Tangible Alignment Design

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An alignment is the top most semantic element of any linear infrastructure asset. It represents the backbone of the geometric shape and linear positioning of other objects. At the beginning of any infrastructure project many alignments are designed and compared in a variant study. We developed an extension for the CDP // Collaborative Design Platform which allows for interactive alignment design. As established in practice the alignment and thus its design is split in two planes: the horizontal alignment and the vertical alignment. This way of input is established in the practise and preferred by the engineers. However, the possibility of interaction with the tangible interface benefits greatly in the early stages of the project. Additionally, this could provide the asset owner with tangible information about the alignment in question without the unnecessary overhead of design applications, or help students understand the topic more easily and clearly.

Keywords: infrastructure, collaborative design platform, tangible BIM, alignment design

1 Introduction

1.1 Motivation

One of the design fields in civil engineering is the design of an infrastructure asset. The design of a road or a railway is a complex task, involving engineers from multiple disciplines. One of the first steps undertaken when designing a new infrastructure object is deciding where its main axis lies – its alignment. To cite the CEO of OBERMEYER Planen+Beraten GmbH:

"He who controls the alignment, reigns over the project." (KRETZ, 2017)

In the search for a harmonious route many different criteria need to be considered. These include construction costs like earthworks and elements' quantities on the one side as well as ecological and social impacts like noise pollution and traffic network improvements on the other side.

In this study we focus on the early design stage in the infrastructure sector. Here, multiple options and variants are designed and compared among each other. The design parameters and information have a certain amount of fuzziness to it, which are further refined in the later stages of the project. Many of the current design tools available on the market provide identical support for all phases – from the early design to the detailed design. There is no differentiation in the processes and thus the intuitive and abstract design needs to be very concrete already in the early stages. However, there is no need for precise data and exact decisions, a certain amount of fuzziness and uncertainty is very welcome.

1.2 Design

Architectural and engineering design is a challenging task belonging to the ill-defined family of problems (CROSS, 2008). Such a problem does not have a single best solution (like chess does) and may even have many correct approaches all leading to different but equally good solutions. The problem description cannot be clearly specified – solution focused strategies are therefore perhaps the best way of tackling design problems (CROSS, 2008). The designer needs to couple innovative ideas and daring approaches in his iterative search for the perfect design. The more options he can produce and evaluate, the more certain he is about the quality of the proposed solutions.

In the last decades, computers have been increasingly integrated in everyday civil engineering project work. Digital simulation and complex calculations can be done on the fly and thus massively reducing the erroneousness while saving the time and resources needed for the project's completion. However, these methods are mostly used in the later design stages because they require precise models rich with various semantic and geometric information (RITTER & SCHUBERT, 2014). Coupling this with the fact that design changes get increasingly complex and more expensive as the project progresses, the need for an earlier integration of digital methods in a project is obvious. A design decision support system (DDSS) provides useful information (e.g., costs, quantities, wind and visibility analysis, ...) that can help the designer lead the project in a sustainable way (SCHUBERT, 2014).

In engineering design in general, boundary conditions and design restrictions from various sources and of different complexity need to be considered during the design. Additionally, the modelling tools being used can obstruct the process with their user interface (UI) and specific quirks. As such, a substantial amount of brain power is spent for handling, which is otherwise much needed for innovation. A clear and intuitive way of representing information as well as using haptic elements like three-dimensional (3D)-blocks and moulds for user input can immensely enhance the design process. The user can draw conclusions much more easily and react and adapt his designs accordingly. Following these findings, a new approach is sought for regarding the design, planing and communication processes (SCHUBERT, 2012).

1.3 CDP // Collaborative Design Platform

An example of a DDSS is the CDP // Collaborative Design Platform, continuously developed in an interdisciplinary research group from 2010 (SCHUBERT, 2012). Tangible design is made available through an interactive table (A) (see Figure 1). The data can be visualised on the table through the projector (B). Touch gestures and physical objects are registered by two infrared sensors (D) and (E) and by the depth camera (I). The fusion of the information is done by the processing unit (F). An additional 3D-view is shown separately as a projection (G, H). With this, the advantages of both the sketch and the model are made available to the user. Thus, the engineer can focus on the design task at hand and not be bounded by the tool's capabilities (SCHUBERT, 2012).

At first, the CDP included the design of building placement within a city environment with wind simulation and pedestrian visibility analysis (SCHUBERT, 2014). In the recent years, the CDP has seen multiple usages enhancing building's energy simulations (RITTER AND SCHUBERT, 2014) and district heating networks (BRATOEV ET AL., 2017). The framework was extended to include support for visual programming which was showcased on diverse city simulations (SCHUBERT, BRATOEV & PETZOLD, 2017). In our study we developed a new extension for the CDP looking at another area of engineering: the infrastructure design.

