DIGITALIZATION IN GEOTECHNICS

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KEYWORDS

Digitalization, geotechnics, BIM, AI, data management, Gartner's hype cycle, keynote, NGM

ABSTRACT

This paper explores emerging technologies in geo-engineering within the framework of Gartner's Hype Cycle, focusing on the adoption and practical application of digital tools in the Nordic region. It examines the progress of Building Information Modelling (BIM), highlighting its benefits and challenges in geo-engineering, particularly in data modeling and standardization. The paper also delves into Artificial Intelligence (AI), including machine learning and digital twins, evaluating their potential and current limitations. Furthermore, it underscores the critical role of data management in advancing these technologies and discusses NGI's development of tailored digital solutions for improved data handling and project efficiency. The study concludes that while significant advancements are being made, further development of digital skills, particularly coding, is essential for continued progress.

1. INTRODUCTION

The purpose of this paper is to present a few emerging technologies within geo-engineering in relation to the Gartner's hype cycle. The paper also looks into some fundamental requirements for any novel and data-driven technology to succeed in the world of geo-engineering.

The paper does not address the most advanced ongoing research and development but focuses on the development within the daily use of digital tools for geotechnical engineers in the Nordics.

2. EXPECTATIONS AND REALITY THORUGH THE DEVELOPMENT OF NEW TECHNOLOGIES

Gartner's Hype Cycle

Gartner's Hype Cycle [1] is a graphical representation that illustrates a common pattern that arises with new technologies. The graph combines the hype level curve, arising from a novel technology, and the typical curve of engineering or business maturity. The hype level curve, the maturity curve and the combined hype cycle is shown in figure 1. On all graphs the X-axis shows time.

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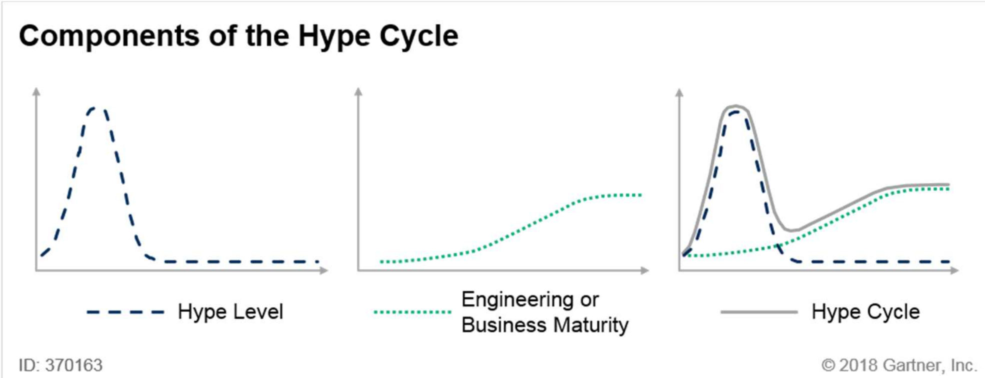

Figure 1 Principle of the hype cycle [1].

Gartner's Hype Cycle is a valuable tool for organizations navigating the complexities of digitalization. It provides a framework for understanding the lifecycle of emerging technologies, enabling better strategic decisions and more effective digital transformation initiatives. It is also a good reminder of the struggle many technologies experience in the phase between very high expectations in an early phase and the final phase where the full potential of the technology is obtained.

The hype cycle can be divided into different stages, which shows the road to productivity, as shown in figure 2.

