Cloud Cost City: A Visualization of Cloud Costs using the City Metaphor

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Abstract: Many companies are in the process of migrating their entire IT infrastructure into the cloud in order to benefit from its high elasticity and scalability. While cloud providers offer basic cost visualizations such as line, bar or pie charts, companies lose track of which part of their infrastructure causes which costs. We adapt the city metaphor to visualize both the architecture and the costs. We offer a flexible framework to structure and tailor the visualization as desired. Using the Goal-Question-Metric approach, we identify cost savings potential and demonstrate for an example cloud infrastructure that the defined metrics are easier to grasp in our visualization compared to a standard cost dashboard.

1 INTRODUCTION

In the cloud, operational servers, databases, and middleware components are just a mouse click away. Compared to conventional IT infrastructure, cloud infrastructure offers better scalability and elasticity than conventional IT infrastructure and greatly reduces fixed costs and the need to plan ahead. The commercial success of cloud solutions is testament to their economic potential. However, the flexibility of the cloud infrastructure also increases the risk of losing track: which instances are actually running in the cluster? Which of them are still needed? Most companies only check at the end of the month whether the accumulated costs are more or less reasonable, but rarely overlook their infrastructure and the costs in detail.

Cloud providers offer cost dashboards that show a summary of costs and, e.g., cost increases compared to the previous month. These dashboards use simple two-dimensional graphs such as line, bar and pie charts to visualize costs. They also provide simple grouping and filtering options. But all of them only visualize the costs without connecting them to the infrastructure architecture.

This paper presents Cloud Cost City (CCC), a flexible framework to import, structure, and visualize a cloud infrastructure and its costs using the city metaphor. CCC allows to understand both the costs and the complete cloud landscape. We argue that the city metaphor that is already used for visualizing large software systems (Fittkau et al., 2013; Steinbrückner and Lewerentz, 2010; Wettel and Lanza, 2007) can be adapted to also visualize large cloud landscapes in an understandable way, i.e., to visualize both costs and infrastructure. To make this helpful for cloud cost reduction approaches known from literature, we use the Goal Question Metric method to derive metrics that are relevant for identifying savings potential. Compared to the cloud providers' cost dashboards, the features of our visualization are more useful. To our knowledge we are the first to provide a 3D visualization of both the cloud infrastructure and its costs.

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2 RELATED WORK

2.1 Cost Dashboards

Most cloud providers offer similar cost dashboards.

The **Cost Summary of Google Cloud Platform (GCP)** (Google Inc., 2020) displays costs and trends with tables, (stacked) line, and bar charts. They provide basic slice-and-dice operations to group and to drill down on the data w.r.t. team, service type, and environment. The x-axis of all cost charts is the time range, with selectable aggregation (month or week) and cannot be configured. Costs can be filtered both

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with predefined filters (such as the last 7 days) and with custom filters. It is possible to select one grouping dimension and an arbitrary number of filters.

Microsoft's Azure Cost Analysis (Anderson, 2020) uses the same straightforward lines and bars to visualize costs. In addition, there are pie charts for an accumulated view over a selected time range. While filtering is not restricted, grouping is again only possible for one dimension.

The **Cost Explorer of Amazon Web Service (AWS)** (Amazon Web Services Inc., 2020) shows similar visualization and exploration capabilities.

All these cost dashboards are mere 2D diagrams and do not offer any possibility to visualize the infrastructure architecture together with the costs. Our 3D visualization allows to explore and analyze both.

Since the dashboards are so similar Sec. 5 only uses GCP for a detailed comparison to our prototype on an example cost analyzing project.

2.2 Cloud Architecture Visualizations

There are several commercially available tools to visualize the cloud infrastructure. Compared to them, our prototype is not yet as closely integrated into the commercial cloud platforms. None of the tools we know of can display costs. They also lack options to customize the visualization while we provide flexible filtering and grouping options. While some tools provide a 2D visualization(Cloudviz Solutions SIA, 2020; Lucid Software Inc., 2020), isometric 3D representations are also common(Arcentry Inc., 2020; Cloudcraft Inc., 2020; UMAknow Solutions Inc., 2020) and closer related to our work.

