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Landscape analysis methods carried out using digital models

AUTOREFERAT

Paweł Ozimek
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PUBLICATIONS DOCUMENTING A WORK SUBJECT TO ASSESSMENT

Appendix 1: Paweł Ozimek „REKONSTRUKCJA WIRTUALNA OBIEKTÓW ARCHITEKTONICZNYCH”, Roczniki Geomatyki - 2007, T. 5, z. 8: zes. spec., s. 173-185, bibliogr. s. 185.Rekonstrukcja wirtualna obiektów architektonicznych

Rozdział 2.2. Badania w zakresie cyfrowych analiz terenu
Rozdział 3.3: Doprecyzowanie granic opracowania analiz widokowych
Rozdział 5: Analizy cyfrowe z wykorzystaniem modeli


I submit for assessment my original methods of landscape analysis that utilise digital models. They enable the analysis of a large scope of problems that occur within the landscape, particularly at the level of visual perception, through the stimulation of spatial phenomena within a digital environment. In these methods I proposed data structures, processing algorithms used for simulations and precepts of the interpretation of their results that had not been used before. The proposed solutions introduce an entire analytical domain, one that makes it possible to objectively assess the qualitative and quantitative elements of the landscape, into landscape architecture, spatial planning and urban design. These assessments make it possible to compare existing and designed states, in addition to providing decision-making support in planning.

These methods were published in monographs, articles and in an academic handbook for students of landscape architecture. The approach presented in those publications constitutes an essential contribution to the development of the landscape architecture discipline.

MOTIVATION FOR CONDUCTING STUDIES WITH THE GOAL OF DEVELOPING LANDSCAPE ANALYSIS METHODS USING DIGITAL MODELS

The use of a ray tracing algorithm for landscape expertises made it possible to objectively evaluate various states of space, as the result calculated from graphs and visibility maps is a numerical index that unambiguously evaluates a given characteristic and is easily comparable. The effects obtained thanks to its use encouraged the carrying out of research in the direction of the development of digital methods used to objectivise conclusions in landscape analyses.

Broad discussions that take place almost constantly on the significance of spatial planning in the organisation of the country were an additional motivation to continue this research. In these discussions, hard economic arguments aimed at intensifying short-term gain have and still are pitted against the soft rationale concerning the value of beauty, the protection of nature and cultural heritage or pursuing utilitarian solutions. I saw a chance for constructing a solid argumentation supporting matters that had so far been seen as unquantifiable in the objectivisation of landscape analysis methods. Digital modelling, which makes it possible to simulate various states of an analysed phenomenon, appeared to be an appropriate platform for research towards this end.

Another argument for conducting research was the high level of subjectivity in assessing landscape phenomena when using traditional methods. In the monograph entitled „Planowanie przestrzeni o

wysokich walorach krajobrazowych przy użyciu cyfrowych analiz terenu wraz z oceną ekonomiczną [OBOW], on pages 8 and 9, I presented a short discussion on this subject, using Adelson’s checkerboard2, in which the actual brightness of individual fields does not correspond to general experience, as an argument. The problem of subjectivism is particularly essential in the case of assessing the impact of planned development projects on various elements that coexist in space. Such transformations obviously affect natural, social and economic systems. They cause controversy and such interference with the general surroundings is assessed differently in circles with various groups of interest. Similar spatial phenomena can be rated completely differently by experts3. This is most often a result of different cultural conditions or motivations. The same expert, as a human being subjected to emotions of varying nature, can also assess the same phenomenon in different ways. They are less inclined to voice extreme opinions on measures taken by institutions with which they are associated and tied with partnering relations. On the other hand, extreme opinions come easier in relation to measures taken by persons who act upon a different system of values. We are often dealing with a wrongful interpretation of data and an underestimation or overestimation of the impact of changes on elements that co-create space. This is often the case because of a lack of quantifiable evaluation methods. Many analyses are based on the intuition of experts who are not without an emotional relationship with the subject they analyse. Subjectivism in expert assessments is a factor that can be an obstacle in performing appropriate evaluation. Of course, in some situations it will be treated as desirable. However, methods of performing assessments on the basis of objective analysis should exist.

The problem of subjectivity in decision-making is key. It is essential to pursue research methods that ensure objectivity in assessment and decision-making. When searching for these methods, I adopted an assumption that achieving an objective level is not possible. Objectivism is an absolute. Insofar as we can assume that assessments that make use of a specific scale, an index-based valuation system, measurable parameters can be objective, decisions made by an expert who is not a machine will always feature an element of subjectivity. It thus appears justified for subjective or objective assessment to be performed in a conscious manner, on the basis of the fullest possible knowledge of a given phenomenon. This knowledge should be expressed in reliable data, models and indices. Furthermore, it should also cover various historical conditions in which a given phenomenon took place, in addition to making it possible to take into consideration various situations that can come about as a result of the execution of a decision on transforming our surroundings.

When dealing with various spatial problems in the time that has passed since I formulated the basic principles of digital landscape analyses, I perfected procedures and expanded algorithms which made the methods based on them capable of solving an entire spectrum of analytical tasks. It should be highlighted that my works did not deal with axiology but with technology, which can be used for landscape analyses and developed towards this end so that will satisfy the needs of analyses. My pursuits were primarily focused on existing solutions that had been initially developed for other purposes. The overarching goal was to provide landscape architects with tools making it possible to


3 Example of court verdicts in which an essential role was played by contrary opinions of 2 organs on the subject of the need to perform an environmental impact assessment: Centralna Baza Orzeczeń Sądów Administracyjnych, II SA/Kr 263/15 - Wyrok WSA w Krakowie, [http://orzeczenia.nsa.gov.pl/doc/5B84A110AF](http://orzeczenia.nsa.gov.pl/doc/5B84A110AF), retrieved on 13.08.2018.
collect data that could enable the assessment of a given spatial situation in a manner that is as close to objective as possible.

DESCRIPTION OF ACHIEVEMENTS

The achievements presented for evaluation features results of studies concerning geographic data that can be used and the manners of their adaptation. This data comes from various sources, while one of my goals was to lead to a situation in which analyses would be performed entirely using digital data. In the process of striving for said goal, appropriate data structures and organisation methods were selected, in addition to methods of their adaptation, so that they would be fit to solve specific analytical tasks.

This research played an ancillary role to the main current, which was the application of existing algorithms to process data in order to obtain knowledge on spatial phenomena and assess them. There is a broad selection of algorithms, statistical and functional models that were analysed from the perspective of the scope of their use and utility. The models have open and universal structures. They were typically not developed with the express purpose of performing landscape analyses. They were formulated with the intent to build environments for the modelling of spatial phenomena across a broad spectrum of characteristics. Their basic functionality is used to model geometric objects, model various surfaces, including terrain surfaces, to produce design project visualisations and to create entertainment such as animated films or interactive games. These technologies had been developed for other fields and I do not know of any examples of their use for landscape analysis in a similar scope to that of my applications. Oftentimes their functionality exceeds the needs of this form of use. Appropriate adaptations, simplifications, as well as manners of filling in any gaps in algorithms in appropriate cases are proposed.