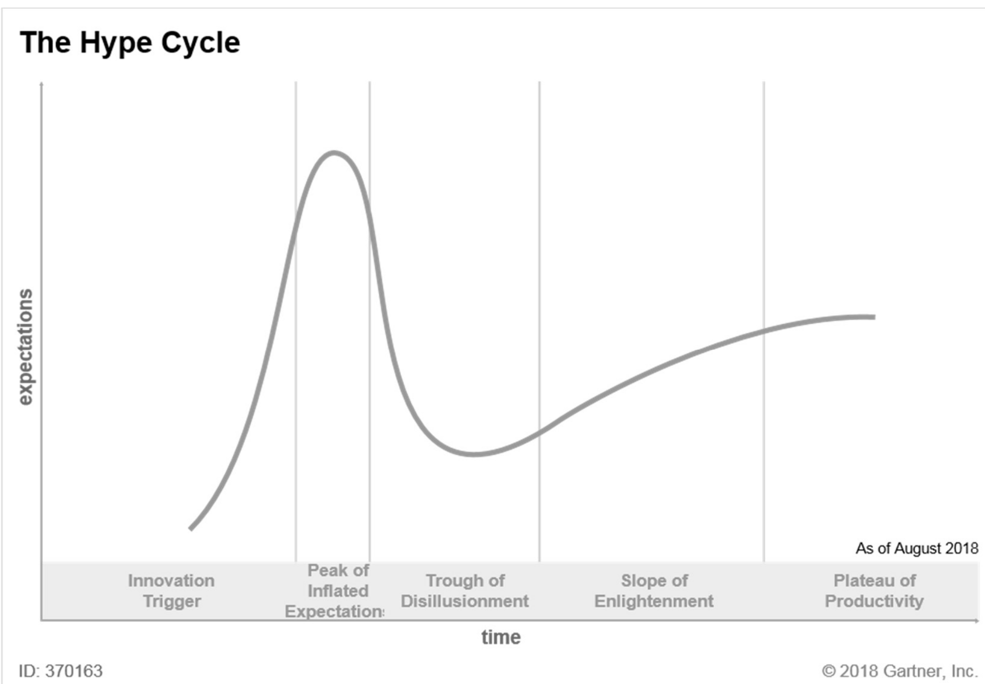

Figure 2 Different stages of the hype cycle [1]

Adoption for geoengineering technologies

In his keynote for the 5th International Conference on Information Technology in Geo-engineering, Erharter [2] assessed several geo-engineering technologies and their position in the hype cycle during spring 2024. The assessment is given in figure 3.

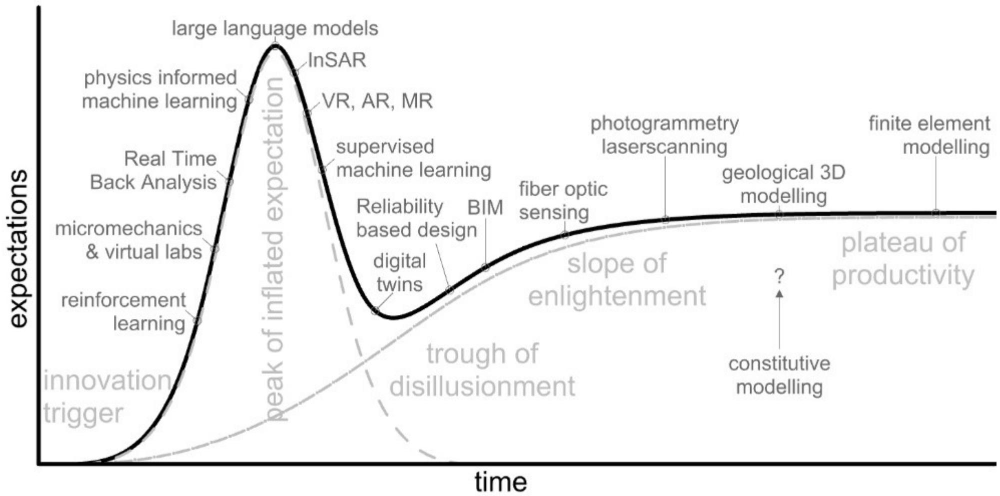

Figure 3 Assessment of geo-engineering technologies in the hype cycle

It is important to emphasize that this is a subjective assessment of the different technologies made by the author. The actual position for each technology is also influenced by factors such as geography, time of assessment, and for what field within engineering that is considered.

Even though, this is still a state-of-the-art assessment for how far we have come in digitalization within geo-engineering.

3. BIM – BUILDING INFORMATION MODELLING

Introduction to BIM

Building Information Modelling (BIM) is a process involving the creation and maintenance of a digital 3D-model which includes a set of information properties embedded in the model. The information describes the physical and functional characteristics of the asset, such as materials, demands, execution of construction, maintenance, etc when it comes to both construction and operation phase. A full BIM model can therefore be seen as a replacement of a combination of 3D-models, drawings and to some extent also the written report.