2.3 Colored TreeMaps and Map-like Visualizations

To our knowledge there is no work in the broad field of TreeMaps (Schulz et al., 2010) and map-like visualizations (Hogräfer et al., 2020) that focuses explicitly on the visualization of cloud infrastructure and its costs. Nevertheless, colored TreeMaps might be useful to visualize cloud infrastructure. E.g., each cloud resource can be represented by a rectangle and grouped by a defined hierarchy. The area, color and - in case of 3D TreeMaps - also the height of the rectangles can visualize additional information such as costs or usage.

Other visualizations that use the city metaphor (e.g., source code visualizations (Wettel and Lanza, 2007)) are referred to as 3D TreeMap visualizations (Schulz et al., 2010). As we also use the city metaphor in the Cloud Cost City, our approach belongs in this category as well.

2.4 Reducing Cloud Costs

There is a body of literature on the reduction of cloud costs. (Beloglazov et al., 2012; Beloglazov and Buyya, 2010) and (Berl et al., 2010) achieve an energy-aware resource allocation, (Li et al., 2012; Shastri and Irwin, 2018) and (Zohar et al., 2011) reduce cloud costs by means of resource prediction. (Fang et al., 2013) and (Vieira et al., 2014) optimize the utilization of resource units, i.e., the cost-benefit ratio.

These cost reduction techniques are orthogonal to our work as they can be applied after our visualization has been used to identify the main savings potentials.

3 IDENTIFY SAVINGS POTENTIAL

For the primary goal to *identify savings potential in the cloud infrastructure costs from the point of view of operations*, we examine relevant questions and necessary metrics (according to an adapted Goal Question Metric (GQM) approach (Caldiera and Rombach, 1994)). Note that the literature on cloud cost reduction uses similar questions and metrics.

Sec. 4 later shows how we present the metrics in a Cloud Cost City. Sec. 5 shows that it is much more trouble to find the answers with a cloud provider's typical cost dashboard.

3.1 Which Resource Units Cost the Most?

The most expensive resources are apparently also those with the most potential for savings. Since in general, several projects are provisioned in one cloud infrastructure, it is not enough to know which resource unit is most expensive, rather it must also be determined to which project it belongs. Literature on cloud cost analysis and reduction also suggest to identify the project that is using the infrastructure (Kondo et al., 2009; Nanath and Pillai, 2013).

To answer this question, the metrics *M1: total cost of each resource unit by project* is required. This metrics needs a two-fold grouping, first by project and then by resource unit.

While it is reasonable to sort the resource units w.r.t. their costs, sorting the projects w.r.t. the total cost of all their resource units may or may not be reasonable. A large productive project obviously often has higher costs than a small development project with more savings potential. Hence, each of the grouping levels may benefit from a different sorting.

3.2 Which Resource Units Are Provisioned in Expensive Regions?

Depending on the region a resource is provided in, the prices differ. At the end of 2020, a specific virtual CPU located in Europe costs $20.81 per month, while the same resource unit located in the USA is cheaper ($16.15). Other research also highlights cost differences between regions (Martens et al., 2012; Shastri and Irwin, 2018). To optimize costs based on the region, we must therefore measure which project uses resources in which region. Since the regional prices also vary depending on the type of resource, e.g., virtual machines are more expensive than SSD storage, a breakdown by resource type can also help identify the highest savings potential.

This results in the necessity of the metrics *M2: total costs of each resource unit per project per/within a region*, that needs a multi grouping on region (first), project, and resource type (last).

For the *region* level of the grouping hierarchy it again is obvious that for finding cost savings potential, it is more relevant to sort according to where resources are cheap than to where the IT infrastructure actually spends the money.

3.3 Which Projects Use Too Expensive Resources for Their Use Case?

For each resource unit providers usually offer different flavors that vary w.r.t. their specifications, e.g, regarding speed or storage capacity. The premium versions are more expensive than the basics. When a project shows a low usage of an expensive resource this often indicates a savings potential.

