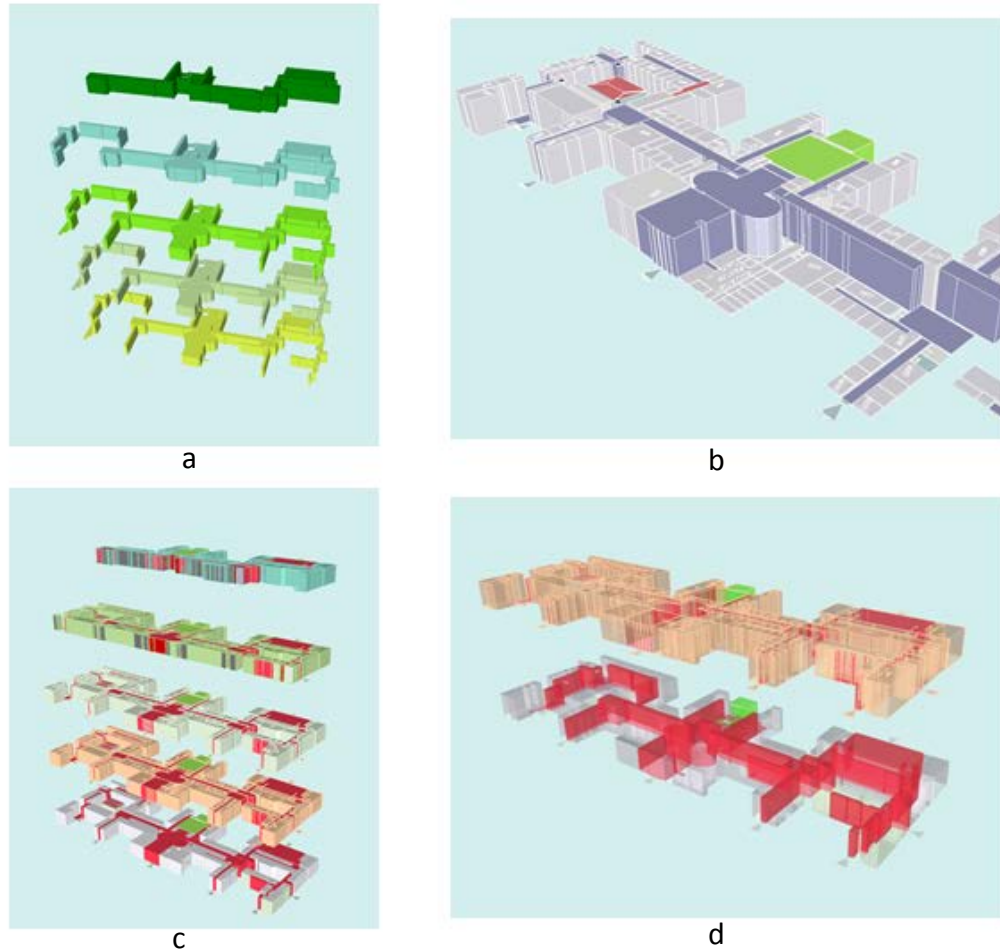
Fig. 30: Corridors and passages visualization in TUM Campus 3D map

Fig. 30a: shows different floors corridors

Fig. 30b: shows TUM main building, first floor, different colors for main hall, and corridors

Fig. 30c: shows rendered corridors in floor structure for better way finding

Fig. 30d: Same building floor plans with X-Ray representation, so user is able see simultaneously see the whole building and inside routs

3. **Index Structure:**

In every mobile application user request for inquiries with keyboard as an input, in this mobile App mock up similar to every other App user is able to request some information such as search rooms, names or POIs then in the database there is indexing for interior space's names and numbers which was defined and explained in section 3.2.3 (Conceptual model) and section 3.2.4 (physical model). Full text search is also an option like search engines where user can search any

information just by keywords, for the users that are not familiar with the German language and do not know the correct spell of the buildings. One of the privileges of mobile application is that any student especially foreigners and for instance exchange students or guest Professors should be able to use the system easily without too much familiarity with the campus environment. Then the result of the search will show up in an info screen and communicate with the map by the user selection from the list (see Fig.31).

4. **Navigation Function:**

Navigation function is the most important of the map which contains all the important components of the application. The layers which are illustrated in the figure 31 represent not only geographical layers and order of the information but also explain various layers in the data base for every component.

For navigation functionality we have the base map as the background which is the floors 2D map representing interior spaces, this map explained in first part, and then we have POIs and Names as point layers represented by symbols and texts. Routing graph is an important layer that in case of routing shows the routs and behind the scene is used for the way finding. Routing graph can be generated for all the routs and save in the spatial data base and then be applied or it can be generated real time by using routing algorithms such as shortest path and shortest time. Other component of navigation function is *spatio-temporal data*, this data should be update in the time of using the App. Spatio-temporal data is information about the current situation in the campus buildings and floors. For instance a rout is blocked because of construction or an elevator is out of service. Then the app will be updated with this information and change the rout. In addition it is possible to visualize spatio-temporal data on the map for better user communication. For instance a useful usage of this data is finding lecture rooms that at the moment are not holding lecture and are available for study or teamwork projects or even more in detail free seats in the library. The same approach is applied for POIs, for example working hours of some offices should be available and inform the student whether the service offices are open. Information about the events, lectures schedule, restaurant daily food menu and exam schedule can be updated in this part and linked to the geodata. Another component of navigation function is speech layer. This functionality boosts conventional indoor navigation which is just showing routs on the map. With speech layer and using the natural language of way finding we can get rid of a long list of descriptive form of routing presentation such as "follow the hallway

20 m", "after 5 m turn left", "take the lift in the right". Users experienced this speech navigation in

5. **Outdoor Environment:**

A seamless navigation from outdoor to indoor is an essential necessity for any indoor application. To apply this in campus mobile application user via interface would be able to steer from 2D map to outdoor map and get his/her orientation in a zoom out level on the campus environment. So far the 2D map and 3D map just show the buildings and indoor areas but outdoor map is an integration of floor plans in current map services such as Bing, OSM, ArcGIS online and so forth. Get benefit of GPS positioning and outdoor navigation services which available by means of APIs[34]; the user can navigate in outdoor area or even search rooms or POIs and see the result location in an overview map.

In proposed work frame outdoor environment component contains layer and services such as satellite image for image view, outdoor routing representation and outdoor base maps (see Fig.31). Needless to say since mobile devices are powerful media devices other kinds of representation forms such as images, videos, augmented reality, vibration, and signs can be added to the components.