BIM has been used in the Nordics for several years already, and as in the rest of the world, the development sems to have been pushed by projects working with the construction of buildings rather than linear infrastructure.

There are several advantages with BIM, highlighted by Borrmann et. al. [3]:

- Better visualizations
- Improved collaboration
- Increased productivity
- More accurate documentation
- Enhanced coordination
- Cost and time savings
- Better lifecycle management
- Improved quality

All these benefits are probably more applicable in a situation where the full potential of BIM is utilized. As shown earlier in figure 3, Erharter assessment predicts that BIM has passed the hype peak but is yet to reach the full plateau of productivity.

From personal experience gained over the past years, both the general focus as well as utilizing BIM in the construction phase has increased. Especially early in the projects, the client or contractor wants to use BIM for the construction. What often happen though, as the start of the construction work is getting closer, is that the wish or need for supplementary drawings arises and sometimes even removes the wish for BIM. This is sometimes also due to different wishes and expectations in the client or contractor organisation. The people making the early decision has another wish than those responsible for the construction. As a result, BIM models tend to be more used in the design phase than in the construction phase.

BIM for geo-engineering

For the modelling part, BIM-models for geo-engineering can roughly be divided into three different types of models:

- Factual data models
- Interpretation models of the stratigraphy/layering
- Geo-structures, for examples sheet piles, deep-soil-mixing etc.

The factual data models are 1D or 2D models with results from soundings, lab-tests, observations, geophysical surveys etc, while the interpreted models give a 3D-model of the geological, geotechnical or hydrogeological conditions.

The M in BIM - modelling

In recent years, Leapfrog Works has gained traction in the industry for creating a combined factual and interpreted model of the soil and/or bedrock. However, a limitation with the current version of the software is that it cannot natively produce a project-specific property set during IFC export and hence is a simple 3D-model instead of a full BIM-model.

There is several other software that also can be used alone or together, making these factual and/or stratigraphy models. Erharter et. al. [5] for example, shows how one can combine different software to make such models for a large linear project. In his work a combination of MOVE, Rhino/Grasshopper and BricsCAD BIM is used.

One challenge when going from factual data models to interpretation models is communication of uncertainty. With borehole data gathered in 1D or 2D, and models illustrated in 3D, one must perform e.g. linear interpolation or use geostatistical methods such as kriging to model the full 3D geometry. This yields a 3D model where the modelled geometry in between the data points is, at best, inaccurate. This fact is often obvious to the geotechnical engineer but may not be so for the client, contractor or other designers using the geotechnical model as baseline for further design, such as mass balance calculations. NGI have used colour-coding, as shown in figure 4to communicate uncertainty in 3D geometry. Here, det colour in the 3D-model gets lighter with the increasing distance from the borehole.