This leads to the metrics *M3: ratio of cost and usage of each resource unit per project*. Other research on cloud cost reduction also uses the utilization of cloud components (Fang et al., 2013; Li et al., 2012; Vieira et al., 2014; Zohar et al., 2011).

Again, instead of sorting w.r.t. where the money is spent, it may be better to sort according to the price tags (premium vs. basic) of resource units, i.e., the savings potentials.

4 CLOUD COST CITY

Let us describe how we apply the city metaphor, known from visualizing software systems, and turn it into a Cloud Cost City that eases answering the above questions on cost saving potentials.

4.1 3D Visualization

The result of the GQM approach leads to the following design requirements in order to provide all metrics in one visualization: multi grouping, display of costs and display of usage. The cloud providers' cost dashboards use 2D stacked bar charts, that are not sufficient to meet the design requirements. Even if we assume that the x-axis of these charts can be arbitrarily chosen, it is impossible with the three degrees of freedom (x-, y-axis and color) to group by ≥ 2 properties as well as to show cost and usage at once. Therefore, in contrast to our approach, several views are necessary to obtain the metrics.

As we already explained in Sec. 2.3, the Cloud Cost City can be seen as a 3D TreeMap visualization. We decided to use a 3D representation to (a) counteract the problem that the flat layout makes it more difficult to truly understand the hierarchical structure (Bladh et al., 2004; Long et al., 2017) and (b) support the understanding by using a well-researched visualization metaphor (Averbukh et al., 2007; Duit, 1991).

In our example analysis, we could not observe the known weaknesses of 3D visualizations, namely occlusion and the difficulty of performing actions (Teyseyre and Campo, 2008), probably because our prototype relies on familiar navigation principles from PC games.

4.2 City Metaphor

The familiar city metaphor is widely used to visualize and to help in grasping a complex software systems. Traditionally it is used for code written in object-orientated languages and represents classes as buildings. As classes belong to (sub-)packages, buildings are placed into districts that represent the corresponding package. Districts can be nested just like packages. Metrics are incorporated into the visualization by mapping them to the heights, widths, and depths of the buildings to provide further information about them. For instance, the metrics *lines of code* can be mapped to the height of a building.

To apply the well-researched city metaphor to visualize cloud costs instead of software, we use a different mapping to city artefacts. Buildings no longer represent classes, but resource units (or aggregated bundles thereof). Instead of source code related metrics, we map cost metrics to building properties like height, width and depth, see Sec. 4.3. Districts no longer reflect (sub-)package relations, but visualize hierarchically structured aspects of the resource units, e.g., the region of the world in which a resource unit is actually running, see Sec. 4.4. A third major difference to traditional Software Cities is the layouting of city artefacts. While traditionally a TreeMap layout is used, Sec. 4.5 shows how we give the possibility to also use a sorted grid layout to order buildings and/or districts so that the best cost savings potential is placed upfront.

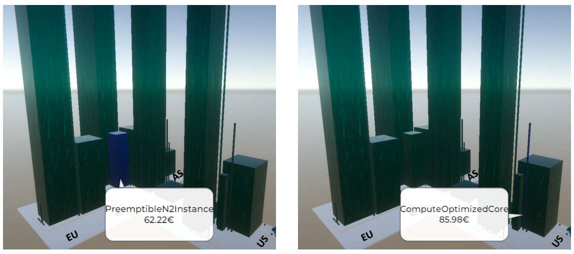
4.3 City Properties

As has been discussed in Sec. 3, to identify potential for cloud cost savings, one needs to know both the costs per resource unit (metrics M1 and M2) and the cost-usage ratio per unit (M3).

Hence, the Cloud Cost City maps the cost of a resource unit to the height of its building. The tallest buildings are easy to spot and point out the most costly resource units. If several resource units are grouped/bundled together in a building, its height reflects the aggregated costs.

The Cloud Cost City does not directly map the cost-usage *ratio* to a property of a building. Instead, it maps the usage of a resource unit (bundle) to the area of its building. This allows users to easily spot anomalies/bad cost-usage ratios, because they show up as tall buildings with a tiny area.

