On Spatial Data, Computation, and Public Participation for Regional Multi-Use Trail Design

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Abstract: This paper broadly explores the relationship between spatial data, computation, and public participation in the design process. In particular we evaluate a strategy for computing alignment alternatives for a regional trail network. The computation of trail alignment alternatives is one step in a larger, collaborative process, which relies on the input of professionals, stakeholders, and the public at multiple stages. The role of computing in an early stage of the planning process is generative, and the resulting alignments serve as subjects for more detailed conversations about trail design and development. Multiple alternatives are generated through a geospatial modeling framework based on different weightings of project criteria i. e., values. The resulting maps allow for conversations and feedback about specific material realities in the landscape and the values and goals represented by the modeling framework. We evaluate the Geographic Information Systems (GIS) modeling approach for its ability to overcome shortcomings in data completeness and consistency. The results may inform future strategies for trail corridor planning, especially for multi-jurisdictional projects at the regional scale.

Keywords: Trails, regional design, GIS modelling

1 Introduction

As towns of the American West shift from extractive natural resource-based economies toward tourism-based economies, communities seek new ways to connect residents and visitors to outdoor recreation experiences (LYBECKER 2020). Interest in long-distance cycling tourism has increased in recent years (DEPEW AND SMITH 2020, YOUNES et al. 2023). This trend was recognized by bipartisan legislation introduced in the United States Congress in 2023. The Biking on Long-Distance Trails (BOLT) Act (H.R. 1319/S. 605) directs federal land managers to work together to identify long-distance bike trails which utilize existing roads and trails. The bill indicates the long-distance trails should be greater than 80 miles in length.

The objectives of the BOLT Act are mirrored by other projects which seek to improve trail connectivity, access to recreation amenities, and the economic impact of trail-based tourism. For such design & planning projects, it is appropriate to work at a regional scale (NEUMAN 2000, KEMPENAAR et al. 2018). Trail planning at the regional scale requires strategies, tools, and methods that enable professionals to work with communities and stakeholders across a large geographic area. The Eastern Sierra Towns to Trails plan is a project currently underway which is emblematic of the growing interest in the development of regional trail systems:

> The Eastern Sierra Towns to Trails plan will identify a trail network to connect Eastern Sierra front-country communities to each other and to adjacent public lands throughout the region. The project parallels the Eastern Sierra escarpment from northern Alpine County through Mono County and on into southern Inyo County – a distance of approximately 200 miles. The trail network alignment intends to use existing soft surface roads and trail infrastructure. It will cross multiple jurisdictions and lands managed by multiple entities. (TOWNS TO TRAILS PLAN 2023)

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The Eastern Sierra Towns to Trails Plan is an optimal case study for processes and methods related to long distance trail planning. The framework used for the Towns to Trails Plan draws on principles of geodesign, which entails processes through which professionals, stakeholders, and other participants collaborate in devising and choosing landscape change scenarios using spatial data (STEINITZ 2012, CAMPAGNA 2016). CORONA and CAMPAGNA (2012) have documented geodesign-based approaches to bikeway design using network data models at a municipal scale.

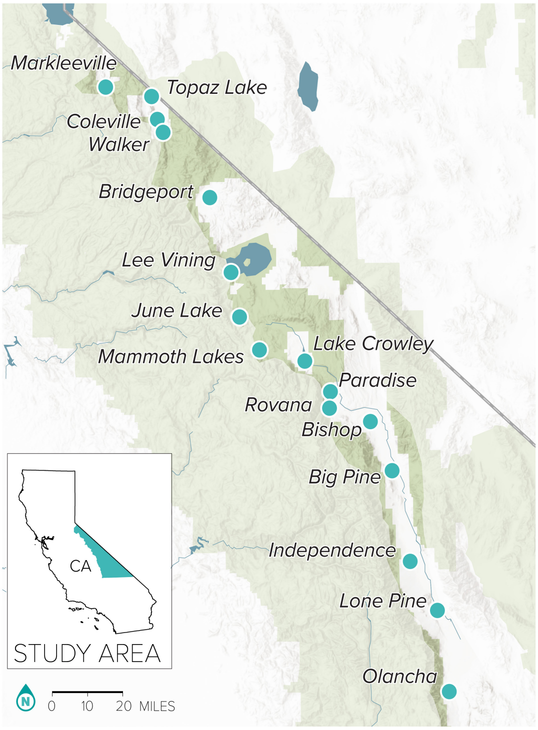

Fig 1:
A map of the study area showing the 16 communities that will be connected by trail. The inset map shows the study area highlighted within the State of California, USA.