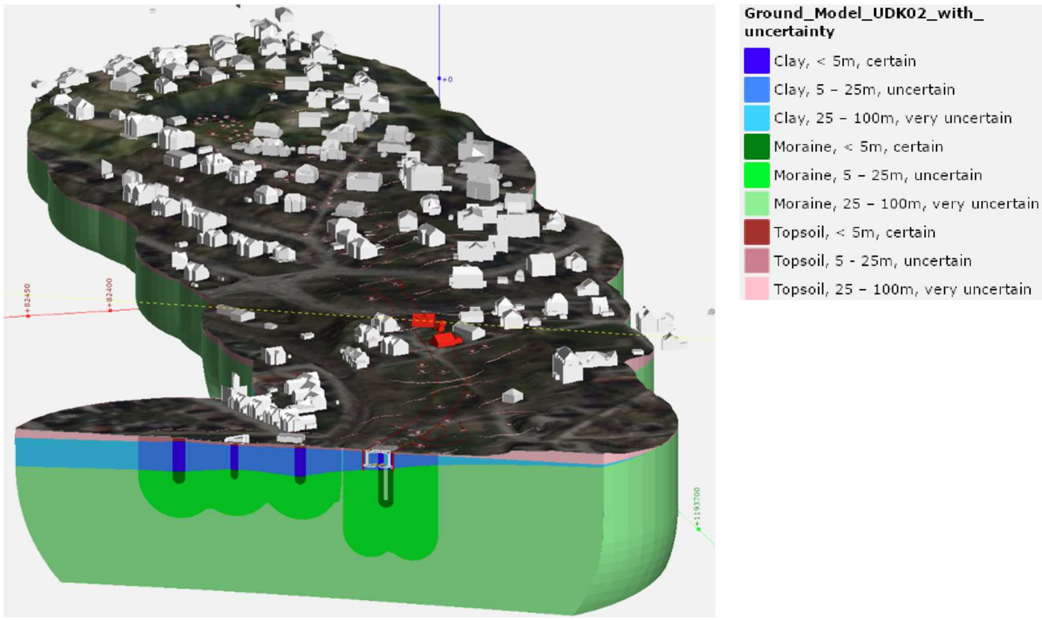

Figure 4 Communication of uncertainty [4]

When it comes to the geo-structures, there has been a shift over the last couple of years. Traditionally, the 3D modelling was a highly manual and time-consuming process. However, with the use of parametric modelling techniques in software like Rhino/Grasshopper and Revit/Dynamo, things have changed a lot. Parametric programming involves creating complex geometric models using variables and mathematical rules, allowing the model to be easily adjusted and modified by changing parameter values.

Development of the parametric programming scripts will (likely) take some time for the first model. This will normally give a larger time use for the first model. But as there is need for the first revision of the model, the code can be re-used and the designer will save time for each new revision. The scripts are also re-usable for other projects and will therefore definitely be time- and cost-cutting over time.

This has also drastically changed the timing of delivery for the geo-structure models. While most of the models earlier were created and delivered at the end of the design phase, to avoid re-making every time there was a change, the models are now created as early as possible in the project. This enables communication of the approximate presence, location and size of geo-structures to the other disciplines in the interdisciplinary model. This will also give an early assessment of the quantities from the geo-structures, and hence also the cost.

The I in BIM - information

The property set in the BIM model always contains a value for MMI (model maturity index) or LOD (level of development), which gives a pre-defined value on how developed the model is. And as the model evolves with the project, the MMI or LOD changes with it, from for example “early phase” to “ready for construction” and at the end “as built”. A typical example on the different levels given for the MMI is established in the Norwegian “MMI guide” [20], which is a collaboration between several large governmental organizations and organizations for engineers, architects and contractors to establish a unique system for MMI in Norwegian construction projects.

When to comes to the information given in the BIM models, there is one large challenge: standardization. Very often the property sets are customized and unique for each project, which is challenging when it comes to data sharing and project lifecycle management.

On reason for this, is a limitation in the data schema for the IFC-format. The current version, IFC 4.3 given in ISO 16739-1:2024 [6], does not contain data sets for geo-elements. Hopefully this will be included in future IFC 4.4-version, which will be an important step forward when it comes to BIM-models within geotechnics.

At the same time, do we have to have everything the same at each project? As geotechnical engineers, when making drawings or models for the contractor, we have a lot of requirements and demands when it comes to the execution of the work. This is very often linked to standards but can also be project specific demands that are annotated on the various drawings. This is for example typical rules when it comes to sequence of work, execution of work, temporary solutions etc. This information is essential during execution, but not so after the construction is completed. We often also want to limit the amount of information in the models the contractor is using as basis for the construction, to prevent an information overload and that the important information disappears.

On the other hand, what is important to have after completion is a good documentation of what was actually installed in the ground and the location and properties of this. The as-built must be in a "language" that everybody can understand, meaning that we must make understandable and precise as-built models that can be understand and used by everybody in the future.

This difference in the needs when it comes to the information in the models, makes it highly relevant to think of different data sets should be used in different stages off the project. This challenge may be one of the reasons why BIM models in many projects not are used in the actual construction phase.