Fig. 1 shows the Cloud Cost City visualization of a real cloud infrastructure. It is easy to spot the tall buildings of costly resource units (metrics M1 and M2). The blue cubic building in Fig.1(a) has a more reasonable cost-usage ratio (M3) than the thin needle-style building in Fig. 1(b).



(a) Blue resource unit with a good cost-usage-ratio.

(b) Blue resource unit with a bad cost-usage-ratio.

Figure 1: Cloud Cost City visualization of an example IT infrastructure. Cost of resource units grouped by region and within a region by project.

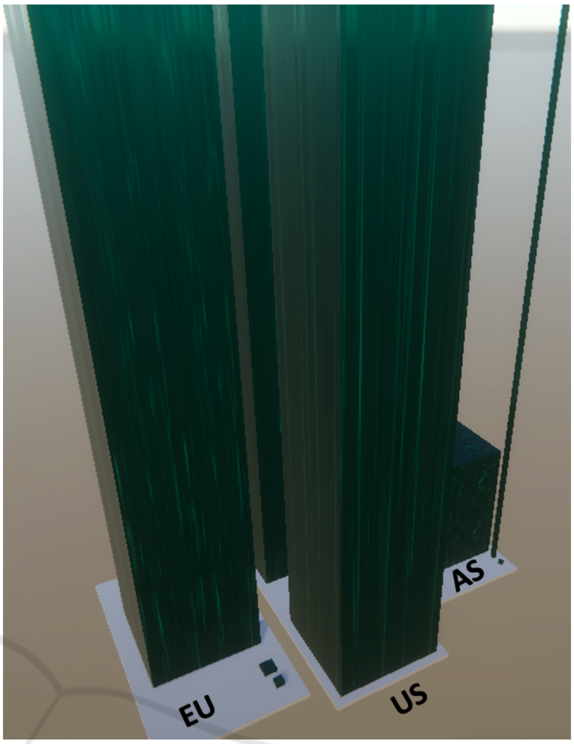


Figure 2: Cloud Cost City visualization of the example from Fig. 1 with project costs aggregated across all resource types.

4.4 Custom Hierarchies and Aggregates

All the metrics from Sec. 3 needed a grouping either by different features or a different number of features. Both metrics M1 and M3 need a first-level grouping by project, i.e., for each resource type (second level) the costs are accumulated across all regions. Metrics M2 uses a grouping according to $region \rightarrow project \rightarrow resourceType$. Some cloud infrastructures have other additional custom features, e.g., resource units can belong to different *environments* like production, integration, or development.

CCC uses nested districts to represent grouping. For full flexibility, in the Cloud Cost City the user can pick an arbitrary ordered set of n such features, including custom ones. The CCC maps the n selected features to a hierarchy of districts. The costs of all resource units that have the same values in the n selected features are bundled/aggregated in a single building, regardless of their other features.

For grouping, Fig. 1 uses the feature hierarchy $region \rightarrow project \rightarrow resourceType$. All buildings in the district on the right belong to the same region *US*. A bit hard to see are the orange lines on the ground that embrace projects. Fig. 2 uses a more shallow hierarchy and a coarser granularity $region \rightarrow project$.

The nested project districts of Fig. 1 vanish, buildings no longer represent resource units, but aggregate costs per project across all resource units.

4.5 Custom Sorted Layout

For each of the levels of a grouping hierarchy per default CCC orders the components according to their total costs, i.e., buildings line up in a district according to their heights; neighboring districts are ordered with respect to the sum of the cost of their subdistricts or buildings. As we already have discussed in Sec. 3, this sorting order may or may not help in identifying the highest savings potential.

For instance, recall that prices vary between regions. Sorting the buildings w.r.t. the price niveau makes it easier to see that projects or resources should be shifted to cheaper regions, than with the default order that tells the user where the money is spent.

Consider Figs. 1 and 2 again. The former uses the default ordering for the regions. The latter uses the ordering w.r.t. the price niveau and makes it a lot easier to see that it may be a good idea to shift the costly resources that currently are running in Europe to the US or even to Asia.