2 Data and Methods

A major issue addressed in this study is the incompleteness and inconsistency of spatial data for facilities on public lands. This is especially true for study areas with several jurisdictions and land managers. Available Geographic Information Systems (GIS) datasets for unpaved, backcountry roads and trails are incomplete. Datasets include topology errors, e. g., fragmented geometry disconnected from the larger network. It is the authors' understanding that these datasets do not reflect material reality on the ground. In lieu of digitizing and ground-truthing hundreds of miles of backcountry roads, this study seeks to develop a methodology that accommodates data that is potentially incomplete.

We evaluate a raster-based approach to trail design analysis. A similar approach is discussed by PETRASOVA et al. (2018), albeit for a project at a drastically smaller scale with fewer variables. For our regional scale study, we created raster surfaces for several variables, including existing road and trail infrastructure. We combined them to create multiple cost surfaces and performed Least Cost Path (LCP) Analyses (CHANG 2015). Each cost surface represents a distinct set of project goals, and the resulting paths represent design alternatives. Our objective is to leverage spatial modeling and computation as part of a larger process for trail planning at a regional scale.

2.1 Data Management

The study area covers Alpine County, Mono County, and Inyo County. There are multiple large public land management agencies present, including the US Forest Service (responsible for Inyo National Forest, Humboldt-Toiyabe National Forest, and Federal Wilderness Areas), the Bureau of Land Management, and the Los Angeles Department of Water and Power. In addition to public agencies, the Mammoth Lakes Trails and Public Access Foundation maintains a spatial database of recreational destinations and facilities in the region. Each jurisdiction maintains GIS data with different standards for attribute information. Due to the spatial overlap and incongruent attribute information of the data, the data was evaluated, collated, and merged. We created a new classification system for roads and trails, which accounted for the varying attributes of the source data. The roads and trails were assigned to one of three classes: Tier 1, Tier 2, and Tier 3. Tier 1 segments represent non-motorized trails. Tier 2 segments represent unpaved backcountry roads which are accessible to motorized vehicles. Tier 3 segments represent paved roads.

Fig. 2: Photos illustrating three tiers of existing infrastructure: Tier 1 non-motorized trails (left); Tier 2 unpaved backcountry roads (middle); and Tier 3 paved roadways (right). Left and middle images courtesy of Alta Planning + Design; right image accessed from Google Street View 2022.

2.2 Raster Data & Least Cost Path Analysis

The project team identified seven variables related to project goals for which there was available GIS data. Project goals associated with connectivity, sustainability, and user experience were derived from stakeholder feedback in public meetings. For each variable, described in Table 1, we created a raster surface. Raster surfaces were derived from a USGS Digital Elevation Model (DEM), or from vector data using the "feature to raster" function of ArcGIS Pro. Each raster has a resolution of 10 meters, with a cell value range of 1-10. The existing road & trail network data was converted to a raster image, with values corresponding to the tier of each segment (see Figure 2 & Table 1). The point data for regional recreation amenities was buffered by a distance of 2 miles, then converted to a raster, with areas near amenities assigned a low value (see Table 1). Using the United States Forest Service standard slope classification, we performed a slope analysis on the DEM, and assigned lesser slopes with a low value and greater slopes with a high value (see Table 1). The DEM was also classified into above and below 5,000 ft elevation, with areas of higher elevation given a lower value due to the user comfort associated with elevation-related differences in ambient temperature. Federal and State Highways were buffered by a distance of ¼ mile, which were then converted to a raster; cells within the highway buffer were given a high value while cells outside the buffer were given a low value (see Table 1). A polygon layer of critical habitat areas for the threatened greater sage-grouse was converted to a raster, and habitat areas were assigned a high value while non-habitat areas were given a low value (see Table 1). A polygon layer for federally designated Wilderness Areas was converted to a raster; Wilderness Areas were assigned high values while other areas were given low values (see Table 1).

Table 1: Definition of values for each raster surface used to create cost surfaces. Each raster surface has values between 0-10. Values were assigned based on the variables' impact on trail feasibility and desirability: a positive impact has a low value (low cost) and a variable that has a negative impact has a high value (high cost).