4. AI – ARTIFICAL INTELLIGENCE

Artificial intelligence (AI) is a current buzzword within both daily life and digitalization. For many, the term AI is linked to either ChatGPT or similar large language model (LLM), or to the stories about deep fakes in the news. But AI is a lot more than that. The Norwegian Consulting Engineers Association (RIF) divides AI into four different categories [7] which are "recognisable for engineers":

- Data analysis
- Generative AI
- Generative design
- Digital twin and sensor data

Data analysis

Data analysis is classic recognition of the content of an object, where you have an input and the AI helps understanding this input. This can also be called machine learning (ML) or supervised machine learning. Relating this to geotechnical engineers, this can for example be interpretation of site investigation, correlations based on different types of site investigation etc.

Data analysis through machine learning is probably what we have seen most examples of when it comes to AI within geo-engineering. As shown in figure 3, ML is evaluated to be over the highest hype, but the full potential is so far not reached.

The maybe most used application for ML in geotechnics has been using it for interpretation of soundings. Kydland et. al. [12] showed how they used ML for automizing the interpretation of stratification in soil based on the results from Norwegian total soundings. The work is done based on approximately 170.000 soundings executed all over Norway, where the algorithm has been trained on data from CPTUs, soil samples and drilling logs. Through APIs (application programming interface), the interpretation is used in software for either calculations or modelling of the ground conditions.

EMerald Geomodelling is a company using ML to get the best out of a combination of airborne resistivity measurements and site investigations. In one of their projects [13] they have combined the results from helicopter based electromagnetic survey, with existing geotechnical site investigations. Combining these two, they get a 3D-model with a given probability of quick clay, shown in bottom left in figure 5. Based on this they can also extract the volumes having the largest probability for quick clay, bottom right in the same figure.

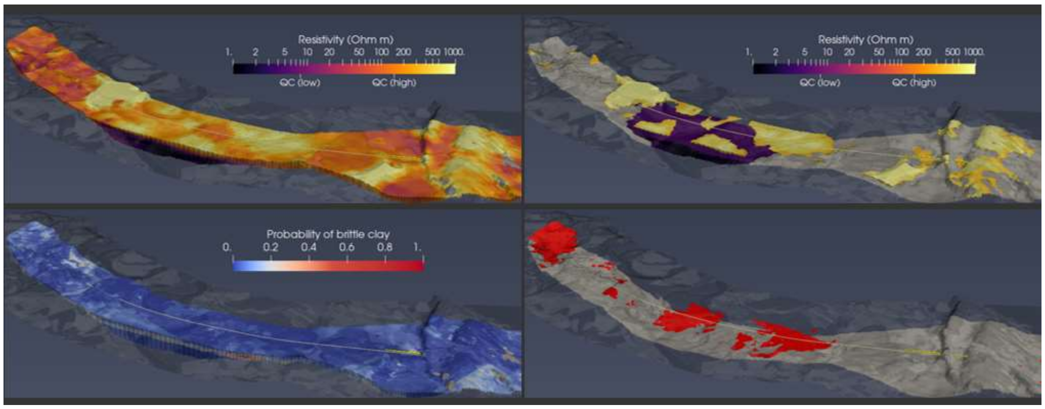

Figure 5 Bedrock and probability for quick clay, from [13].

Ten noorden van de Waddeneilanden Wind farm Zone is a project covering roughly 120 km^2 in the sea north of the Netherlands [14]. Site investigations included CPTs and sampling in 106 locations and almost 200 seismic lines. Combining these data, NGI together with Sand Geophysics used ML to predicted synthetic CPT data across the full 3D of the area. This provides the designer a possibility to obtain the parameters needed for the wind turbine foundation design at any location, making it possible for optimized design for the entire area.

Generative AI

This category includes e.g. LLMs and the automatic generation of pictures and videos. A perhaps underrated feature, which is highly relevant for geotechnical engineers, is that the generative AI also can help generating code, which again can be used in for example ML or handling of large data sets.

Going back to figure 3, Erharter has places the LLMs at the peak of the inflated expectations. Which means the hype is at the top, but we are still far from taking out the full potential of the technology.

An example on the use of these LLMs is the worked recently shown on LinkedIn by Henning Frodahl Firman [18]. Here, he developed a web application that incorporated a standalone GPT that is used in the process of searching for certain types of reports (in this case Factual geotechnical report) in a folder system. The application finds the reports, while ChatGPT helps the user in structuring the information found by the application.