To open up this flexibility to the user, the CCC allows to specify a custom sorting order per dimension of the hierarchy. The example uses $EU \succ US \succ AS$ for the regions in metrics M2. For specifying an order, users can also use wildcards instead of a concrete feature values like *AS*.

5 EXAMPLE ANALYSIS

This section reports on a cost saving project for a real cloud infrastructure that hosts 10 productive projects that operate autonomously. The projects are of varying sizes and have different infrastructure requirements. In addition, the cloud platform is used for 4 test projects that are started up and shut down within hours or days and therefore cause low costs. The total fee in April 2020 was 5.473€.

To gauge the advantages of CCC, we performed the cost analysis both with the dashboard of the Google Cloud Platform (GCP), as a representative of the state-of-the-art, and with our CCC visualization.

5.1 Which Resource Units Cost the Most?

GCP. Out of the box, the dashboard shows costs per resource type, but only aggregated over all projects. Finding the costly resources for each project requires several manual steps because of two reasons: (a) the x-dimensions of the dashboard's line or bar charts always is the time, either on a daily or monthly basis, and (b) there are no multi grouping options in GCP. The manual steps are:

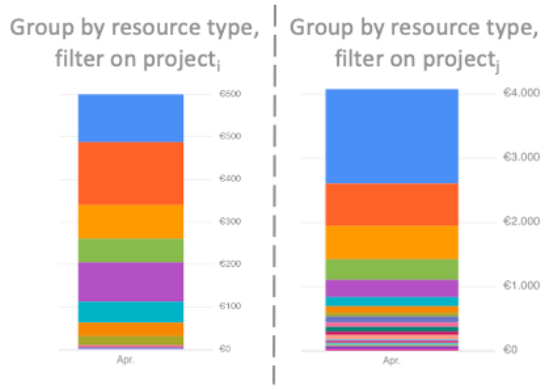


Figure 3: GCP view for 2 projects: a stacked bar chart shows the costs per resource type (different color per type).

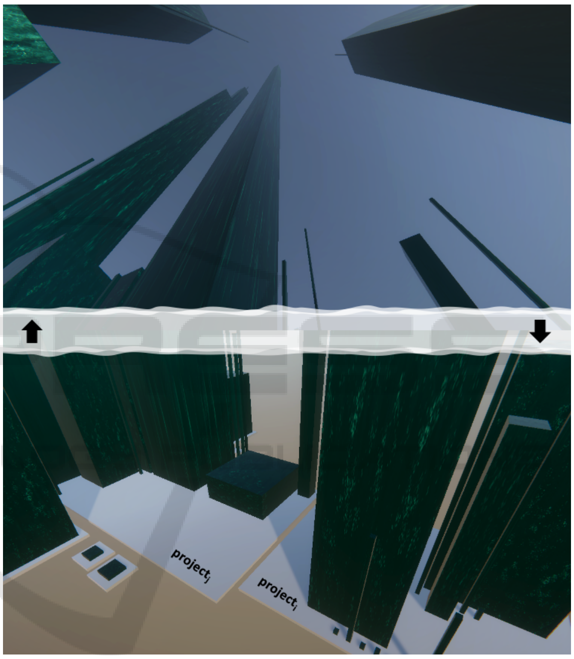


Figure 4: Cloud Cost City viewed from 2 angles; custom grouping $project \rightarrow resourceType$. Top: Look up to easily spot tallest towers. Bottom: Look down to identify the projects to which the tall towers belong.

1. Group the costs by resource type.
2. For each of the 10 projects do:
   (a) Filter/select the cost data of that project.
   (b) Identify the most expensive resource units (the largest areas in the stacked bar chart) and note them and their costs.

3. Determine the most expensive resource units among all projects.

This process is tedious and time consuming. Neither are the resulting 10 charts (examples in Fig. 3) displayed side-by-side in the cost dashboard, nor do they use the same scaling of the cost-axis. There is no support to find the most expensive resource types across the projects. Hence, due to the multiple manual steps and the necessity to note and compare the costs across projects, the metrics needed to answer this question is not easy to obtain.