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[34] Application Programming Interface
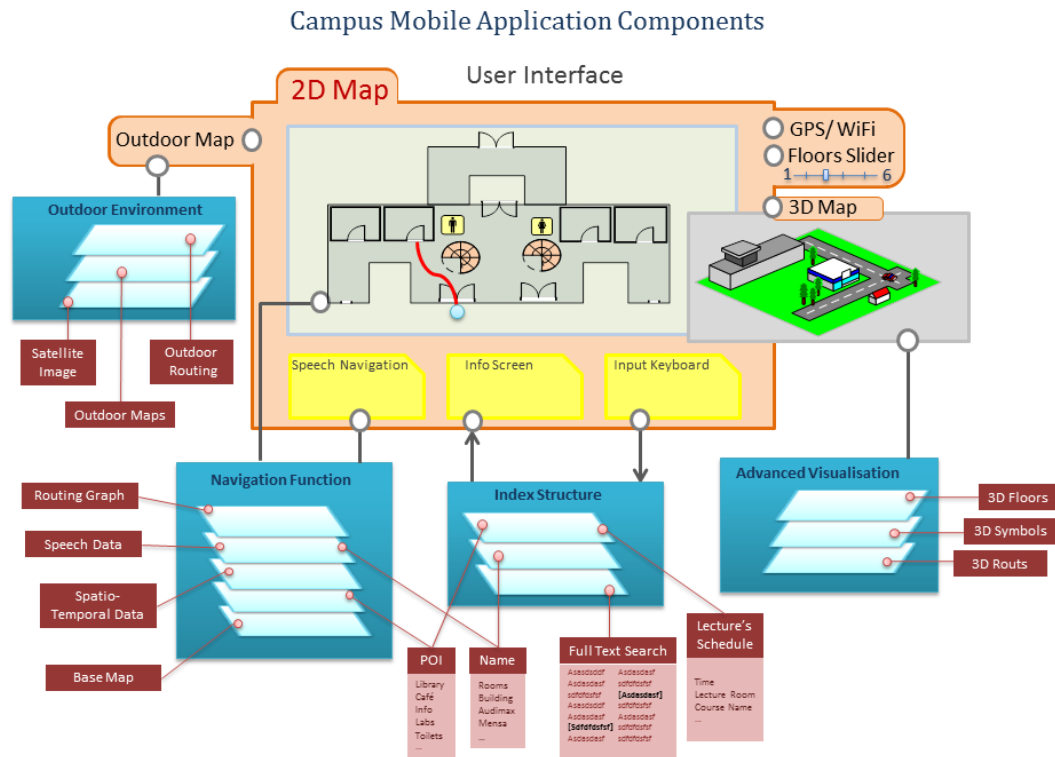
Fig. 31: Proposed Indoor Navigation System Framework for Mobile Application

This framework contains 5 main components: 1. 2D map which is floor and indoor area representation, 2. advanced visualisation which represents 3D maps, 3. Index structure for indexing and fast queries, 4. Navigation Function for indoor positioning and routing, 5. Outdoor environment which represents outdoor maps and supports outdoor navigation

4.2.4 Smart Campus Map in 3D

Building a proper 3D model of campus environment and interior spaces is a challenging part of indoor navigation systems. For 3D models we pick up an approach which is compatible by the system programming platform. As mentioned before the software environment for 3D map can be CityGML, VRML (Virtual Reality Modeling Language), 3D MAX, SketchUp 3D models and converting them to readable formats for mobile platform. Whatever we use for 3D visualisation depends on mobile devices, programming language platform, positioning system and server/client structure. Since generally 3D models need huge amount of rendering, hence during development computation costs and fast loading should be considered. The core element of the mobile cartography concept is adaption. In this

sense the application visualization should be adaptive to user's activities and current information in demand. Advanced visualization should be an available medium adapting to the user's goals and activities. Since mobile devices are compelling media devices other kinds of representation forms such as images, videos, augmented reality, vibration, and signs can be added to the components. The workflow for generating TUM 3D campus map is a continuation of 2D maps preparation which descriptively declared in previous section. Here we briefly explain how we prepared 3D models and specify some characteristic of a comprehensive campus 3D model for mobile applications. There are many similar 3D models for indoor environment but mainly designed for web applications. Hyeyoung (Hyeyoung et al. 2009) propose a 2D-3D hybrid data model for indoor routing in a SDBMS (spatial database management system). In this research they provide a 2D and 3D model and integrate them in PostGIS tables and then simulate a rout finding approach. In this model the author claims less complexity and fast computational process for the model. In TUM 3D campus we import CAD plans which prepared in SVG format into SketchUp using a plug in and then put different floors in the same position. Each floor imported in one layer and the component of each floor also separated into different layers for better management (see Fig. 32). Applying texture in SketchUp can be a useful approach to represent a real world model. For representing the whole buildings we use shape file of the campus which already have prepared and geo-referenced in ArcGIS by using a plugin we import the shapefiles into SketchUp and then add some texture and materials such as 3D tree and benches to the model.
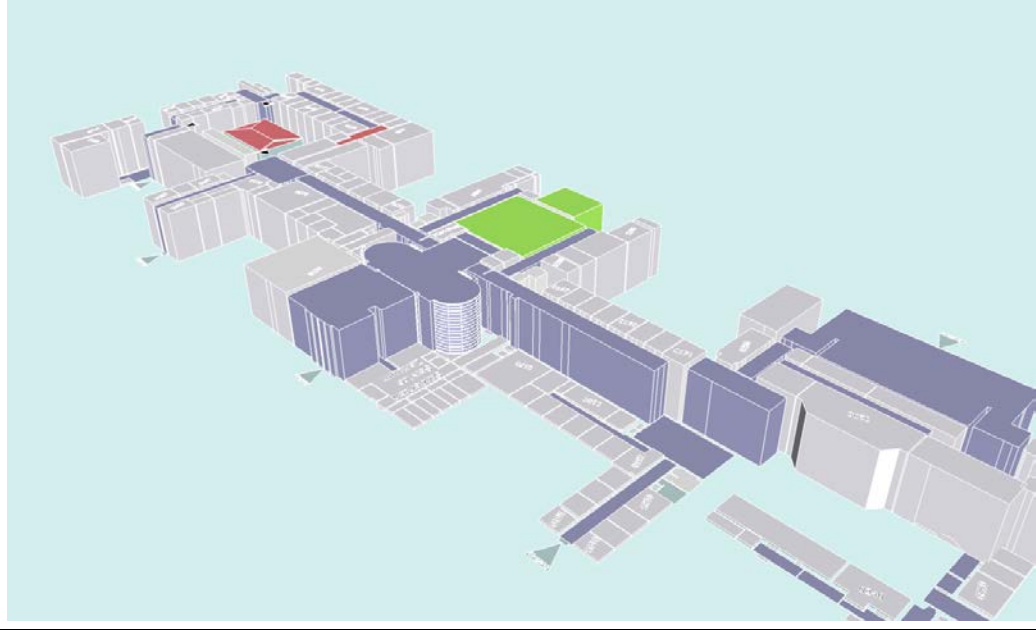
Fig. 32: TUM Main Building 3D model

This is a 3D visualisation of the campus; all buildings are not extruded in this scene.
Corridors and passages are rendered in different colors. The main entrance also is represented in green color for better localization.

Residential and commercial environment are not needed to be elevated thoroughly to avoid rendering problems during loading the 3D model on mobile screens (see Fig. 33). In case of zoom in and zoom out we can represent different scene of buildings details. For campus environment just some important buildings and POIs such as stores, subway entrance, and bus station are extruded in 3D. Also for better representation SketchUp has many options for shadowing. Therefore in an adaptive context-aware system based on the daytime the application can be adopted and represents different models with various shadowing views for instance morning and afternoon (see Fig. 34). Other following examples show TUM campus main buildings and floors with different representations. Each representation can be useful in different scenes. For instance wire frame (see Fig. 35) or X-Ray scene (see Fig. 36) are useful for showing routs from outside view.