Generative design

Generative design is a design optimization, for most maybe know through software like Autodesk Forma (earlier Spacemaker) [8] or Infraspace [9]. The key here is also that the machine learns from the design, which differs it from a parametric design. This is so far not much used within geotechnics, but there is a clear potential here when it comes to design optimization and material optimization.

Digital twin and sensor data

The last one is digital twins and sensor data. Or as some calls it, the modern and digital observational method. The exact definition of a digital twin is somewhat up for discussion, depending on if there is a two-way real-time data integration or not. Fuller et. al. [10], se figure 6, differs between a digital mode, a digital shadow and a digital twin based on how the data flows between the physical and digital object. Another definition is made by DNV GL, given in figure 7 [11], where one operates with different levels. With reference to figure 6 one can say that level 0 is BIM, level 1 and 2 are a digital shadow, and level 3, 4 and 5 are a digital twin.

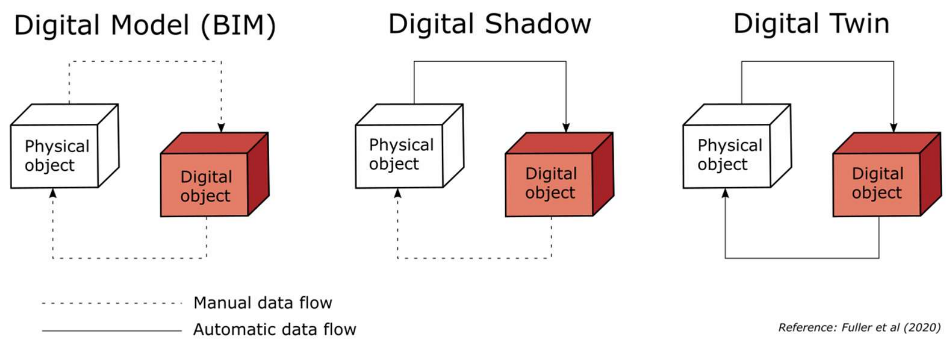

Figure 6 From BIM to Digital twin, after [10]

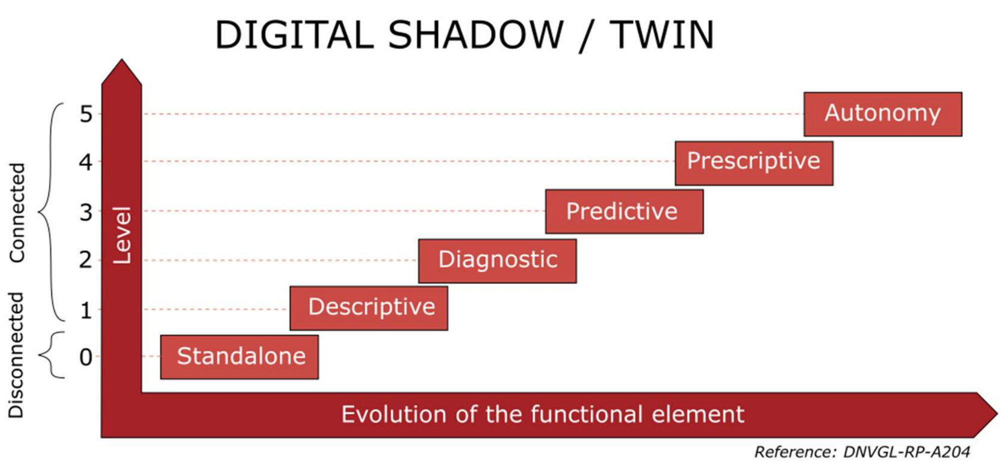

Figure 7 Levels of digital twin, after [11]

Piciullo et al. [19] shows how one can combine real-time hydrological monitoring, public metrological data and automated numerical modelling for a live prediction of the safety factor for a natural slope. In the foot of the slope there is a double track railroad, and the real time safety factor of the slope is there important during heavy rain. This case is a good example of a descriptive digital twin, according to the different levels given in figure 7.