CCC. The only thing that needs to be done is to specify the custom hierarchy $project \rightarrow resourceType$. Then CCC automatically maps the costs of the resource units to the heights of the buildings and groups them in a district per project. There is no need for a custom sorting. Fig. 4 shows the visualization from two angles. When the user looks up, it is easy to spot the tallest towers, see Fig. 4(top). A click on a buildings reveals its actual cost value. Going down on a tall tower to the floor reveals the district/project as shown in Fig. 4(bottom).

While GCP requires a filtering step per project, CCC shows all projects in one view and with a common scaling. Both the number and cost of resource types across projects can be grasped at once and with less manual work than in the GCP dashboard.

5.2 Which Resource Units Are Provisioned in Expensive Regions?

GCP. To retrieve this metrics also several manual steps are needed due to the same reasons (fixed x-axis and lack of multi grouping).

The manual steps are:

1. Set a filter to extract the data of the region with the highest price niveau and identify the $m (\leq 10)$ projects running in this region.
2. For each of the m projects do:
   (a) Filter/select the cost data to that project.

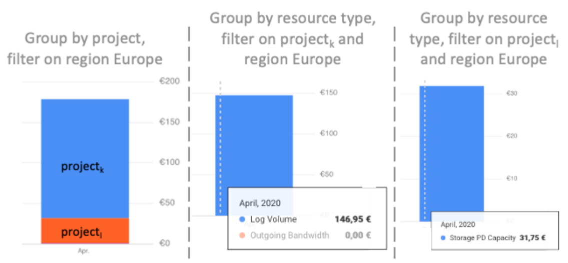
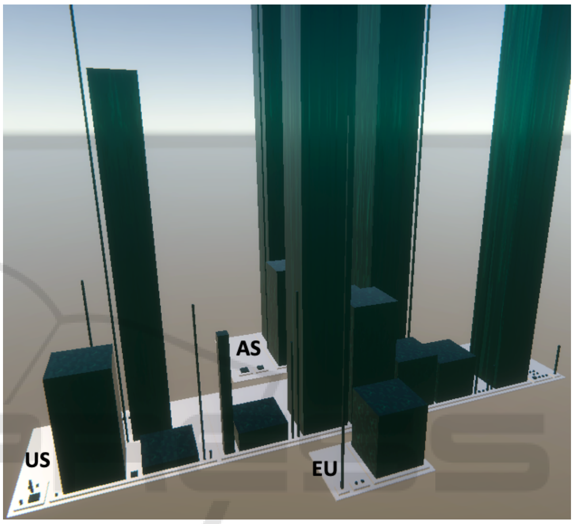


Figure 5: Left: Projects running in the region with the highest price niveau (Europe), different color per project. Middle and right: resource types of two projects from Europe (same color for different resource types).

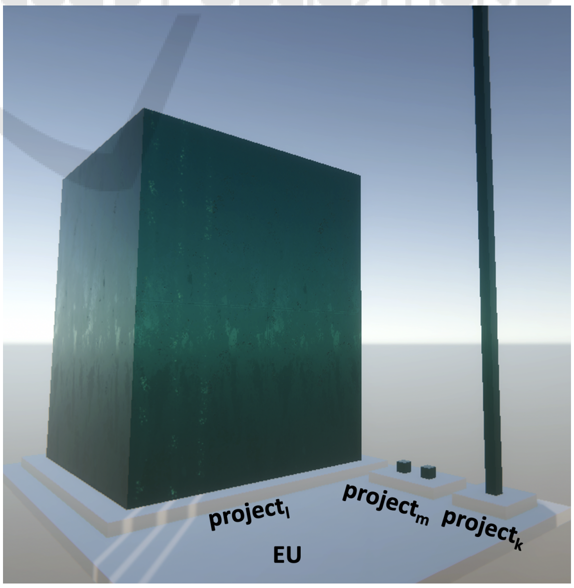
   (b) Group the costs by resource type.
   (c) Identify and note the most expensive resource units (the largest area in the stacked bar chart).
3. Determine the most expensive resource units among all projects.