Fig. 33: TUM Main Campus (Stammgelände) overview 3D model

Fig. 34: TUM Main Campus with different shadowing and perspective
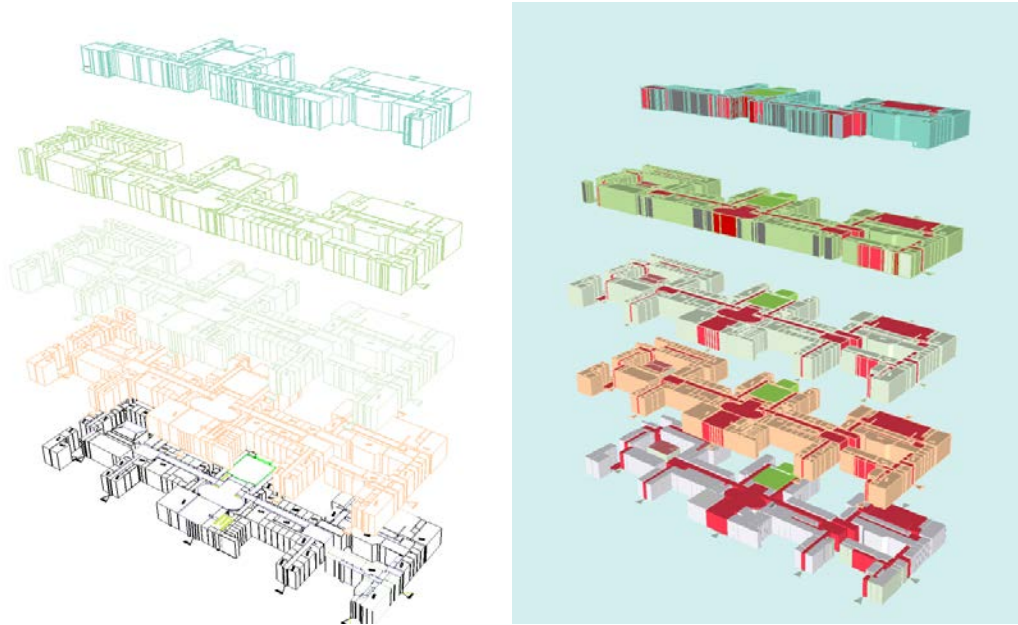
Fig. 35: TUM Campus, main building wireframe and corridor representation

(Left) TUM Campus, main building in wireframe representation
(Right) Same building, showing floor plans with different rendering for corridors
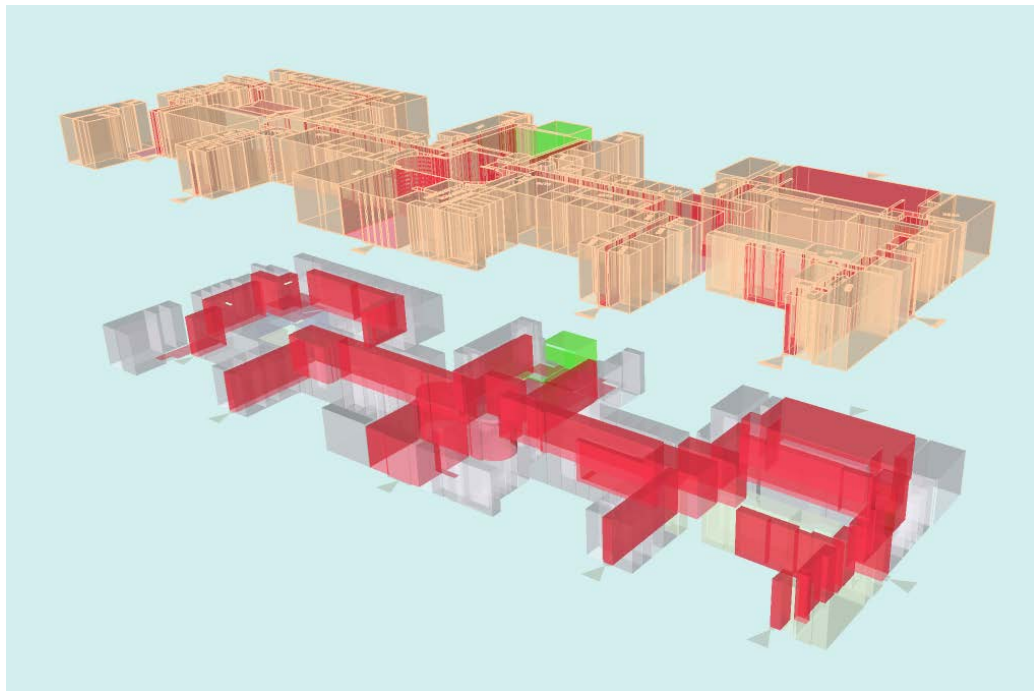
Fig. 36: TUM Campus, main building X-Ray representation. Red areas are passages.

Referring to the definition of smart, smart cities and smart buildings in the beginning of this work we can conclude smart map for digital purposes can get benefit of many sensors available in mobile devices. These censors such as light sensor, accelerometer, orientation sensor, magnetic field sensor and obtaining user location help the user in different situation get relative information. Getting benefit of these sensors we can also make an adaptive map/App which based on daytime, user location, or ambient light and noise adapt itself. For instance based on the ambient and daylight 3D map can apply different shadowing and coloring for the map or considering the user location just render part of the map environment that user is located and give relevant information to that position. Since every indoor LBS system should be a context-aware adapted system, here we remark some of the properties of such a system. Context-aware adaption has the following dimensions: Why (why do we need system adaption to a particular context), What (which features of the system can be adapted), To what (what aspect of the system context can be taken into account), When (timing and triggering of adaption), How (which procedure of adaption is needed?)(Huang and Gartner 2010). Considering these dimensions for a context-aware system we can generate a smart campus map which should entail as many as mentioned factors.

4.3 Campus Map and App Survey

 "The key challenge for decision-making in today's world is not having enough information: it is having the right information at the right time (PSRAI, 2013)[35]."

To finalize this work and get also have a user side opinion over campus map and mobile App, we implement an exploratory survey among 30 students and staff. Focus group is campus map users, staff and students, some of these students were familiar with the campus and some not. Few of surveys also are done by the students from other universities who just were here for one semester and experience being in different campuses. The number of questions is 20 and the questionnaires distributed in printed form among focus group.

4.3.1 Survey objectives
Since this survey is an exploratory type of survey, the goal is collecting information from students and staff about a smart campus map specification and mobile application requirements. The questions in the survey cover both campus map and

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[35] Princeton Survey Research Associates International, 2005-2013
http://www.psra.com/index.shtml

mobile application. Questions are designed in three categories: descriptive question which needs to be explained (just few questions), multiple choice questions (most of the questions), multiple choice with several answers, and scaling (degree of importance).

The objective of this survey is collecting informative data about campus map in mobile application. In this sense both the campus map and mobile application is the subject of questions. Questions cover three main topics (1) user previous experience with indoor maps and application (2) user's opinion about the map/App's design and style (3) user's opinion about the map/App's functionality and features.

4.3.2 Our survey result

The survey questionnaire distributed in printed format between 30 students of different filed of subject and different campuses. Most of the students are from geodesy and geoinformatics background that already are familiar with maps and LBS, others were from informatics, and economics. The survey was done by the students between 18 to 30 years old and also some staffs, two third of participants are male and except 7 out of 30 students the others have smart phone. Students were asked about their previous experience with the indoor maps and most of them have seen indoor maps of shopping malls, universities and airports. Other examples are too few to mention here. Around 45% of participants mentioned that they need campus maps just for the first time they were in the university and 25% during the exams and the rest during events. Since there are floor plans (you are here map) installed on the university indoor walls and hallways, student were asked about the frequency usage of these maps, around 25% the participants claimed that they used these maps just once, and the same number claimed that they used it weekly, the others answers was monthly and never respectively. It shows that these maps at the same time that for some students are useful for others are not. One reason could be the poor representation and communication form of these maps. Moreover students were asked if they pay for such App or not, if yes what is the range. Most of the students were not agree to buy or pay for the App.