Digital twins and sensor data has an unleashed potential when it comes to the use in geo-engineering. This is the technologic observational method and will have a large impact on geotechnical design an execution in the future. Even though there has been a lot of talk about it, it is still somewhat surprising that this have not had a larger impact on the geotechnical projects already. That might also be the reason why Erharter in figure 3 have placed digital twins in the “trough of disillusionment”. We are well over the over hyped phase where everybody talked about digital twins, but we have not managed to take out the potential in the technology.

5. DATA MANAGEMENT

Historic data management

As geotechnical engineers, we have been used to combine data and result from several different sources in our projects. As an example from NGI, 10 years back, the result from site investigation were stored in one proprietary software and the interpretation of the soundings in another one (or in an Excel spreadsheet). The data from the lab was in several PDF and/or Excel files, while monitoring data was in both a software and in excel spreadsheets. If one had some field observations, this was stored in an Excel or Word file, hopefully in the same folder as the pictures taken in field.

Using data from these different sources kind of worked while working with the project. But going back and find details in these bad data structures years or decades after can be a nightmare. This limits in many cases the potential to reuse this data, which is not only economically poor, but a lot of this data could also had been used for development within geotechnics. As an example, for decades different correlations within geotechnical engineering are developed, correlations that could have been improved and further developed if one had access to all data located on the servers in the industry.

Going back to figure 3, data management is not rated as a technology itself. But data management is basis for many of these technologies, and the quality of the data is essential for many of them. For some of these technologies it is also reasonable to say that the time between the “peak of inflated expectation” and the “plateau of productivity” is longer than it could be, since the data quality and the structure of data is limiting the development. Going back to the two previous examples in this article: what limits the development on BIM is the data set in the BIM models, and what AI is 100% dependent on is the data set that AI either should be trained on or should help the user understand.

Improved data management

To have better management of all the data NGI produces through our own field department, 3 soil and rock labs and 2 instrumentation sections, an internal work started 5-6 years ago to investigate alternative solutions. This work concluded that relaying purely on external software would not solve the demands NGI had set for its data management. This was both because we did not get a good enough structure and system on the data, but also that we did not get the interface to the data that we wanted. We also did not want to rely only on large international companies where we would be bound to both their strategic choices and their licenses. A strategic decision was therefore made that we would start developing our own software for many of the core data producers at NGI, in addition to keep using some off-the-shelf software. This has resulted in numerous cloud-based applications in what is called NGI’s GeoHub, see figure 8.

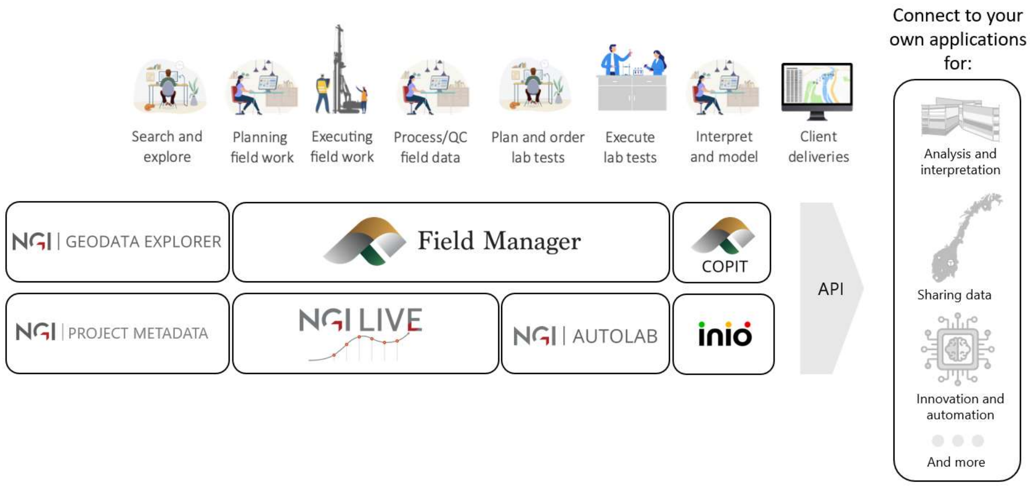

Figure 8 Overview of the NGI Geo Hub

In the following, some of the main part of the Geo Hub will be shortly explained.