The third research problem is an analysis of the possibility of drawing conclusions on the basis of information provided by digital procedures. This information is processed using mathematical and geometric operations in order to obtain complementary data aggregated into individual data files that can be used in decision-making. Aggregated data features structures that depict the spatial distribution of analysed values. The research applies to processing algorithms used to filter insignificant information, aggregate complex data and manners of presenting this data, ensuring proper legibility and utility.

My research achievements have been presented in the publications section, the most important ones being my fully original (100%) chapters in the monograph entitled „Planowanie przestrzeni o wysokich walorach krajobrazowych przy użyciu cyfrowych analiz terenu wraz z oceną ekonomiczną” [OBOW]. I have placed these chapters in appendix 2. The monograph includes results of research performed as a part of a project of the same name, on the basis of agreement no. 2901/B/T02/2009/37 signed with the National Science Centre, of which I was a director. The remaining chapters of the monograph were written by Aleksander Böhm, Agnieszka Ozimek and Wiesław Wańkowicz. Each of the authors wrote at least one large chapter and several smaller subchapters, which could form separate monographs illustrating individual achievements over the course of the research project. The decision to publish the entirety of the work in a single Polish and English-language publication was dictated by considerations linked with the popularisation of science. The authors decided that this form would be more comfortable for users and thus the results of the research would be applied better and quicker. My own original chapters within this monograph constitute the most important material documenting studies on digital methods, containing a presentation of data structures, models of spatial phenomena and result interpretation.
methods. The remaining publications submitted for assessment feature complementary materials, expansions and examples of the application of selected landscape analysis methods.

**GEOGRAPHIC DATA, THEIR ACCESSIBILITY AND STRUCTURES**

The period in which the research presented for assessment was performed was marked by a development of geographic information systems and their saturation with increasingly precise data. Progress in this field was truly significant. Proof of this can be found in the fact that when I had worked on writing my doctoral thesis, I based it on analog data sources that I had to digitalise myself, while the latest projects described in the monograph[^8] (appendix 2) were executed entirely on the basis of digital, high-density data, provided by institutions responsible for managing the land surveying and cartographic database. Today we have access to geographic data that can be used for private, commercial and scientific purposes. Each of these purposes can utilise data with varying degrees of precision, density and processing.  

In the work „Rekonstrukcja wirtualna obiektów architektonicznych”[^2] (appendix 1) I performed an analysis of the representation of three-dimensional objects used in the digital modelling of geometry in terms of usefulness in geographic information systems and adaptation to the requirements of the INSPIRE convention[^4]. In it I postulated an object-based approach to defining geographic data models in which a model is understood as a database containing all of the information about an object. This concept was already being broadly and successfully implemented in industrial systems organised on the basis of computer integrated manufacturing (CIM) and building information modelling (BIM), as well as in the specific implementation of Landscape Information Model Building. In the case of an existing object, the database model features information collected through measurements and analyses, while information about an object that is being designed is defined and created by its designer. Based on information collected in the database, various representations of the model can be generated, depending on current needs. Thanks to this approach, elements of space can be represented by data structures orientated geometrically, functionally, on the basis of a design as well as analytically. In the case of the need to three-dimensionally represent a layout or topology, the object-based model could generate a geometric representation composed of lines that reflect this layout. For visual analyses, the spatial model should take into consideration visibility relationships, which is why it should be represented by surfaces that can block light. Due to the large scope of space within which visibility relationships play out, it is essential for this representation to be as simple as possible so that it will not contain additional data that has no significance to the analysis. This is why polygon meshes were indicated as the best representation of models of space that enables the performance of visual analyses. It is also the basic structure of data representing surfaces, which can be relatively easily obtained using laser and photogrammetric scanning. It is composed of points with specific positions. Points close to each other are linked by edges, while enclosed sequences of edges form the outlines of polygons. In representations of terrain surfaces we are most often dealing with triangles and rectangles. Meshes composed of such polygons can be defined and topologically ordered digitally in various ways.

Data necessary for the generation of polygon meshes in the form of points that are processed into a form of polygon vertices can be imported from GIS systems (Geographical Information System). In

the monograph entitled „Planowanie przestrzeni o wysokich walorach krajobrazowych przy użyciu cyfrowych analiz terenu wraz z oceną ekonomiczną” [OBOW] in chapter 2.2. „Badania w zakresie cyfrowych analiz terenu” (appendix 2) I performed an analysis of data structures available in GIS systems, which can constitute a basis for the generation of polygon meshes. Precepts of working with DEM and TIN type meshes were presented, as well as manners of processing them for the purpose of their use in visual analyses. I also compared these basic data structures in terms of the precision of depicting space in relation to their use in landscape analyses, as well as combining them into systems with data representing other subject layers.

A terrain surface model represented in the form of a DEM (Digital Elevation Model, Polish equivalent: CMW, cyfrowy model wysokościowy) is a regular point mesh, ordered in the form of a rectangular table with fixed distances between rows and columns. Its regularity is associated with the method of measurement, performed using remote sensing techniques, and is derived from the pixel grid of photogrammetric images. The model’s point structure is perfectly suited for the use of a rectangular grid. In this case, the edges of polygons and their spatial layout are clearly defined. They form rectangles when viewed in orthogonal projection. Thus, we can conclude that spatial singularities or oddities\(^5\) can be located between systematic measurement sampling points that are ignored in the model. It is an essential conclusion resulting from studies of the usefulness of this data structure in landscape analyses. It should be highlighted that the DEM model is used in GIS systems to generate visibility graphs using a method that compares the elevation of point locations on the visibility line. It is not necessary to generate a polygon mesh for this method, which makes it fast. It is a method that works well in determining the range of telecommunications stations, but is insufficiently precise for visual analyses, in which a small visual window sometimes significantly affects the landscape value of a particular point.

The second type is TIN (Triangular Irregular Network, the triangular model). As the name suggests, it is composed of triangles, the simplest of polygons. In this representation, points are placed irregularly within space and the edges between them do not have a defined course. In order to generate the structure of edges, it is necessary to employ additional triangulation algorithms. Usually, such a mesh is more precise than the previously mentioned one and makes it possible to define every point that has been measured. It can feature both points determined by stereoscopic measurements performed by a surveyor on-site, as well as by LIDAR or photogrammetric flyovers utilising a drone. It is also possible to clearly define the edges of escarpments or embankments where they are present in the terrain, as well as the adaptation of point densities to the dynamic of the shape of the terrain.

The abovementioned studies point to TIN representation being better suited to the needs of visual analyses. However, they also demonstrate that digital analysis methods should not be abandoned in the case of only having a DEM representation at our disposal. The analyst should perform them while taking this representation into consideration and should appropriately annotate the degree of precision of the results. It should also be remembered that DEM representation is better suited for analyses that are based on comparing data from raster maps that have a structure of rectangular tables. In particular, the use of older information from scanned maps in analyses can predestine the use of this structure and even force the discretisation of TIN surfaces to a systematic representation. It should be noted that these two representations will affect load placed on computers in different

\(^5\) Singularity as something rare, unique, extraordinary. The cosmological meaning of the term is not appropriate here.
ways. Of course, this load depends on data density in both cases. However, TIN representation is more load-intensive due to the necessity of performing triangulation. It is also a consideration for the selection of representation for specific analytical tasks. Problems concerning processing power and the selection of surface representation models relative to technical capabilities were discussed in chapter 2.2 of the monograph (appendix 2).