Regarding map/App functionalities upcoming result is perceived. Most of the students prefer better functionality comparing design and style. For instance fast loading plays an important role between the most important factors in the map/App

(see Graph 1). Other important factor is map reliability and in contrast coloring, symbolization, and labeling has the least degree of importance for the users.
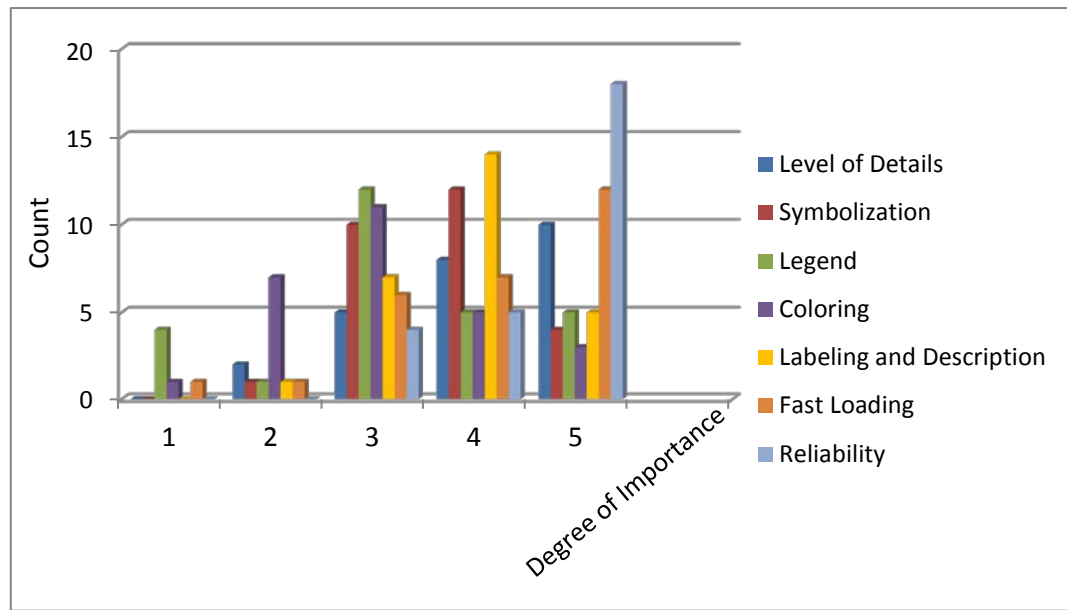
Graph1: Degree of importance for key factors in a digital campus map

As the graph shows there are 5degrees of rating for important factors in the digital campus map. Reliability and fast loading have the significant weight from student perspective.

When students were asked about the most important functionality of the campus map /App, or in similar concept for which applications they use the campus map/App the result shows the main intend is for find lecture rooms and routing. Other important applications in order of importance are find staff and Profs, search nearest POI (such as restrooms, library, restaurant, café and soft drink automat, etc). Other items such as finding events, finding free rooms for study has less importance. From students point of view finding friends functionality has no importance in the App (see Graph2 and Graph3).
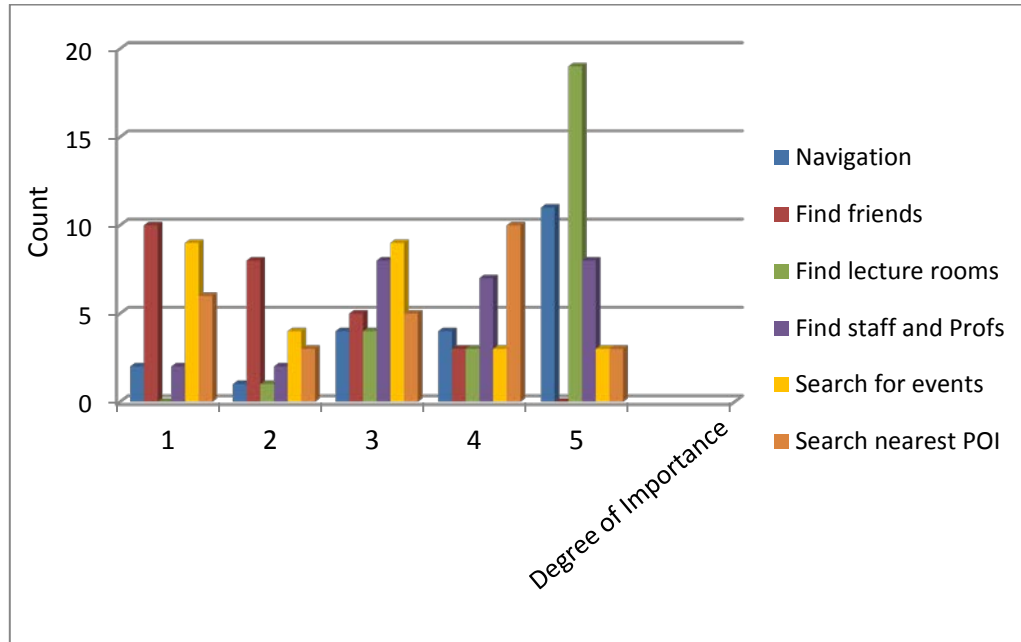
Graph2: Degree of importance for <u>functionality</u> in campus map/App

Finding lecture rooms is most on demanding functionality, respectively Navigation and search nearest POIs have more rate of importance. Finding friends functionality is not interesting for participants.
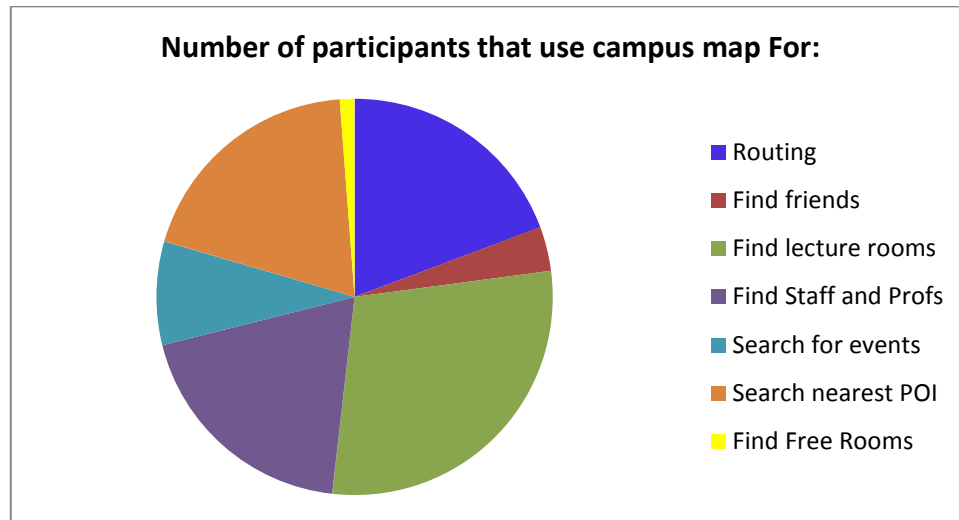
Graph3: Proportion of campus map usages

Give similar result to graph2 finding lecture rooms and routing play important role in campus map applications.