Note that all steps must be repeated to also apply the analysis to the second most expensive region.

In the example $m = 3$ projects ran in costly Europe, see Fig. 5(left). Only 2 of them have noticeable costs that step 2 of the manual analysis has to look at (manually one after the other). Again the up to



(a) Overview of all regions.



(b) Zoomed-In view into Europe.

Figure 6: Cloud Cost City visualization with custom hierarchy $region \rightarrow project \rightarrow resourceType$ and custom sorting order $EU \succ US \succ AS$ for the $region$ level.

Table 1: Accessibility of metrics in the visualizations.

Metrics	GCP	CCC
M1	(✓) multiple steps required	✓
M2	(✓) multiple steps required	✓
M3	✗	✓

m charts are neither displayed side-by-side nor with the same scale. For project_k, Fig. 5(middle) reveals the costs of its resource *Log Volume*. For project_l, Fig. 5(right) shows the costs of its resource *Storage PD Capacity*. The different scaling between the project charts make it difficult to visually compare absolute costs and to find global maxima.
CCC. Whereas with the GCP dashboard a user needs several steps to retrieve the information, in CCC it is available at a glance.

The following custom hierarchy does the work: $region \rightarrow project \rightarrow resourceType$. This leads to project districts that are nested within region districts. CCC maps the costs of resource types to buildings. In addition, it is beneficial to use the custom sort $EU \succ US \succ AS$ for the first level of the hierarchy. Fig. 6(a) holds the result. The most expensive region comes first. In contrast to what GCP can do, cheaper regions are also visible. Fig. 6(b) zooms into Europe. The three European projects are clearly visible as districts. It is obvious that there is one resource in each of the projects *l* and *k* that causes costs. The heights of the two buildings use a common scale.

5.3 Which Projects Use Too Expensive Resources for Their Use Case?

Recall that there are different versions for each resource type that vary w.r.t. speed or storage capacity. Premium variants are more expensive than the basics. Metrics M3 helps identify bad cost-usage ratios, i.e., low usages of expensive variants.
GCP. Since the dashboard does not show the usage of the resources at all, it is impossible to extract this metrics from the visualization.
CCC. The usage of the resource units corresponds to the area of the buildings in CCC. A building with an extreme shape (needle or sheet) is easy to spot. It indicates a potential misselection of the resource variant, i.e., a bad cost-usage ratio. Some example anomalies can be found in Figs. 4 and 6.

5.4 Summary

Table 1 summarizes the questions to be asked for identifying saving potentials, the metrics needed to answer them, and whether they can be found in GCP and CCC. All in all, it is easier to derive the metrics in a Cloud Cost City visualization than with the GCP dashboard. The main reason are differences in the feature set given in Table 2.

Table 2: Comparison of features.

Feature	GCP	CCC
Single grouping	✓	✓
Multi grouping	✗	✓
Ordering	✗	✓
Filtering	✓	✗, use grouping and navigation instead
Zooming / Navigation	✗	✓
Costs over time	✓	✗

CCC lacks two features of the providers' dashboards. First, there is no way to filter/select parts of the data. But Fig. 6 has shown that since users can multi group and order their buildings and then zoom into the area of the CCC that they need to select.

Second, CCC does not attempt to show the development of cost over time. However, this did not hurt at all in finding potential savings in the current costs. It is in our future work to let the user work with the mouse wheel to roll back and forth in time and watch how the CCC changes over time.

6 CONCLUSION

The Cloud Cost City is a novel visualization that is based on the city metaphor. We have demonstrated the framework's flexibility by using a CCC to identify savings potential in cloud infrastructure costs. The key ideas are that users can provide custom hierarchies to group and aggregate resource costs w.r.t. their projects, regions, types, environments, etc. They can also use custom sorting orders per hierarchy level. By mapping the cost of resources to the heights of their buildings and the usage to their area, cost anomalies become obvious. CCC pairs this with both custom viewing angles in 3D and navigation/zooming to make answering of cost saving questions easier than with traditional dashboards. Furthermore, the CCC provides both, an overview of the infrastructure architecture and its costs.

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