In chapter „5.1.1. Model cyfrowy terenu” (appendix 2) of that same position I presented terrain models available for scientific research and commercial applications. Models with two levels of precision, used depending on problem precision level and available processing power, were selected for this work. Two precisions levels provide a broad spectrum of processing, combining and adaptation methods for the purposes of specific analyses. Thanks to this, among other elements, these methods are universal and can be used in other cases and on other types of data.

The accessibility of these models was up to date in 2013. Although they are still available, we now have the possibility of using much more varied and detailed ones. In the field of geographic data sharing we are dealing with highly dynamic changes and developments. The carrying out of the ISOK Project (Informatyczny System Osłony Kraju przed nadzwyczajnymi zagrożeniami— computer system for the protection of the state against special threats)\(^6\) had made it possible to perform an aerial laser scan (LIDAR), which is used as a base for various derivative models. The direct product of this action is a point cloud with a density between 4 to 12 pts/m\(^2\) and which contains information about the location of a point within the coordinate system and its colour. The point cloud covers 93% of Poland’s surface and constitutes a resource for the creation of various lower density data. We thus have the ability to generate TIN meshes directly on a dense point cloud, as well as to use DEM models with a 1 m mesh. The density of this data places immense requirements on computer systems, however, these problems are the subject of my current research that has so far not been submitted for assessment.

Nevertheless, the issue of the development of database technology and geographic information completion procedures did not constitute the main current of my research in terms of the creative aspect. I used them to define models that were useful in performing landscape analyses. In chapter 2.2. of the monograph (appendix 2) I performed a comprehensive analysis of data structures that existed in current geographic information systems that were suitable for processing in the models that I had proposed. I distinguished the basic representations of numerical terrain models and listed their advantages and disadvantages therein, in addition to their suitability for landscape analyses. In chapter 5.1 I discussed static models, manners of their obtainment and most of the problems that occur in processing them. The content of these chapters constitutes a complete set of information that can be considered useful to digital system operators in preparing geographic data for analyses.

**STATIC AND FUNCTIONAL MODELS**

Modelling is based on defining individual objects by describing their characteristics and formulating algorithms that correspond to their functions. Objects are often subjected to iterative functions in order to obtain their current state that reflects transformation. This state can correspond to a situation under specific conditions or development over time. The system that operates in this manner contains all of the necessary knowledge concerning the simulated problem. Circumstances

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can be a result of the intended precision level and modelling scope. We are dealing with a sort of situation of having knowledge about a phenomenon in space and time. In general, we can consider a model to be a database of information about a phenomenon. The modelling of a specific phenomenon is possible to the degree to which qualitative and quantitative data, as well as knowledge of its functionality, is available. Data can be obtained through measurements and be calculated based on interpolation functions. An appropriate density of this data is necessary to ensure the continuity of the modelled phenomenon’s states. The number of measurements, as well as their precision, is limited, which is why a model is only an approximation of a real-world situation. The study of a phenomenon using a model must assume that it reflects the main characteristics that are significant to obtaining results and drawing conclusions.

The division into static and functional models is essential in the modelling of spatial phenomena associated with landscape visibility. In the monograph (Appendix 2) I introduced this distinction in order to separate static geometric objects representing defined states of space from the functions and algorithms that work towards the transformation and evolution of states. I proposed to have them distinguished into static and functional models.

Static models are closer to the their lay understanding as they are similar to the creation of minimised objects on the scale of paper, wood or other modelling materials. Here the linear scale is irrelevant and the material consists of digital graphical primitives. Scale has significance in relation to the level of precision. Primitives include descriptions of objects such as points, lines, surfaces and solids, appropriately placed within space and located within it on the basis of a defined topology. Terrain surfaces, land cover and other elements of space represented by geometric objects that show their shape and reflect spatial relationships between them are composed of those primitives. Elements of land cover, such as buildings, can be represented by solids and placed relative to its surface or independently in a specific coordinate system. Their precision levels determine the quality of analyses. The size of these models is counted in the number of triangles that they are composed of, which affects calculation and manipulation time. This dependency is exponentially proportional.

Models are also algorithms that simulate states that take place within states that space can find itself in. They can reflect the functionality of a phenomenon and, as a result, simulate the results of its effects. We can define them as functional models. In my work comprising the scientific achievement under assessment, there are analyses that are primarily based on determining visibility. The functional model used in these analyses is the ray tracing algorithm. When compared to other methods used in determining visibility, particularly those used in Geographic Information Systems (GIS) on DEM terrain models, it is more precise and yields correct results with geometric objects representing architecture and infrastructure. I demonstrated the superiority of this model over other models in the work „Digital Analyses of Visual Aspects of Wind Farms in South-East Poland” (Appendix 3). The functional models used in these analyses include the empirical illumination model, which is used to mark visible objects.

I also consider systematic sampling algorithms—used to solve surface and linear integrals in the obtaining of visibility maps—as functional models. They make it possible to calculate the values of the visibility sum of an area's surface in the case of surface integrals and path section in the case of linear integrals. The sampling density of a surface or path depends on the precision of terrain models and linearly affects map generation time.

All of these static and functional models grouped in a single environment are called a simulation, visualisation or rendering scene. Simulation is the preparation of a functional model of a given
phenomenon inside a static model. The results of such a simulation can be visualised in various ways. They can take the form of graphs, images, 3D objects, etc. Rendering is a form of visualisation that is based on projecting a multidimensional space onto a two-dimensional space. It can be a visualisation of different simulation phases. Functional models are executed within a scene and their operation is based on conditions set by static models. In contrast to a scene in a theatre, we are dealing with a simulation taking place within a scene, as it is a virtual environment composed of models that are its immanent elements. The scene is a virtual environment populated with models, understood separately from specific computer programs. It can be built in different programs from analogous models, whose data structures and algorithms do not depend on a specific programming environment.

The paragraphs above present a general understanding of the subject matter of computer modelling which constitutes an immanent quality of my academic work. In this body of work I made attempts at demonstrating the characteristics of specific static models and proposing functional models that could be useful in landscape analyses. These models are implemented in various programming environments, however, their definitions are independent of specific programs. Based on these definitions I proposed practical solutions independently of a given environment. Thanks to this, everyone can use these methods in their favourite programs provided that they are capable of accepting the appropriate definitions and algorithms. When selecting a programming environment to model in, the preferences of the team performing the analysis are of paramount importance. The operational skill level developed in a given environment rarely transfers to a different one. Software developers take great care for users to constantly be involved with their products through restrictive licensing conditions, often producing subsequent versions with changing user interfaces and manners of use so that users have no time to become familiar with competing products. This is why users rarely switch programs. When achieving a high level of operating proficiency that covers programming skills in a given environment, it is often better to adapt data used in it, as well as adapt the environment itself, instead of familiarising oneself with and learning alternative skills.