Regarding design and style characteristic of campus map/App most of the user prefer a map without legend and about integration floor plans on a base map (Google, Nokia, OSM, etc) of outdoor there is not a clear decision some of the users prefer with base map some others mentioned that they do not need base map. For instance they mentioned that they already have the base map of Google or other map service. However in previous section when we explained user interface for the mock up application we separated 2D floor maps from outdoor maps under condition that user be able to get outdoor orientation by means of other option in the App. Also as important features on the map for the user we proposed some POIs and were asked an open end question then user would be able to add more answers. The result is shown in graph4. It shows that lecture rooms are the most important features for the user and features that more or less have the same proportion of importance are café and restaurant, labs and computer pools, staff's rooms. Also some student added other features such as food and soft drinks automats, toilets and unoccupied lecture rooms for study.
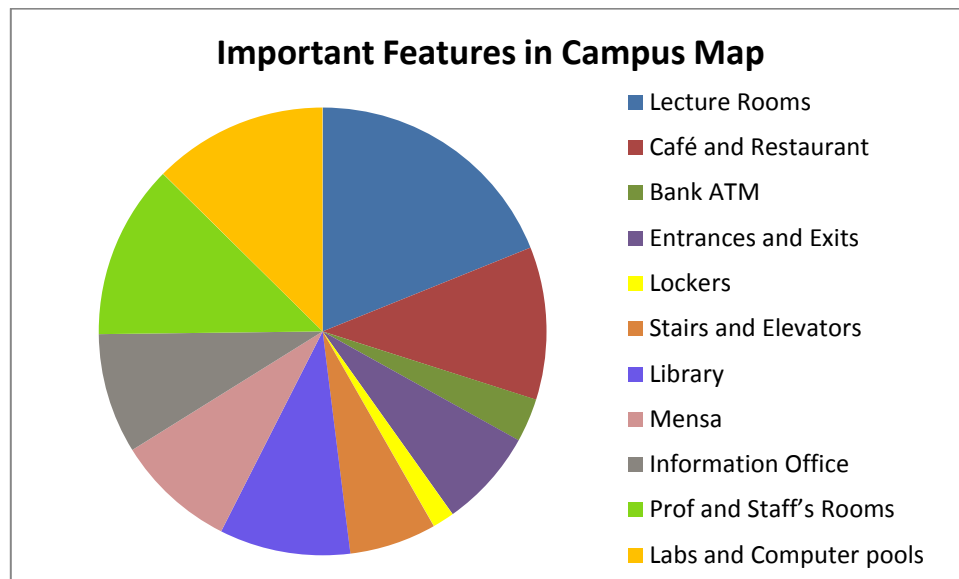
Graph4: Important features in campus map/APP

Lecture rooms has the most significance for students, other items are labs, staff's rooms, café and restaurant and library

Also students were asked about the time they spend every time using the App, most of the answers is about 1 to 3 mins and a few of them mentioned 4 to 7 mins, this is good to know for developing stages that how much user devotes time for to use the

App per case. Regarding using 2D or 3D map as the main communication map interface, most of the user agree with 2D maps because they are fast loading and easy to read and use. Another question regarding the App design is using images for indoor spaces, question asks that is it useful an image be available upon request of the user (for instance by clicking on a POI or lecture room). Most students state that all they expect from the App is finding the target like lecture rooms and for this purpose map itself should be enough not necessary to extra media. Also they mentioned that since interior areas for most floors look similar images of rooms cannot be useful moreover the user need to be located in the camera position for better perception of the image which is practically not efficient. Others that were agree with image on the map as an extra option utter that it could be useful as a confirmation for finding target. Finally most students were moderately and very likely agree if such App be available for the campus they would use it.

As a conclusion of the result we should mention that the most significant features and functionality are finding lecture rooms and using map for routing. The reliability and fast loading of the map is in highest degree of importance. And users prefer 2D representation than 3D without legend and extra media information. The functionality of the map/App has significantly more value from student's perspective of view than design and style such as labeling, coloring and symbolization.

For a detail of questions refer to appendix F.

Chapter 5: Discussion and Conclusion

5.1 Result

We try to discover the answer of the question:

- Why we need a smart campus map?

Smart campus map is not only a map but a smart system. Smart in this concept means an intelligence location-based system that applies available indoor and outdoor sensors combining with mobile sensors such as gyroscope, compass, light sensor, accelerometer (motion sensor), orientation sensor (position) and many others to provide a context-aware adapted system.

- What are the standards and specifications for a smart campus map for indoor LBS purposes?

The requirement for an indoor navigation system discussed from different perspective of view: localization methods, navigation context and topographic representation. Then considering these requirements we developed smart campus map models and discuss the components of our models. For model components various attributes were assigned and explained then some topological rules and the logic behind these rules based on current standard models discussed.

Formerly we explained data preparation for outdoor and indoor environment and explain a work flow to approach a smart campus map and we filled our proposed data model with some sample data and represented it in 2D and 3D layouts for desktop applications and mobile applications.

We investigated current TUM campus mobile and web applications and explained one indoor navigation mobile application so called TUM-Navi which has developed recently in a parallel project with this work.

As a termination for the work was done so far we proposed an indoor navigation system framework. This framework assembles and considers all the requirements for a thorough location-based indoor system in mobile applications.

The results of our work are four main items:

- smart campus map data models,
- smart campus map 3D model standards,
- indoor navigation system framework and mobile user interface,
- smart campus map survey

We can use the result of survey in smart campus map and App for better user fulfillment. The main points that we can conclude from the survey is listed below:

- Finding lecture rooms is the most important application of the campus map/App
- Routing, find POIs (toilets, restaurant, staff's rooms, library, café automats,…) and staff's room are secondary important functionalities of the App
- Students prefer 2D maps than 3D maps, preferably without legend
- Using background maps (such as Google map and OSM) and images has less significance for students
- Students prefer better functionality of the App comparing design and style
- Reliability and fast loading are key factors in designing map/App

5.2 Discussion and Further Research

This research aims to enlighten and simplify the obscured path for making a proper campus map for indoor LBS objectives. Although indoor LBS is a science that emerged in recent years and still there are many dark points and ambiguities that should be discussed and solved on the other hand there are many scientific and industrial projects in progress. But still there are not enough standards and specifications to clear the path. Especially in the area of 3D navigation and modeling there are numerous arguments. Reviewing current projects and literatures we demonstrate following points which should be consider and need more attention:

- Localization methods
- Indoor data preparation and topology standards
- Compatibility between indoor navigation model and 3D building models
- Sensor fusion
- Seamless routing between indoor and outdoor
- More attention to the user priorities
- Context awareness

As a positive point we can discuss that considering the development in sensors, communication technology and smart devices besides more and more enhancement in smart buildings construction, the future of indoor LBS would be very affirmative.

Indoor LBS is a cutting edge topic and in recent years there were too much consider in this area from both industry (indoor Google maps, Indoor Bing maps, Navteq, indoor OSM) and science. For indoor navigation systems mobile applications are rapidly in progress and many startup companies emerged and give services in this area. It is feasible in near future the number available indoor maps increase and be available for public. Therefore developing navigation system on this platform is straightforward and faster. The same extent will be happen for university campuses. In this work we proposed and extent models for both data and mobile application. This data should be prepared for all indoor and outdoor areas of campuses (Stammgelände, Garching, Wiehenstephan, Olympiapark and Clinic Rechts der Isar). Then data model should be extended with this data and mobile application with mentioned abilities and standards develop on this platform. Besides, generating 3D models which load and render fast is essential.

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Abbreviations

AOA: Angle of Arrival

BIM: Building Information Model

BISDM: Building Interior Space Data Model

CAD: Computer Aided Design

CSG: Constructive Solid Geometry

DOA: Direction of Arrival

GIS: Geography Information System

GML: Geography Markup Language

GPS: Global Positioning System

HVAC: Heating, Ventilation, Air-Conditioning

IFC: Industry Foundation Classes

JOSM: Java OpenStreetMap

LBS: Location-Based Service

LOD: Level of Details

OGC: Open Geospatial Consortium

OSM: OpenStreetMap

POI: Point of Interest

QGIS: Quantum GIS

RFID: Radio Frequency Identification

RSS: Received Signal Strength

SVG: Scalable Vector Graphic

TDOA: Time Difference of Arrival

TOA: Time of Arrival

TUM: Technical University of Munich

UML: Unified Modeling Language

VRML: Virtual Reality Modeling Language

WGS84: World Geodetic System 1984

WMS: Web Map Service

Appendix

Appendix A: List of TUM Campus Outdoor Features

Zoom Level	Layer name	Feature Type	Label	Visibility Scale	Source
1 1000	point_railway_subway_entrance_2000	Point	ON	Range 1:250 – 1:1400	OSM, Sattelite Image
	point_railway_tram_stop		ON	Range 1:1400 – 1:2500	OSM
	point_shop_supermarket		ON	Range 1:250 – 1:1400	OSM
	point_amenity_bank_atm		off	Range 1:250 – 1:1400	OSM
	point_amenity_bar		off	Range 1:250 – 1:1400	OSM
	point_highway_traffic_signs		off	Range 1:250 – 1:1400	OSM
	point_highway_bus_stop		ON	Range 1:250 – 1:1400	OSM
	point_tourism_museum		off	Range 1:250 – 1:1400	OSM
	point_historic_monument		off	Range 1:250 – 1:1400	OSM
	tree_sc1000		off	Range 1:250 – 1:800	OSM, Sattelite Image
	tree_sc1000		off	Range 1:800 – 1:1400	OSM, Sattelite Image
	point_amenity_bench		off	Range 1:250 – 1:1400	OSM