Field Manager [15] is a web-based tool with API connectivity for the entire value chain for geotechnical site investigations. The tools improve the collaboration between field operators, engineers, clients and other stakeholders, where everybody can access the progress of the campaign and the status and results of each borehole. The data is assessed and approved by the engineers, ensuring a high data quality. Field Manager is the first ever software developed by NGI which is also open for sale as a SaaS (Software as a Service), and so far, more than 1000 unique users are registered.

AutoLab is developed to process data from advanced tests performed in the rock and soil lab. The software improves processing of lab data from start to end, enhancing the overall delivery and storing the data in a structured way. This has been a large step forward, digitalizing the workflow for all advanced lab tests.

NGI Live is an online monitoring service for field sensor measurements. It has a project specific dashboard from Grafana, further enhanced at NGI with a map plugin and alerting system. The system is so far used on 35 different NGI projects, containing app. 13600 sensors and 78 different sensor types. NGI Live has not only improved to storage of sensor data, but it has also improved how we present our monitoring data to the client and given us a whole new flexibility in the user-interface.

COPIT is NGIs internally developed CPTU interpretation software. The software seamlessly connected to both Field Manager and AutoLab through APIs, which makes it easy to import the data one need for the interpretation. The software makes it possible for the user to do manual interpretation of the CPTUs or use correlations such as e.g. Karlsrud et. al [16] or Paniagua et al [17].

The possibilities through APIs and the use of these are essential for all the software in the Geo-Hub family. We geotechnical engineers have always dealt with and worked with correlations, and having easy access entry point into these databases will give us unique opportunities to further develop and create new such correlations. Additionally, as we increasingly build in densely populated areas, being able to easily share data about ground conditions and existing underground structures between these projects is crucial for reducing costs related to ground investigations and creating predictability regarding what is already underground for new projects. Perhaps underground structures, whose location and properties are well documented, can also be reused in new projects on adjacent plots.

6. CONCLUSION

This paper has, with the basis of Gartner's hype cycle, presented two different technologies which the geotechnical engineers have adopted in recent years, and which they will meet more and more in the future. The paper also presents the importance of good data management, which is a key for further technology development.

Even though the focus in this paper has been mainly on Norway and partly on the Nordics, it has also come clear that there are endless number of initiatives and development going on worldwide. A key for these initiatives and developments seems to be two aspects: geo-engineers with large digital curiosity and support from management/upper management.

To increase the digital curiosity amongst geo-engineers, it is important to help them develop especially one important tool: coding. This is a key for developing skills that is needed for much of the digital development which is presented earlier. It is also a key in optimizing other part of a geo-engineer's daily work. There is a lot of possibilities on optimizing and improve simple and potentially repetitive working processes with coding and programming.

Support from management and upper management is, as mentioned, the other key. Almost every company these days has digitalization as part of their strategy, but not all companies manage to put word into action. The funding for digital development might sometimes be reduced because of securing enough revenue for the company, but in these cases the digital development will probably also stop, or the initiator will in worst case find something else to do. To make sure that these initiatives manage to grow, management/upper management must be both supportive and have funding for the initiatives.

At the same time, one should not throw away money on every digitalization initiative within the company. And assessment of the initiatives and the value of these is needed. Which takes us back to Gartner's hype cycle. The hype cycle can as mentioned be a good tool to assess the engineering or business maturity of the initiative, and help decided if this is the right time to invest in development or not.

ACKNOWLEDGEMENT

First of all, a thank you to NGM 2024 for asking me to present a keynote and write this paper. It has given me a perfect opportunity to dive into some more details within digitalization, that have been on my mind for a while.

Also, a big thank you to several of my good colleagues for useful input and discussions around the paper, especially Georg Erharter and Mats Kahlström. You have been of great help.

Finally, I want to thank Andi Pfaffhuber and Craig Christensen in Emerald Geomodelling, Niklas Engebretsen in Cowi AS and Henning Frodahl Firmann in Norconsult AS for sharing some experiences and content that I can use in both the paper and presentation.

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