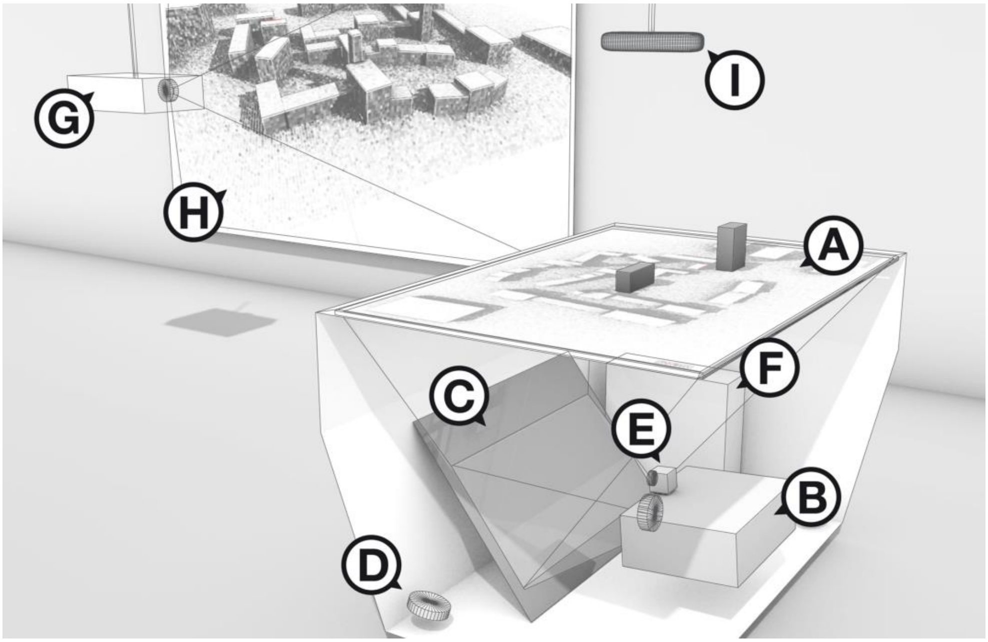

Fig. 1: The architecture of the CDP // Collaborative Design Platform (CDP): the interactive projection table (A), the projector (B), the mirror between A and B (C), the infrared sensors (D and E), the computing unit (F), the second projector (G), the projection plane (H) and the depth camera (I) (SCHUBERT, 2012).

2 Alignment

The alignment is the backbone of every infrastructure object as it describes the object's base curve. It is its top most abstraction and serves as a positioning reference. It can be compared to the structural axes in the building sector.

2.1 Geometry

An alignment can be accurately represented as a 3D-curve in the engineering Cartesian coordinate system (x,y,z). It is a superposition of two planar curves: the horizontal alignment (HA) and the vertical alignment (VA). HA is the projection of the aforementioned 3D-curve onto the horizontal (x,y) plane. As usual in practice, we define a new coordinate axis s along the HA called the stationing axis. VA is the projection of the 3D-curve on the curvilinear (s,z) plane.

Each alignment consists of an ordered array of elements of three types: straights, curves, and transition curves. There are many types of curves and transition curves used in practice. The used types depend on the type and category of the infrastructure asset and are presented in

Table 1. Knowing the order, the types, and the parameters of each individual element in both HA and VA the resulting alignment is uniquely defined.

Table 1: Different types of elements for alignments of different infrastructure objects. All types and alignments include straight elements, which are excluded from the table[1].

Type	Alignment	Curve	Transition curve
Roadway	HA	circular arc	clothoid
	VA	circular arc, parabolic arc	-
Railway	HA	circular arc	clothoid, Bloss curve, Vienna curve, sinusoid, cosinusoid, cubic parabola, biquadratic parabola, Schramm curve
	VA	circular arc, parabolic arc	-
Magnetic levitation tracks	HA	circular arc	clothoid, sinusoid
	VA	circular arc	clothoid

2.2 Modelling

There are two possible ways to uniquely represent both alignments, either by segments or point of intersection (PI). The former option considers each alignment's element to be an individual segment with its own parameters. The latter option represents the HA and VA with an ordered array of points – points of horizontal intersection (PHIs) and points of vertical intersection (PVIs), respectively. These can be obtained by extending all sections of zero curvature to obtain cross points.

Both options are exemplary shown on Figure 2 for a typical road alignment. The HA includes elements of type straight, circular arc and clothoid transition curve, while the VA includes elements of type straight and parabolic curve. The used notation is explained below.