			Range	
point_amenity_entrance		off	Range 1:250 – 1:1400	OSM
point_amenity_fastFood_Cafe_Merg		off	Range 1:250 – 1:1400	OSM, generalised
point_amenity_cinema		off	Range 1:250 – 1:1400	OSM
line_building_stairs_prj_osm		off	Range 1:250 – 1:1400	Auto CAD Map
line_highway_street_Merge	Line	ON	Range 1:250 – 1:1400	OSM, generalised
line_highway_service		off	Range 1:250 – 1:1400	OSM
line_highway_footway		off	Range 1:250 – 1:1400	OSM
area_amenity_ConnectionBiulding_university		off	Range 1:250 – 1:1400	OSM
area_leisure_playground		off	Range 1:250 – 1:1400	OSM
area_tourism_museum		ON	Range 1:250 – 1:1400	OSM
area_manmade_structure_merge		off	Range 1:250 – 1:1400	OSM, generalised
area_amenity_parking	Polygon	off	Range 1:250 – 1:1400	OSM
area_leisure_park		off	Range 1:250 – 1:1400	OSM
area_amenity_bicycle_parking		off	Range 1:250 – 1:1400	OSM
area_amenity_restaurant		ON	Range 1:250 – 1:1400	OSM
area_amenity_university_build1_prj_osm		off	Range 1:800 – 1:1400	Auto CAD Map

				Range 1:250 – 1:800	Auto CAD Map
	area_amenity_university_build1_prj_osm		ON		
	area_amenity_university_1000		ON	Range 1:250 – 1:1400	OSM
	area_highway_pedestrian		off	Range 1:250 – 1:1400	OSM
	area_boundry_university		off	Range 1:250 – 1:1400	OSM
	point_railway_subway_entrance_2000		ON	Range 1:1400 – 1:2500	OSM, Sattelite Image
	point_railway_tram_stop		off	Range 1:1400 – 1:2500	OSM
	point_shop_supermarket		ON	Range 1:1400 – 1:2500	OSM
	point_amenity_bank_atm		off	Range 1:1400 – 1:2500	OSM
	point_amenity_bar		off	Range 1:1400 – 1:2500	OSM
1 2000	point_highway_traffic_signals	Point	off	Range 1:1400 – 1:2500	OSM
	point_highway_bus_stop		off	Range 1:1400 – 1:2500	OSM
	point_tourism_museum		off	Range 1:1400 – 1:2500	OSM
	point_amenity_library		off	Range 1:1400 – 1:2500	OSM
	point_historic_monument		off	Range 1:1400 – 1:2500	OSM
	point_amenity_information		off	Range 1:1400 – 1:2500	OSM
	tree_sc2000		off	Range 1:1400 – 1:2500	OSM, Sattelite Image

bench_2000		off	Range 1:1400 – 1:2500	OSM, generalised
point_amenity_entrance		off	Range 1:1400 – 1:2500	OSM
point_amenity_fastFood_Cafe_Merg		ON	Range 1:1400 – 1:2500	OSM, generalised
point_amenity_cinema		off	Range 1:1400 – 1:2500	OSM
line_highway_street_Merge	Line	off	Range 1:1400 – 1:2500	OSM, generalised
line_highway_service		off	Range 1:1400 – 1:2500	OSM
line_highway_footway		off	Range 1:1400 – 1:2500	OSM
area_amenity_ConnectionBiulding_university	Polygon	off	Range 1:1400 – 1:2500	OSM
area_leisure_playground		off	Range 1:1400 – 1:2500	OSM
area_tourism_museum		ON	Range 1:1400 – 1:2500	OSM
area_manmade_structure_merge		off	Range 1:1400 – 1:2500	OSM, generalised
area_amenity_parking		off	Range 1:1400 – 1:2500	OSM
area_leisure_park		off	Range 1:1400 – 1:2500	OSM
area_amenity_bicycle_parking		off	Range 1:1400 – 1:2500	OSM
area_amenity_restaurant		ON	Range 1:1400 – 1:2500	OSM
area_amenity_university		ON	Range 1:1400 – 1:2500	OSM

			Range 1:1400 – 1:2500	
area_highway_pedestrian		off		OSM
area_boundry_university		off	Range 1:1400 – 1:2500	OSM
Text_4k	Point	ON	Range 1:2500 – 1:6000	Author
point_railway_subway_entrance_2000			Range 1:2500 – 1:6000	OSM, Sattelite Image
point_shop_supermarket			Range 1:2500 – 1:6000	OSM
point_highway_bus_stop			Range 1:2500 – 1:6000	OSM
point_amenity_information			Range 1:2500 – 1:6000	OSM
tree_sc2000			Range 1:2500 – 1:6000	OSM, Sattelite Image
point_amenity_entrance			Range 1:2500 – 1:6000	OSM
line_highway_street_Merge	Line	off	Range 1:2500 – 1:6000	OSM, generalised
line_highway_service			Range 1:2500 – 1:6000	OSM
line_highway_footway_4k			Range 1:2500 – 1:6000	OSM, generalised
area_leisure_playground	Polygon	off	Range 1:2500 – 1:6000	OSM
area_tourism_museum		ON	Range 1:2500 – 1:6000	OSM
area_manmade_structure_4k		off	Range 1:2500 – 1:6000	OSM, generalised

Note: left column spans with "1 4000".

area_amenity_parking		off	Range 1:2500 – 1:6000	OSM
area_leisure_park		off	Range 1:2500 – 1:6000	OSM
area_amenity_bicycle_parking		off	Range 1:2500 – 1:6000	OSM
area_amenity_restaurant		ON	Range 1:2500 – 1:6000	OSM
area_amenity_university_4k		ON	Range 1:2500 – 1:6000	OSM, generalised
area_highway_pedestrian		off	Range 1:2500 – 1:6000	OSM
area_boundry_university		off	Range 1:2500 – 1:6000	OSM
clip	Polygon	off	All scales	Author