In chapter 5.1 of the monograph (Appendix 2) I presented problems associated with defining polygonal meshes used to represent terrain models and land cover elements. I highlighted it as the appropriate method of representing terrain and land cover models. In addition, because it is composed of polygons that can obscure light, it works well with the visibility model. Polygonal meshes have various applications. In the aforementioned work I presented and characterised them in terms of their usefulness in analyses, in addition to pointing to specific implementation in reference to specific object models and their effectiveness or display speed. When working with these types of objects, representation errors can occur and being unaware of them can significantly affect analysis results. This is why I presented various problems that I encountered during work and how to solve them. The monograph includes a description of a large project that covers terrain and land cover models in which various meshes were used with varying levels of detail from various sources. This is why experiences discussed in it constitute a large body of methods that are ready for application.

Apart from a comprehensive discussion of polygonal meshes in the aforementioned work, I also presented an approach for other elements of space represented by graphical primitives, which are counted among static models. It includes proposals of approaches for modelling a scene of the simulation of land development with varying degrees of precision, as well as roads, tourist trails, engineering structures, observation points and other elements that define the individuality of a landscape within three-dimensional space. Of note are the presented proposals of using data that is not a part of the Geographic Information System—in the presented example these were tourist maps.
They are a source of data that is not without impact on landscape analyses. Tourist maps served as a basis for the vectorising of point objects such as observation points, architectural heritage sites, places that are important to cultural heritage or telecommunications masts. Such objects are clearly marked on these maps. Unfortunately, they are not a reliable source of data. This is why verification is required, which can be performed using orthophotomaps available at geoportal.pl.

Over the course of research work on projects, I proposed appropriate data formats in which the attributes of individual objects should be defined and what content they should contain. For instance, the WOK-n layer (ważne obiekty krajobrazowe, negatywne - significant landscape objects, negative) featured objects with a disharmonious development structure. This applies to, for instance, sports halls and schools which are of a different character from rural development in areas outside cities. In order to produce an effective visibility graph of such an object, we require information about its dimensions that are entered into the range function \( r(x') \) discussed in chapter 5.2.1 of the monograph \( \text{OBOW} \) (Appendix 2). This principle also applies to other elements that affect the landscape that are marked on point layers and that are of non-negligible size.

Computer rendering methods make it possible to produce visualisations of modelled phenomena within digital space. They are characterised by a wealth of imaging properties as they are developed in the direction of obtaining realism in images of virtual models that simulate any phenomenon that can be observed in the real world. These are very demanding tasks which place these technologies at a level that makes it possible to visualise both real, unreal and abstract phenomena. They are also optimised to a degree that is allowed by the current advancement of computer technology. Thanks to this they are fast and precise. However, for the purposes of landscape analyses, particularly those that are based on determining visibility graphs, algorithms that produce fully realistic images are not necessary. We can only use a portion of their functionality. Based on a general rendering equation, I performed a simplification of individual functions that together comprise said equation in order to reduce the amount of calculations and accelerate the operation without loss in analysis results.

In chapter 5.2 of the monograph \( \text{OBOW} \) (Appendix 2) I formulated a visibility model that is sufficient for the generation of visibility graphs. They are composed of a visibility function, a point’s own emission, a fading function associated with distance and a function of the relationship between the size of an object and its distance. The model’s essential element is the visibility function, which can be executed in various manners. In my works I proposed a ray tracing algorithm, which uses a parametric straight line equation. Its operation in a static model environment built from polygonal meshes is based on solving sets of two straight line equations representing the radius and the polygon, which is an element of the mesh, in order to find an intersection point. The number of rays is dependent on resolution, which is set according to the needs of the analysis and the capabilities of computational hardware. The algorithm iteratively runs through all of a render’s pixels and generates the entire image on which we can see objects that are either lit or are shaded. The ray tracing model is universal, as it solves visibility for projected rendering according to user parameters, a map in orthogonal projection and other projections that are representative of a given task. Furthermore, this model takes into consideration all the standard spatial representations of three-dimensional objects. Thanks to this, visibility graphs can define both terrain surfaces as well as elements of land cover and even objects like car or billboard models or other moving elements.

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7 WMS browsing service, geoportal.gov.pl, Ortofotomapa, In order to display maps, the user must connect with a WMS server using a special application map tool. Orthophotomap server address: http://mapy.geoportal.gov.pl/wss/service/img/guest/ORTO/MapServer/WMSServer
When using computer rendering methods, it is possible to use local lighting models to highlight places that are visible from a given point on the graph. I proposed a modification of the model formulated by Phong Bui Tong, which reduces the impact of exposure on the brightness of a point that is reached by traced rays. Originally, a point's brightness was dependent on the incidence angle of a ray to a surface and covered all the shades of gray that a given format had available. Thanks to the proposed modification, the information about a point is reduced to a disjunction that can be recorded in a single bit: 1—visible, 0—not visible.

The proposed visibility model is based on two models used in computer graphics. They are the ray tracing model and the empirical local illumination model. Basing landscape analyses on these models enables the use of standard software that is typically used to visualise designs, create animations and computer games, to generate graphs and visibility maps. This provides significant benefits in the form of the speed with which results are obtained through perfectly optimised software that utilises multi-processor computer architecture and automates the generation of large amounts of graphs. These programs are graphical environments with sophisticated functionality that supports the solving of atypical problems. This leads to benefits in the form of the ability to model a broad spectrum of spatial phenomena and a hope for covering all factors that are essential to landscape analyses and that define the individuality of a landscape with appropriate functions in the future.

**VISIBILITY MAPS AND GRAPHS—DEVELOPMENT AND FORMALISATION**

I used the notion of the visibility graph already in my doctoral dissertation. In later works I formalised it in mathematical terms into the form of a binary matrix (chapter 5.2.2 “Wykresy widoczności” w monografii (Appendix 2)). I also associated the resolution of the graph in orthogonal projection with spatial size. Thanks to this, the number of pixels corresponds to a specific terrain surface and the graph image histogram can be used to calculate them. I used this dependency for the first time when formulating landscape expertises concerning the possibility of constructing large buildings in the vicinity of landscape parks, such as theme park facilities (cableway, Ferris wheel) and wind turbines. Tying graph image resolution with spatial resolution resulted in significant capabilities in terms of combining graphs and visibility maps with other data mapped in geographic information systems. In the work “Digital Analyses of Visual Aspects of Wind Farms in South-East Poland” (Appendix 3) I presented an analysis of the impact of a wind farm on the landscape, in which areas of the visibility of individual turbine elements were essential. They were assessed with a precision level of 1 m² of the digital surface model and it is from this precision that the assessment precision depends on.

The fundamental tools that make it possible to visualise the spatial distribution of visibility are visibility maps. They display cumulative visibility. Visibility maps contain aggregated information derived from a set of visibility graphs. They are created through the matrix addition of graphs of the

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same size and resolution and are later standardised over the entire available bit space of an image. They can be used to map information about the visibility of linear and surface objects. In specific cases, a visibility graph of a point object can be treated as a visibility map. I also used them in my doctoral thesis, however, I developed this proposal at a later date. In the monograph (Appendix 2) I included cases in which visibility maps were materials on the basis of which other maps are generated and which are a representation of the visibility of simulated phenomena. In those operations, appropriately selected graph sets are summed into component maps that constitute elements of various matrix operations used to generate resultant maps that present a more complex issue.