- A_i^b and A_i^a or A_j are the transition curve parameters before (b) and after (a) the curve at i-th PI or at j-th segment. Here exemplary the clothoid parameter $A \geq 0$ in [m], however other parameters may be needed for other transition curves.
- b_j is the bearing of the tangent at the beginning of the j-th segment in HA, i.e., the azimuth angle.
- g_j is the grade of the tangent at the beginning of the j-th segment in VA, i.e., the slope in the direction of s-axis.
- i is the index of a PI.
- j is the index of a segment.
- l_j is the length of the j-th segment. The length is always measured along the s-axis.
- R_j or R_i is the radius of the curve at the i-th PI or at j-th segment (in [m]). In case of a parabolic curve, the value denotes the radius at its vertex.
- $[x_i, y_i]^T$ and $[s, z_i]^T$ are the coordinates of the i-th PI in HA and VA, respectively.

[1] The possible types have been obtained from the software ProVI: www.provi-cad.de

- $[x_j, y_j]^T$ and $[s_j, z_j]^T$ are the coordinates of the beginning of the j-th segment in HA and VA, respectively.

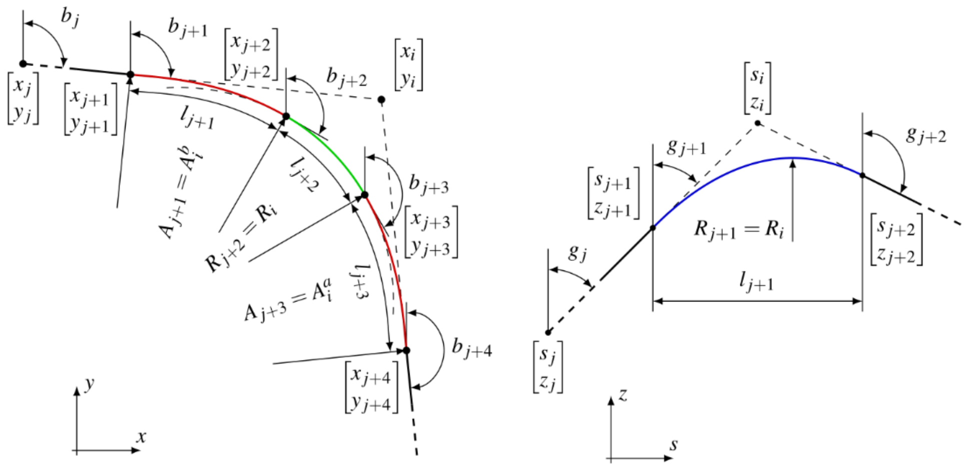

Fig. 2: Different types of segments and their relation to a PI for a HA (left) and VA (right). The segment's length l_j is only marked for curved elements.

3 Process

Our process is graphically depicted in Figure 3 and is described in the following sections.

3.1 Digital Terrain Model

When designing, the data about the already existing objects is a necessary input. In the case of the alignment design, this is topography, the existing infrastructure network and additional geospatial data. The former is the bare minimum, otherwise the VA design cannot take place (MAKANAE & MATSUDA, 2018). A common form of representing topographical data is with a digital terrain model (DTM) whose geometry is a triangulated irregular network (TIN). TIN consists of 3D points connected in irregularly shaped triangles and is usually obtained from a field survey.

To depict the 3D nature of the DTM on the two-dimensional (2D) surface of the CDP we use the contour lines as established in the practice. First the minimal and the maximal elevation z_{min} and z_{max} of the TIN is determined. This interval is then split in an array of distinct values $z_{min} \leq z_i \leq z_{max}$ for which the contour lines are calculated. For each of the values z_i the following procedure is carried out. The vertices of each triangle are split into two groups: those above and those below the z_i. If one group is empty, the triangle is skipped since it is either wholly above or wholly below the height z_i. Otherwise, one group has a single vertex (called A) and the other group has two (called B and C). For each of the edges AB and AC we linearly interpolate the elevations of the vertices in order to obtain the x and y coordinates of the two points with elevation z_i. These two points are connected with a line and the procedure continues until all the elevation values z_i have been processed.

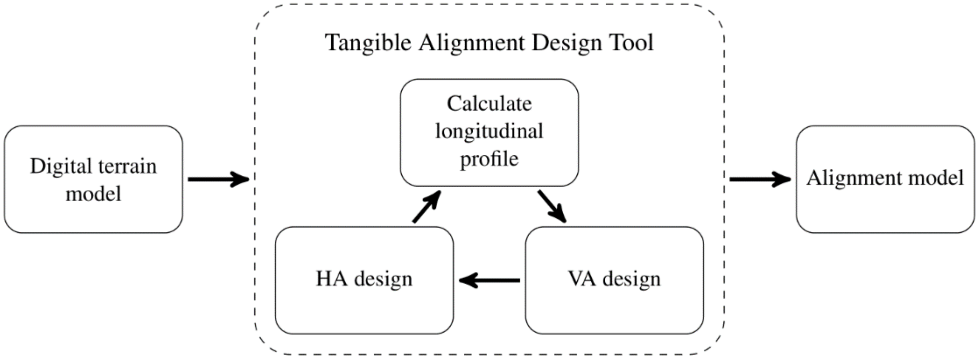

Fig. 3: The process of alignment design.