Appendix B: TUM Campus Map, Stammgelände

Appendix C: TUM Campus Map, Garching
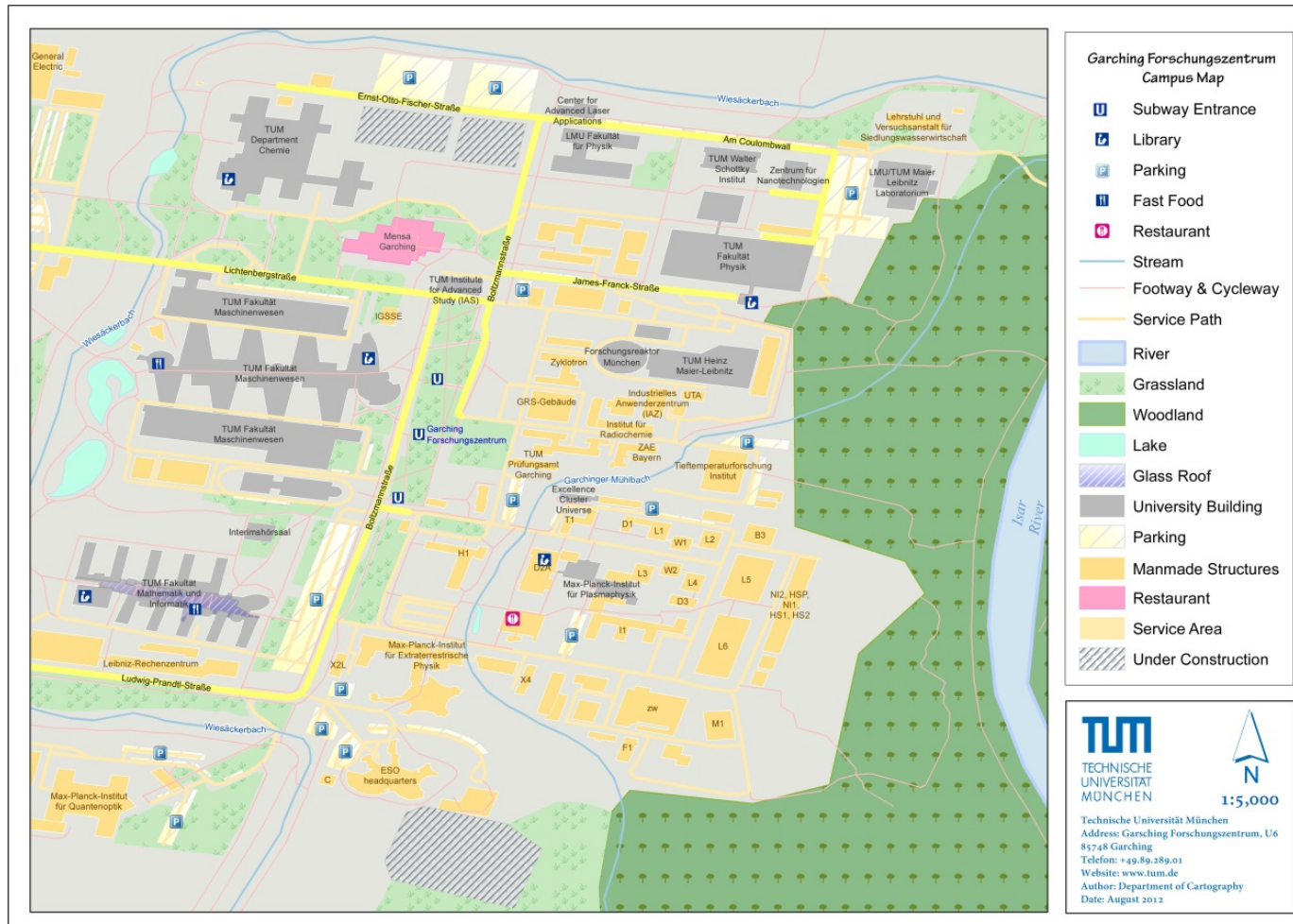
Appendix D: TUM Campus Map, Weihenstephan
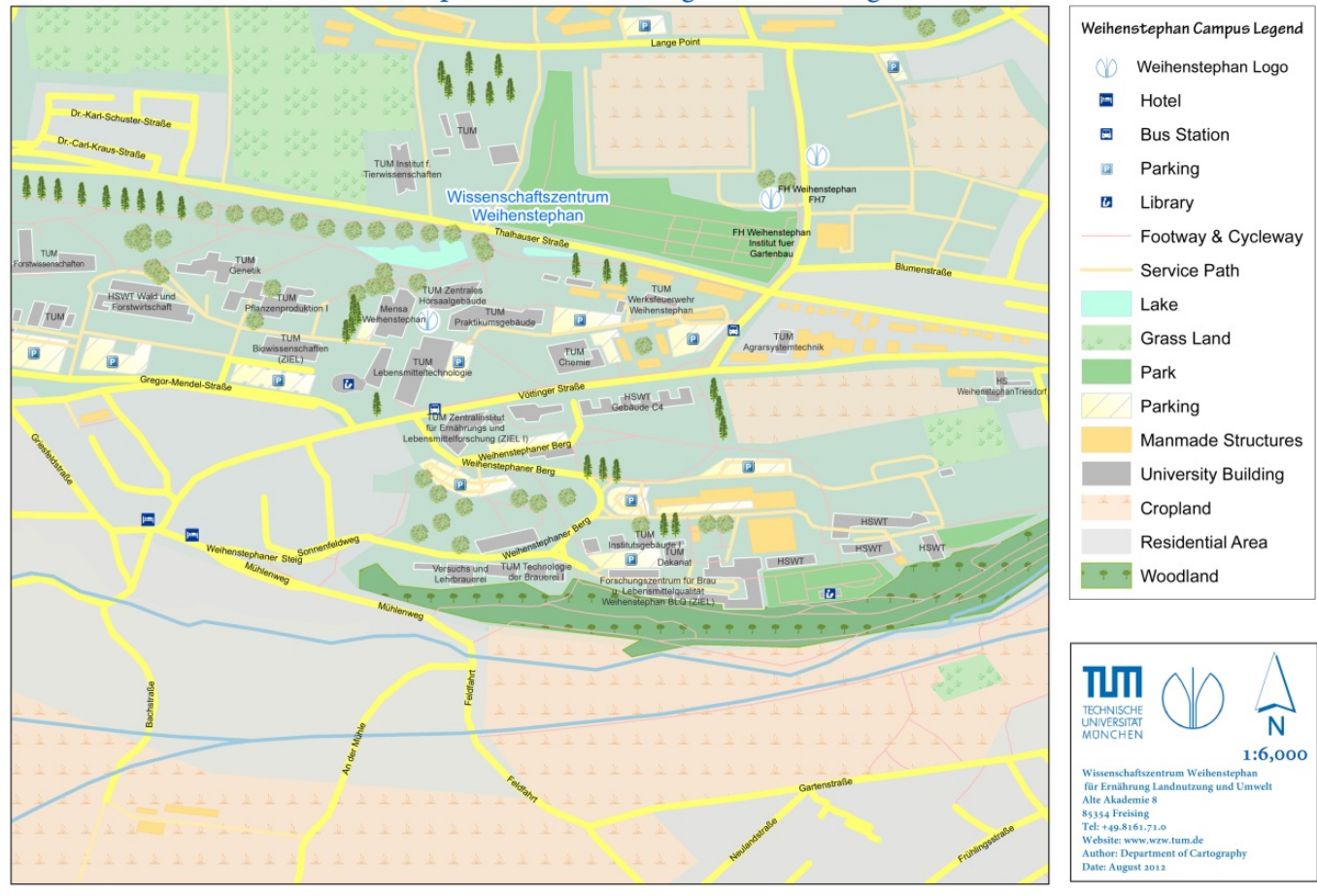
Appendix E: TUM Campus Indoor Data Model
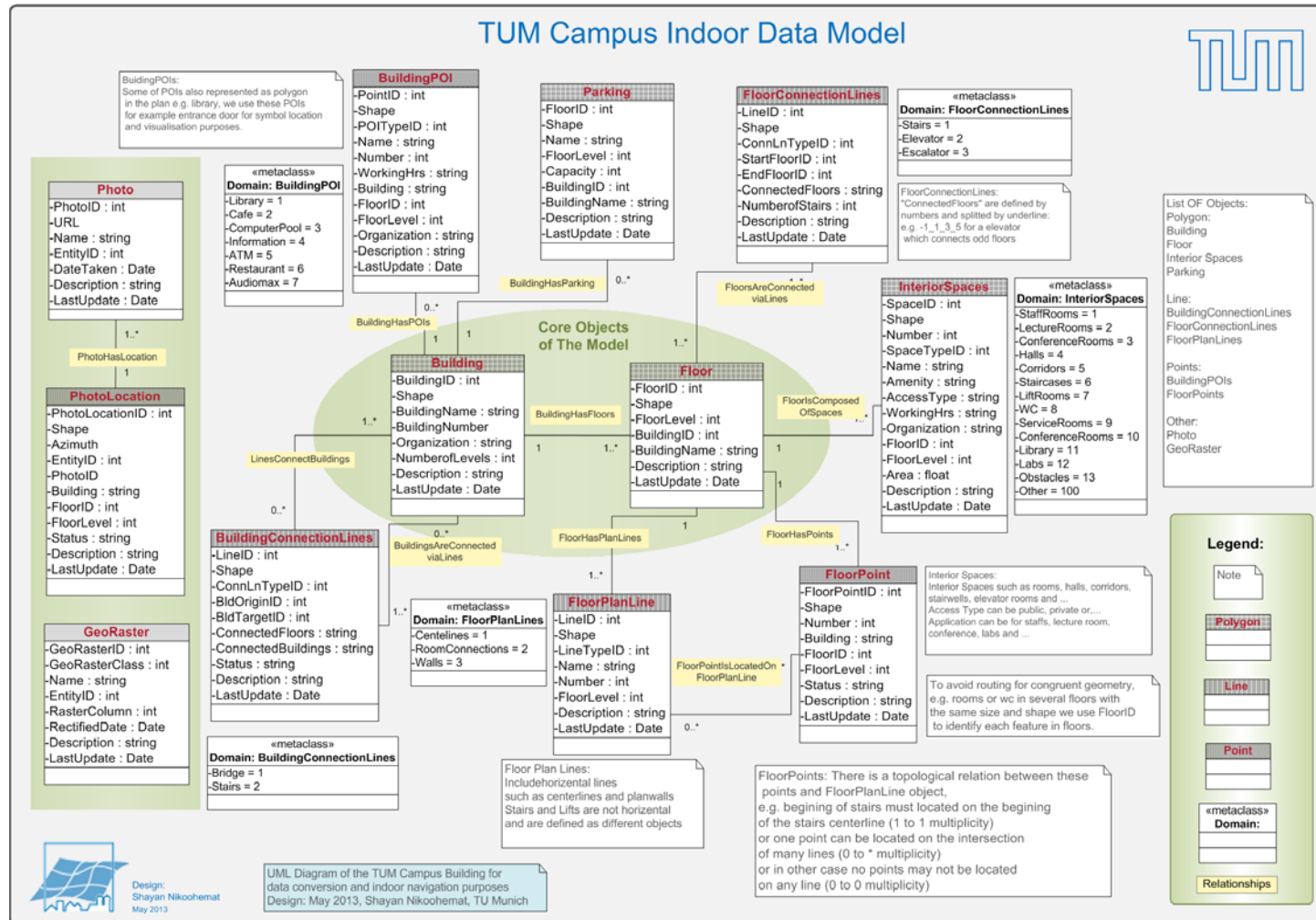
Appendix F: Campus Survey Questions