In the most often encountered cases, in which we are dealing with a visibility map for an object of non-negligible size, such as a mountain chain, an area is displayed from which this object is visible. The object is visible in each fragment of this area (to a greater or lesser degree). Apart from marking the visibility area, information on the scope of the visibility of a given object at a given site is recorded on the map. Every point on the map features a number that represents the scope of the observed object at the point of land surface of which said point is a projection on the map. The map is a raster image, which is a matrix whose cells contain this number. The number is the sum of the visibility of the surface of the object at a given point. I formalised the description of the visibility of such an object using a matrix whose cells contain a number calculated by solving a non-oriented surface integral (chapter 5.2.3 „Mapy widoczności” in the monograph (Appendix 2)). The value of the integral can be approximated using object visibility sampling by producing visibility graphs for points that are systematically distributed over its surface in the densest possible manner. The sum of visibility samples provides an approximation of the surface visibility sum. The denser the sample distribution, the more precise the solution of the integral. However, in order to generate a visibility map with the correct information it is not necessary to solve the integral with a significant degree of precision. The samples are distributed across the surface of the analysed object with a frequency that makes it possible to represent topology, densely enough so as not to omit important terrain oddities and sparsely enough so as to optimise the amount of calculation. Because of these samples, visibility graphs are produced that constitute a set that is taken for the visibility map of a given object. The sampling of linear objects, such as roads, tourist trails, etc. is performed similarly.

The product of sampling is a set of images for which I introduced the notion of the systematic sampling graph and the map generated using these graphs is a systematic sampling map. In order to optimise calculations, I introduced an approach in which systematic sampling graphs can be prepared only once. Generating visibility maps for various sub-sectors can be performed on the basis of those same premade graphs that are expressed in a different manner. Depending on the functionality of the software used to generate maps, graphs can be selected on the basis of either subsector border or mask.

Thanks to this, the most time-consuming and processing-power-intensive process does not have to be repeated each time the need to generate an additional map arises. The process should be performed for all points on a surface and the graphs should be stored with appropriate indicators. Should the need for a subsector map arise, graphs for that subsector are selected. This is important in the case of analytical work, as such needs are often the result of previous analyses.

In chapter „5.3 Mapy składnikowe wykonywane na terenie studialnym” of the monograph (Appendix 2), I presented an example of creating component maps required to model landscape attractiveness factors. These maps constituted elements of matrix calculations at subsequent stages of modelling, their results being visibility maps for those factors, called resultant maps. The
presentation of the landscape attractiveness visibility map generation method using matrix operations on component maps was performed on an example of analyses concerning the valley of Lake Czorsztyn. It is the result for a pilot site adopted for the study. In chapter 3 „Wybór obszaru studialnego” of the monograph, there is a presentation of the territorial selection process for analyses for a specific expert task. In chapter 3.3 „Doprecyzowanie granic opracowania analiz widokowych” (Appendix 2) I presented an approach that makes it possible to determine the scope of an area for which it is necessary to obtain data at three levels of precision expressed in the form of operation levels. These levels and their scopes were determined using an iterative method. It is a method used to satisfy the needs of a specific case of landscape analysis. For this area, a number of specific factors was selected as those that define landscape individuality. The selection of these factors is the expert role of a landscape architect. They featured spatial impact ranges and an influence on determining the range of each operation area. However, other factors, whose impact ranges can be modelled in a similar manner, can be selected for a different area. The approach that I developed is meant to satisfy an expert's requirements and should be modified to take into consideration the specificity of concrete analytical tasks.

However, we can adopt certain elements that are essential to the approach. As a rule, visibility maps for individual surface and linear objects, as well as important point-based objects that define the individuality of a landscape are elements of operations that are aimed at performing complex analyses and the generation of resultant maps. In these operations they are component maps. They contain basic information on the visibility of an individual object. It can concern the visibility of a large object (cumulative visibility) or be an individual graph of a point object. I distinguished two types of component maps, active and passive exposure maps. Passive exposure maps are primarily used to assess the landscape. They are produced due to the visibility of elements that define the individuality of the landscape, with the impact of these elements, visibility range, intensity and frequency of view being assessed. Active exposure maps are primarily used to make comparisons of various situations. They are most often produced for places that are well-suited for landscape observation. They can be observation points or paths. An expert, designer or planner can, on the basis of a passive exposure map, highlight places that are potentially visually attractive and can test them by producing active exposure graphs, select the best observation point, mark the most attractive section of a landscape route etc.

The visibility model for individual factors is affected in various ways by elements that define landscape individuality. Some improve attractiveness while others decrease it. It is primarily the passive exposure maps that contain information that can be compared in order to obtain resultant maps depicting landscape attractiveness impact (Chapter 5.4. Czynniki atrakcyjności krajobrazu gościnnego poddające się modelowaniu komputerowemu. (Appendix 2)). In this method I proposed matrix arithmetic operations to obtain spatial distribution maps for individual factors. Chapter 5.4 features a presentation of proposals of modelling the spatial distribution of 11 positive and 8 negative factors among those that were defined by an expert for the given area to be studied. Identifying these factors, namely, the elements that define landscape individuality, is not a part of the scope of my research. The principles of their identification for the valley of Czorsztyn Lake was described in chapter „4. Studia krajobrazowe”.

**SYSTEMATIC SAMPLING GRAPH FRAC TAL DIMENSION MAP**

The possibility to model factor spatial distributions is conditioned by data accessibility. Among the factors defined by the expert, only 7 factors could not be modelled because of a lack of data. Although we managed to model such factors like sublime character or peculiarity, we could not
devise how to prepare visibility maps for a factor the expert had listed as "dynamic of the "spectacle" of forces of nature against the background of an expansive space (a sunset, a storm, "halny" wind, "a sea of fog"). There are proposals for monitoring the "spectacle" of forces of nature in order to obtain appropriate data. However, such measures have not been undertaken. Most of the proposals for modelling the distribution of visibility sites for individual factors were based on matrix addition of component maps with weights assigned to them. There are also other solutions. In chapter „5.4.4. Bogactwo planów i kulis” (Appendix 2) I proposed a manner of generating a map on the basis of systematic sampling graph fractal dimension maps. The problem of the fractal dimension was discussed by Piotr Łąbędź in his master's thesis entitled „Analiza obiektów w przestrzeniach n-wymiarowych przy pomocy algorytmów fraktalnych”, of which I was supervisor. The box-counting dimension is a type of fractal dimension. Working with Agnieszka Ozimek and Piotr Łabędź as a team, we performed numerous experiments on box-counting dimensions, as a result of which we came to the conclusion that it is a good measure of variety. As a result of these experiments, we used this method to assess changes within the landscape. In the case of calculating the box-counting dimension on an image of the current and designed state, a high change in value signifies a significant formal change. The addition of an object similar to those that already exist on an image did not cause a significant difference in the dimension's value. Thanks to the introduction of the box-counting dimension as a measure of variety, we obtained a second, apart from mean brightness, numerical indicator that enables state comparison.