Similarly to calculating the contour lines for the design of the HA, we derive a longitudinal profile for the design of the VA. This is calculated by intersecting the contour lines with the HA and connecting the points.

3.2 User Interface

Since we are designing a tangible interface, it is of utmost importance for the UI to be clear and concise. With that, the user can focus on the design task at hand and not be distracted by the interaction with the system. Following the definitions in Section 2 we opted for modelling of the alignment using an array of PIs. The design interface is split in two separate windows, one for each of the alignments (see Figure 4). In this first prototype, the user can add, select, move or delete a PI. Additionally, the radius of the curve can be set in a separate menu for the currently selected PI.

3.3 Result

The proposed extension only serves as a preliminary design tool as it is expected for the engineer to wish to refine his design in later design stages. A 3D-polyline represents the alignment in a simple yet sufficiently precise manner depending on the density of points. However, changes to such representation are very demanding as each individual point need to be adjusted. Therefore, we opted for a parametric alignment model export that retains as many of the design parameters intact as possible.

There are many formats available which include a model of an alignment, like industry foundation classes (IFC), LandXML and Objekt Katalog Straße (OKSTRA) (AMANN ET AL., 2014). The chosen format was the recently developed IFC-alignment, as it is becoming internationally very well accepted. The IFC standard extension opted to model the alignment entities according to the segment definitions schema (LIEBICH ET AL., 2017). Thus, we need to transform from PIs to the segments following the definitions from Section 2.2.

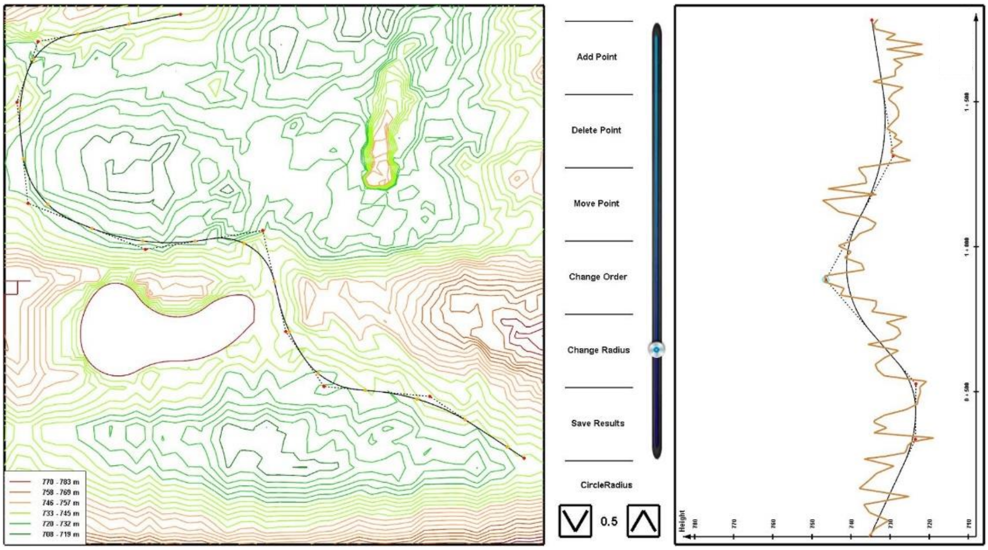

Fig. 4: The UI of the prototype as seen on projection plane (A) from Figure 1. The HA design with contour lines (left) and the VA design with the longitudinal profile (right). Between them a panel with different options and parameters.

4 Conclusions

In our study we present an interactive tool for alignment design. It was developed atop of the CDP // Collaborative Design Platform which incorporates a tangible interface for combining physical working models with interactive simulations and analyses in real time. The tool can be best used during preliminary studies where many different variants are designed and evaluated. It is a great enhancement in the early design stages of an infrastructure project. Additionally, benefits can be achieved when used for teaching or project meetings with the asset owner.

4.1 Future Work

In the future, further geodata like water elements (lake and rivers), existing infrastructure network and environmentally protected zones can be incorporated as input to further support design decisions. Additionally, the tool could be extended to support virtual reality alignment design as proposed by MAKANAE & MATSUDA (2018). The missing functionality of transition curves can be added to the parameters of the PI.

As shown by BRATOEV ET AL. (2017) and RITTER & SCHUBERT (2014), simple simulations and calculations could be carried out in the background to additionally support the engineer at evaluating different variants. These include noise simulations and earthworks costs which are typical quality criteria in the infrastructure sector. Design with the use of haptic elements could be incorporated for the positioning and size of noise protection walls or bridges and tunnels.

4.2 Acknowledgements

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