Title: Survey for Campus map and Campus App evaluation:

1. **What is your age and gender?**

    ☐ Less than 18   ☐ Male
    ☐ 18-30   ☐ Female
    ☐ 31-50
    ☐ More than

2. **What is your field of study or profession and specify which grade or semester are you studying?**

3. **Have you ever used <u>indoor</u> maps or applications?**
    ☐ University Campus map
    ☐ Shopping Malls
    ☐ Airports
    ☐ Sports Venues
    Any other examples?   ----------

4. **Do you have smart phone?**
    ☐ Yes
    ☐ No

5. **How often do you use floor plans hanging on the walls in TUM campuses?**
    ☐ Never
    ☐ Only once
    ☐ Daily
    ☐ Weekly
    ☐ Monthly
    ☐ Quarterly
    ☐ Yearly

6. **Rate <u>functionalities</u> of a campus map based on degree of your importance:**

	Low				High
	1	2	3	4	5

Navigation

Find friends

Find lecture rooms

Find staff and Profs

Search for events

Search nearest POI *

  *POI (Point of Interest such as toilets, registration office, café, library)

7. **Rate <u>important factors</u> in a digital campus map based on degree of your importance:**

	Low				High
	1	2	3	4	5

Level of Details (rooms, entrances, stairs, …)

Symbolization

Legend

Coloring

Labeling and Description

Fast Loading

Reliability

8. **As a user do you prefer a 3D map of buildings or simply a 2D floor plan? And Why?**
   ☐ 3D map because is aesthetic
   ☐ 3D map because is easy to read and use
   ☐ 2D map because of fast loading
   ☐ 2D map because is easy to read and use

9. **When you use a digital map or App how many minutes do you spend each time using the App,**
   for example to find something?
   ☐ 1 to 3 minutes
   ☐ 4 to 7 minutes
   ☐ More than 7 minutes

10. **If an indoor App for campus would be available how likely do use it?**
    ☐ Extremely likely
    ☐ Very likely
    ☐ Moderately likely
    ☐ Slightly likely
    ☐ Not at all likely

11. **If an indoor App for campus would be available how much do you pay for it?**
    ☐ 1 to 3 euro
    ☐ 4 to 7 euro
    ☐ More than 7 euro
    ☐ I do not buy it

12. **What would make you more likely to use a campus map?** (select as many as you want)
    ☐ Routing
    ☐ Find friends
    ☐ Find lecture rooms
    ☐ Find Staff and Profs
    ☐ Search for events
    ☐ Search nearest POI (Point of Interest such as toilets, registration office, café, library)
    ☐ Any other examples? ------------------------------

13. **What are the <u>most important features on the campus map</u> for you?** (select as many as you want)
    ☐ Lecture Rooms
    ☐ Café and Restaurant
    ☐ Bank ATM
    ☐ Entrances and Exits
    ☐ Lockers
    ☐ Stairs and Elevators
    ☐ Library
    ☐ Mensa
    ☐ Information Office
    ☐ Prof and Staff's Rooms
    ☐ Labs and Computer pools
    ☐ Any other? --------------

14. When do you need an indoor campus App? (you can select more than one)
- ☐ Every day
- ☐ The 1st time I was in the campus
- ☐ During exams
- ☐ During events
- ☐ Never

15. Do you prefer also images of indoor areas attached to the map features?

For example when you click on a room or corridor in the map the image also optionally is available.

- ☐ Yes
- ☐ No
  Please explain your answer in few words.

  ----

16. In a campus map how important is to you design and style comparing functionality?

Design and Style   Functionality

5   4   3   2   1   0   1   2   3   4   5
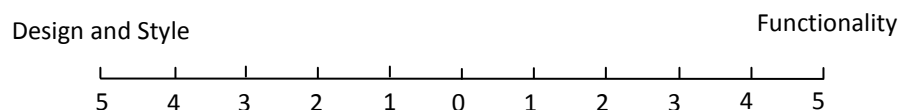
17. Which one do you prefer for a digital campus map?
- ☐ Using a <u>legend</u> for campus map
- ☐ <u>No legend</u>, it should be easy to read and understandable by means of symbols, colors and labels

18. Which one do you prefer for a digital campus map?
- ☐ Campus map integrated in base map (such as OSM and Google maps)
- ☐ Campus map as a separate map without any base map

19. How do you agree an indoor App be available for the university campus?
- ☐ Strongly Disagree
- ☐ Disagree
- ☐ Neutral
- ☐ Agree
- ☐ Strongly Agree

If you have any comment or suggestion, feel free to add here.

End of survey questions.

Shayan Nikoohemat
July 2013