It can be assumed that if a visibility graph is composed of numerous complexly shaped spots with frayed borders that are contained within them, then it is derived from an interesting view, composed of numerous planes and stages. The box-counting dimension of such a graph has a high value. All of the graphs were studied using this method. The values are contained within the interval between 1 and 2. Results were standardised to the image space and recorded in matrix cells corresponding with points of appropriate visibility graphs. Thanks to this, we managed to obtain a map depicting the values of fractal dimensions of visibility graphs produced for given places. This map is a visualisation of a multifractal. It is an example of this type of data organisation structure. I also proposed a different manner of producing maps for this factor, based on an object cohesion's Euler's number. It expresses the dependency between the cohesion of an area and the number of holes. Holes in the visibility graph are a result of obstruction by the shape of the terrain. Methods of obtaining maps of the wealth of planes and stages were described in the publication entitled METODY POZYSKIWANIA MAP BOGACTWA PLANÓW I KULIS DLA CYFROWEJ ANALIZY WARTOŚCI KRAJOBRAZU (Ozi3) (Appendix 4).

CALCULATING VISUAL ABSORPTION CAPACITY

The visual absorption of the landscape of a given area denotes its capacity to absorb new elements without losing the identity of its physiognomy and is defined by the VAC index (Visual Absorption

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I proposed a method based on ray tracing to calculate it in the work entitled „Badanie chłonności krajobrazowej przy użyciu przestrzennego modelu cyfrowego“ (Appendix 5). I defined it as volumetric shadow analysis. In this case, it is the edge of a shadow cast by a specific curtain that is significant, instead of the entire shadow. The curtain can be formed by an object that exists in the landscape or a planned masking object. Based on this shadow edge, the height to terrain elevation is calculated using the systematic sampling method. We can measure its volume, study its height at specific points and generate visual absorption capacity maps.

I used this method to determine the size of designed buildings, precisely determining their height at various points. We can use it to optimise the massing of newly-designed architecture, blend buildings into the landscape absorption space. It is also well-suited for determining places that can absorb objects with given dimensions, particularly height. We can use this method in the case of military installations and other objects for which a character of mimicry is required. Thanks to this it will be possible to perform a product of solids of visual absorption capacity calculated for many observation points, which is well-suited in formulating spatial planning guidelines.

**DIGITALLY PRODUCED MATERIAL-BASED INFERENCE**

The most tangible benefit derived from producing visibility and visual absorption capacity maps is the possibility to calculate indicators that are well-suited for comparison. Maps generated for various states can be visually compared, have their mean brightness calculated in addition to their fractal dimension and be subjected to arithmetic matrix operations. In chapter „5.5 Analiza wpływu podjętych decyzji na krajobraz“ of the monograph I presented an example that demonstrates a comparison of maps of sublime views for the valley of Lake Czorsztyn in the state appropriate to the time of performing the analysis and in the designed state featured in spatial development plans in force in this area. Apart from the ability to compare the visual effects of plan implementation, we can become aware of significant qualitative changes when comparing the mean brightness of these maps. This coefficient, which is expressed by a real number, is easily attainable for monochromatic maps. It reflects differences between states very well.

The comparing of visibility maps with other layers of geographical information systems is a separate problem. The landscape attractiveness map, an example of which was presented in chapter „5.4.5. Mapa atrakcyjności widokowej krajobrazu“ is composed of a passive exposure map of factors that increase landscape attractiveness and another map of the same region featuring factors that lower attractiveness. One of the means of integrating both of these component maps is difference. However, the information it conveys is not unambiguous. We do not know whether the brightness of a specific point is low because we cannot see anything significant from its position or whether it has been lowered by a concurrent view of an object that lowers attractiveness. Another method utilises the placement of both component maps into different colour channels. In the example, the decreasing factors map was placed in the red channel and the increasing factors map in the green channel. This made it possible to see the effects of both types of factors on a single map. A third solution features the placement of both component maps on different layers of a geographic information system. The selection of these negative and positive data aggregation methods is a matter of an operator’s individual preferences.

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The methods that have been developed make it possible to generate specific maps. An example of such a map is the equilibrium equation map described in chapter „5.4.6. Mapa do równania równowagi” of the monograph [OBOW]. The equation requires areas that should be placed under complete protection, marked as CP, those under partial protection, marked as PP and areas that do not require protection—NP. Based on the principle adopted in the research, protection should be extended to those areas whose development is essential for sites characterised by highly valuable views. The map was created as a result of generating visibility graphs through systematic sampling, for areas marked as the most valuable on the landscape visual attractiveness map.

In the work entitled „Analizy krajobrazu z użyciem narzędzi cyfrowych” [OpOa2] in chapter „II.3.2. MAPY WIDOCZNOŚCI OBEJMUJĄCE ZAKRES PERCEPCJI”, I presented an approach in which the impact range of existing elements of space that negatively affect landscape attractiveness and the range of a designed object is studied. In this case, it was a wind farm. Afterwards, a calculation of the logical difference of both ranges is performed, which indicates sites from which only the designed wind farm is visible while other objects marked as negatively affecting the landscape are not. In this case, these were power lines and mobile communications masts. The approach represented in the example was used in visual impact assessments for planned real estate development projects. It is of particular significance for landscape expertises in protected landscape areas.

OTHER RESEARCH WORK

Conducting scientific research on the implementation of digital technologies in architecture, urban planning, landscape architecture and architectural conservation.

PARTICIPATION IN RESEARCH PROJECTS
I taught classes at 4 university study courses and post-graduate study courses. I was a supervisor of around 80 diploma projects at both study tiers and at single-tier master’s studies. These diploma projects were prepared at Technical Physics and Computer Science courses.

The basis of full-time employment at a university like the Cracow University of Technology is didactic work. No matter how high we value research work, it is for the achievement of didactic goals that scientific and didactic positions are created and which constitute almost 100% of a university’s production personnel. They are provided with a stable source of financing from didactic subsidies, which are the fundamental component of a university’s income.

Didactic activity also constitutes the basis of my functioning at the university of technology. I have taken up employment with the inter-faculty Electronic Calculation Technologies Centre, which fulfils didactic functions concerning computer science for all faculties of the Cracow University of Technology. Initially, I taught classes on Computer Aided Design, primarily for students of the Architecture and Urban Planning course, but also for students of the Digital Modelling course. It was the only period during which my design experience and the first scientific conceptual proposals could be implemented into the didactic process. They primarily concerned the subject of digital modelling and visualisations in the design of spatial forms.

Unfortunately, due to organisational changes at the University, these classes ceased to be contracted with the unit that I was employed with. It was during this time that the Technical Physics and Digital Modelling Faculty was established as a result of combining inter-faculty institutes. It resulted in the necessity of taking up didactics at study courses conducted by this faculty. Initially it was Technical Physics and later Computer Science. I was almost immediately asked to cooperate in the establishment of the Landscape Architecture study course. It is because of this history that my field of didactic activity is quite broad and that the field of my research interests is largely interdisciplinary.

At present, the main part of my didactic activity takes place at the Computer Science study course, at which I am a supervisor of the Computer graphics and multimedia specialisation. In addition, I teach classes as a part of Technical Physics and Landscape Architecture courses. Since 1 September 2017 I have fulfilled the function of deputy director of the Institute of Computer Science in charge of didactic matters.

I participated in the programmatic and organisational work of the Landscape Architecture study course under the supervision of prof. dr hab. inż. arch. Aleksander Böhm. In the years 2000-2007 I was a coordinator of a block of mathematical and computer science-related modules of this course at the Cracow University of Technology. Programmatic proposals that I tried to implement into the didactic process at this course were largely influenced by the idea that the current generation of landscape architects will participate in the digitalisation of all space and basic information that will serve them in their professional activity will be digital data. I proposed a block of mathematics and computer science-related modules spanning a period of 3 semesters, whose goal was to equip students with basic knowledge on data structures, object definitions and algorithms that can be
found in computer aided design systems, as well as developing skills in operating the most popular computer aided design systems. As a part of this block, the following modules were taught:

- Mathematics
- Information technology
- CAD - Computer aided design
- Digital visualisation

Starting with the first semester, these modules have taught students to use precise language with a high degree of abstraction in describing space. The concept of the first module already assumed transferring knowledge about the mathematical definitions of data structures and the most commonly used functions in computer graphics. This knowledge is presented during lectures with direct references to graphical objects and representations of elements of space and phenomena that are modelled by landscape architects.

The content includes vector and matrix calculations, elements of differential geometry and selected issues of calculus. They are illustrated by a presentation of the structure of digital images, matrix operations on images and visibility maps, which is one of the few occasions for students to become familiarised with the results of my research. Matrix and vector calculations are also referred to two presentations of terrain models and their transformations in the form of calculating excavations or embankments. Integrals are also discussed on this example. The parametric form of a straight line within space is precisely used in the ray tracing model and the reflection function. Higher order polynomials are presented by drawing Hermite and Bézier curves while function continuity dependency on derivatives is referred to the aesthetics of curves, b-splines and shapes that can be modelled using them.

Classes also feature the solving of analytical assignments using traditional means, as well as graphically, which, along with the use of computer graphics editors, provides equally precise results. Thanks to this method, students can see the direct relationship between an object’s definition and presentation and develop their spatial imagination. Referring mathematical models directly to digital models reinforces the message and stimulates student’s enjoyment of studying. The presentation of mathematical functions in programs that are used in design expands skills of operating them, in addition to showing a semantic continuity in the modelling of spatial phenomena.

Information technology is a supplementary module that is taught in parallel, providing practical skills in the use of popular graphics software. Here students prepare their assigned drawings and models that are thematically selected so as to be in line with the design of landscape architecture features. Assignment subject matter is to realise the goal that is the fastest possible familiarisation with a program that is popular with the architectural profession and which is the strongest global standard. Thanks to this, students have a tool to work with during the Integrated Design module already at the second semester.

As a part of the integration of didactic content, a single design assignment is worked on during several modules at the second and third semester. This includes CAD—computer aided design and Digital Visualisation. This makes teaching this subject flexible and takes the needs of various design assignments into consideration. This limits the possibility of formulating assignments and their requirements concerning the realisation of didactic goals to only teaching how to operate a
computer program. Students, based on knowledge and skills gained during previous modules, must demonstrate creativity and studying ability in solving design problems. As a result, they orientate themselves towards problems instead of tools. This provides a much better didactic effect concerning computer-related competencies and also provides good results in design competencies over the long term.

The didactic scheme presented above has been implemented for 18 years while taking into consideration technological changes in the form of changing programs and hardware. The names of modules have also changed as a result of formulating the standards of individual study courses. I taught these modules between 2000 and 2015. At present, as a result of the formation of a cadre of continuators at the Institute of Landscape Architecture of the Cracow University of Technology, I only teach Mathematics.

**COMPUTER SCIENCE STUDY COURSE**

**COMPUTER GRAPHICS AS A PART OF THE GRAPHICAL ENGINEER PROFILE**

Computer science studies at the Faculty of Physics, Mathematics and Computer Science are taught at two study tiers. Judging how students are hired by software companies, we can assume that the curriculum being taught at the first tier of studies answers the needs of employers. Our first-tier graduates in Computer Science are already educated to a level that is sufficient for many employment positions. They work and earn respectable amounts of money. They are a perfect example of the implementation of the postulates of the Bologna Charter. It assumed a shortening of the time of professional studies down to 6-7 semesters. The fact our students do so well on the employment market speaks volumes of the quality of our teaching. We can only assume that we have a well-prepared vocational study curriculum, as first-tier studies should be treated as vocational studies, as a part of which all content required to work as a computer specialist should be taught. The profile of such a graduate is clearly defined and we only fill it in. This has been confirmed by post-control assessments by the Polish Accreditation Commission.

I teach two modules as a part of this curriculum. One of them is Digital Graphics and Man-Computer Communication, which covers content required by the course standard in terms of digital graphics. It is taught through lectures and computer classes. Lectures present data structures, colour models, graphical data processing algorithms and matters of computer application interface functionality. During computer classes students are familiarised with popular raster and vector graphics software and programming environments. They prepare assignments and program applications in these environments.

The second module, called Multimedia Technologies, gives students much greater creative freedom. The content of lectures features both data structures, algorithms and technologies used in multimedia, but also production processes for multimedia works and examples with particular emphasis on entertainment shows like 3D mapping. As a part of computer classes, students go through stages of multimedia production, from operating on raster images through three-dimensional modelling, digital animation to editing and post-production. It is an opportunity to highlight the element of artistic creativity to students who are highly technology-oriented, as the first class features an assignment to develop a poster design, while throughout the remainder of the classes students are to produce a short animated video.
The Multimedia Technology module somewhat goes beyond the profile of first-tier studies at the Computer Science course, which educates specialists who are meant to be able to solve precisely defined tasks using specific tools. Insofar as assignment subjects and tools are defined for this module, the scope in which individual multimedia works can be produced is blurred. Students have the opportunity to identify their predispositions towards producing work with an artistic element and, afterwards, enrol into second-tier studies in the Computer Graphics and Multimedia specialisation.

The above modules are also taught at the Technical Physics course, although they are slightly modified in scope. The modifications apply to the profiling of class and assignment subjects in terms of the graduate profile for this course. A greater emphasis is placed on engineering graphics and the simulation of physical phenomena that propagate within space. Modelling the geometry of an industrial hall building followed by a simulation of the radiation power of light reflected off of workspace surfaces is performed.

**COMPUTER GRAPHICS AND MULTIMEDIA AS A SPECIALISATION PRODUCING AN INDEPENDENT ARTIST**

2007 saw the formulation of a strategy of the development of the Computer Science course, as a part of which the second tier of studies was to feature specialisations reflecting the main research currents represented at the Institute of Computer Science. Among others, this included the establishment of the Computer Graphics and Multimedia specialisation. I have been its supervisor from its very start. It is being taught on the basis of a set of specialist modules that I am an author of.

Experienced with work associated with the implementation of the postulates of the Bologna Charter within the structures of Le:Notre European projects, I know that the second tier of studies does not have to nor should it be directly linked with a first-tier course. Those graduates who do not want to stop at vocational studies should have the opportunity to broaden their horizons at a second-tier course so as to be more flexible on the employment market and in order to be able to react to its changes and without being restricted to a single profession. This does not mean that the second tier should be conducted in a different direction, but it can. One of the more important goals that are to be obtained during two-tier studies is a conversion as a part of which graduates of one course could continue studying at another course. In order for this to be possible, curricula for the second tier should be selected in a manner that allows them to be studied not only by graduates of closely related courses, but also those of thematically different ones as well.

The discipline that is Computer Science should be able to formulate a programmatic offering for second-tier studies for various disciplines, thanks to which the achievements of computer science could become broadly used in other professions and disciplines. This is to produce an interdisciplinary cadre that will be able to hold its own on the difficult employment market under rapidly changing conditions. This means that second-tier studies curricula should be appropriately "open" and more problem-orientated. So that, for instance, an architect engineer could attend

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14 Le:Notre – Thematic Network Project in Landscape Architecture – a sequence of projects that were co-financed by the European Union as a part of the Soctares and Lifelong Learning Programmes programmes. The goal of the projects was the harmonisation of knowledge and curricula at Landscape Architecture courses in Europe. I was a representative of the Cracow University of Technology with the following projects: Le:Notre, Le:Notre+, Le:Notre TWO.

second-tier studies and be able to not only use software in architecture, but to develop it in accordance with the properly identified needs of architects. Their needs associated with the architectural profession could be defined with a greater degree of precision relative to computer science thanks to the development of a common language for both of these disciplines. It is important for the offering of the computer science discipline at the second-tier of studies to also be attractive for computer specialists, so that they could study together. Thanks to this, computer specialists can become sensitised to the needs of others instead of becoming isolated within their own community. The curriculum of the Computer Graphics and Multimedia specialisation is an attempt at implementing this approach.

When I formulated it, I had in mind a profile of a graduate who is open-minded and highly skilled. If an engineer is to be able to solve a task using specific tools and methods after the first tier of studies, then a master should be able to solve a problem by studying its nature and selecting appropriate tools and methods. A master must be able to formulate a problem and cannot be limited to tools and methods used in a single profession, instead, a master should search for optimal solutions. It is the second-tier studies that should release the master from the limitations of a specific profession in optimally solving a problem. This can be defined in such a manner that a second-tier graduate must be able to formulate an idea, defend it and implement it. This is why I stress the study section in master’s theses, as it is about identifying needs, analysing available technologies and the selection of optimal solutions. The application section is only a verification of the appropriateness of previous choices. Of course, these theses are sometimes better and sometimes worse, as we have better and worse students, but I never allow the omission of studying needs, as an appropriate discussion necessary to draw conclusions, define specifications and assess utility.

One example of such an approach over the course of the studies is the assignment given at the second-semester module Man-Computer Communication that I supervise, and where students develop a website for a specific target audience. They must interview them, identify their needs—which they are most often not able to clearly communicate or define—build information architecture, write an application and test it in terms of utility. Of no small significance is the aesthetic and compositional side of the assignment. The assessment is up to the audience. The module sensitises students to the needs of the user, which must be identified regardless of their programming competencies. Oftentimes clients who commission web applications are not able to define these needs sufficiently well. They should be properly aided in this so that they can become free of stereotypes and erroneous preconceptions. The module includes content related to psychology, interpersonal communication, aesthetics, ergonomics, programming and hardware. It is team-based, which requires task division, work progress control and reporting—an appropriate organisation of work.

Another module that is an implementation of the abovementioned objectives is the Problem Studio, which I teach at the third, final semester. It is a design module which is also team-based. Multimedia assignment subjects for this module are meant to demonstrate the level of knowledge and the development of skills gained over the course of studies for the specialisation. When creating a multimedia work, students must produce its content, which includes textures, digital models and sound. They must solve hardware problems with rendering, its computation time and presentation. They should establish an appropriate organisation and task division scheme within their team. These problems must be solved in an artistic, sociological and technological aspect. These works cannot be produced while limiting oneself only to the scope of a computer specialist’s measures.
Developing a 3D Mapping project is one of the subjects that are worked on as a part of the module and an example of liberation from the confines of a profession and maintaining an open mind. It is an entertainment event based on projecting appropriately prepared animations synchronised with specifically composed music on the surface of a building. A good show is a composition of architecture, light and sound. It has an artistic value and a strong technological aspect. High-quality digital technology is used both to prepare content and perform the projection. It is here that the organisation aspect makes itself known.

The example of a show that took place on the 14th of May 2014 at the Students' Housing Estate of the Cracow University of Technology in Czyżyny excellently reflects the complexity of such an undertaking in all of its aspects. Students prepared all the necessary elements of the show as if they were the employees of a company that specialises in these types of projects. Although their actions were supervised, they had to come up with ideas to solve specific problems themselves. And there was no shortage of those. In order to power the projectors, 32 KW of power was needed. This amount of power was not available at the Students' Housing Estate in Czyżyny. The projectors had to stand on a twelve-metres-tall tower weighed down by 400 litres of water. Pouring this amount of water using a gardening hose was out of the question. Besides, a show should have spectators. It had to be promoted. Students designed posters, organised media patronage, gave interviews to radio and television stations. If they had been limited solely to what is associated with the work of a computer specialist, this project never would have been completed. Similar 3D Mapping shows are organised by students of the specialisation almost every year.

In their professional lives our graduates will often have to carry out such projects. Particularly if they decide to start their own businesses. It is not known when the computer specialist profession will share the fate of the once highly exposed electronics specialist. Our current students will surely experience this. This is more or less what our understanding of the mission of second-tier studies is. It is about people who go a long way beyond being "code writers", who are so eagerly exploited by software companies.

Apart from the ones listed above, I have taught the following modules at the Computer Graphics and Multimedia specialisation since its establishment:

- **3D Modelling**—As a part of the module, students familiarise themselves with methods and representations of computer graphics for the purposes of 3D modelling. Basic application functionality for 3D design is discussed for such software as: AutoCAD, 3DSMax. During classes students of the module develop 3d object modelling skills and their application in representing real-world objects. The software used includes MATLAB, AutoCAD, SketchUp, 3DSMax. After completing the module students should possess the skills necessary to implement and apply graphical representations in 3d modelling using CAD projects and simple 3d models. The knowledge and skills gained during 3D modelling are necessary for Digital Visualisation and Animation as well as CAx Systems modules.

- **Digital Visualisation and Animation**—The goal of the module is familiarising students with the properties of digital content creation systems and their associated artefacts. It features familiarisation with methods of scene modelling for digital renderings, gaining skills in the

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The shows can be viewed on the following channel: wfmi.pk Youtube. 
modelling of illumination, the physical properties of objects, animations and simulation of spatial phenomena, the appropriate use of algorithms to obtain realistic images.

- **CAx Systems**—The goal of the module is familiarising students with the properties of computer aided design, manufacturing, production planning and quality control systems (CAx) and their associated artefacts. As a part of the module, a case study in the form of the digital operation of a design of an industrial building is investigated. The education effects include skills and competencies in effective communication with specialists, CAD/CAM/CAE/CAQ system users, particularly those that make it possible to edit and analyse requirements in projects concerning this field.

- **Multimedia Post-production Processes**—The module is meant to familiarise students with the techniques of non-linear editing of multimedia works utilising digital tools, as well as image and video sequence processing algorithms in order to obtain special effects in multimedia works. Furthermore, computer classes also train skills associated with the production of multimedia works from various types of digital materials and data structures for the needs of contemporary media broadcasters.

Apart from the aforementioned modules, the specialisation course also offers specialised profiled modules such as Graphics Programming, Games Programming and Parallel and Distributed Programming. At the moment of writing this application, I currently only teach Man-Computer Communication, CAx Systems and Problem Studio modules. The remaining modules are taught by a team of my co-workers who are active as a part of the Computer Graphics and High-Performance Calculations Division, of which I am acting director.

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