Raster Surface	Description of Raster Values
Existing road & trail network	Tier 1=1; Tier 2=2; Tier 3=6; Outside network=10
Destinations & amenities	Within 1 mile of a recreation site=1; >1 mile=10
Slope (% grade)	Per US Forest Service Trail slope classifications: 0-5%=1; 5-8.33%=3; 8.33-10%=5; 10-12%=7; >12%=10
Elevation (feet above sea level)	Below 5,000ft=10; Above 5,000ft=1
Proximity to highway	Within ¼ mile from US or State Highway = 10; Other = 1
Greater sage-grouse habitat	US Fish and Wildlife Service critical habitat = 10; Other = 1
Federally designated wilderness	US Forest Service Wilderness Area = 10; Other = 1

Using distinct weighting strategies, the raster surfaces representing each variable were combined into four different cost surfaces. Each cost surface represents a distinct set of project values. For example, the "user-focused" cost surface places a higher weight on variables such as proximity to amenities and seperation from highways (see Table 2), while the "treads lightly" cost surface places a higher weight on greater sage-grouse habitat, steep slopes, and areas with no existing roads (see Table 2). Using each pair of towns in the study area, we used a Least Cost Path (LCP) analysis to determine the path between the communities that had the least "cost" for each cost surface. This resulted in four distinct paths in raster format. The output raster paths were vectorized for cartographic display.

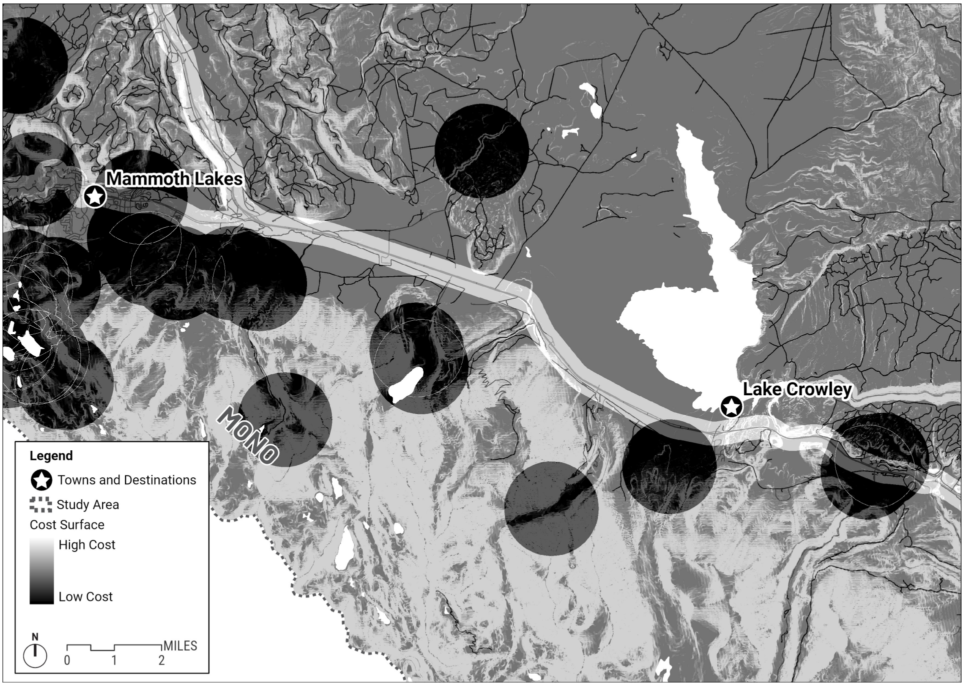

Fig. 3: Map illustrating one of the four raster cost surfaces used to generate Least Cost Path (LCP) alignments. This cost surface represents the "User-focused" model. Darker areas, like those within 1 mile of an amenity, have a lower cost, while lighter areas, like those near a highway, have a higher cost. LCP identifies the least costly path between two points.

Table 2: Weighting strategies for each cost surface: "User-focused" prioritizes amenities and separation from highways; "Quick & Direct" prioritizes the existing network and lesser slopes; "Treads Lightly" prioritizes using existing infrastructure and limiting disturbance to wilderness areas and sensitive habitat; lastly, "Quick & Light" is a compromise between the two previous cost surfaces.

	Weighting of Contributing Variables						
Cost Surface	Existing Network	Recreation Sites	Distance from	Elevation	Slope	Wilderness Area	Sage-grouse
User-Focused	25%	25%	20%	10%	20%	0%	0%
Quick & Direct	75%	0%	0%	0%	25%	0%	0%
Treads Lightly	35%	15%	0%	0%	10%	20%	20%
Quick & Light	40%	0%	0%	0%	25%	25%	10%

3 Results

3.1 Raster-based Least Cost Path Analysis

We used a Least Cost Path analysis to generate four different routes between each community in the study area. Each route represents a different weighting of project variables. These alternative paths converge in some locations, but often offer distinct options for traversing the landscape. The computer-generated routes are depicted in Figure 4. In locations where trails and/or roads are disconnected, the least cost path will create connections through the landscape. The feasibility of such connections must be assessed in subsequent project phases.

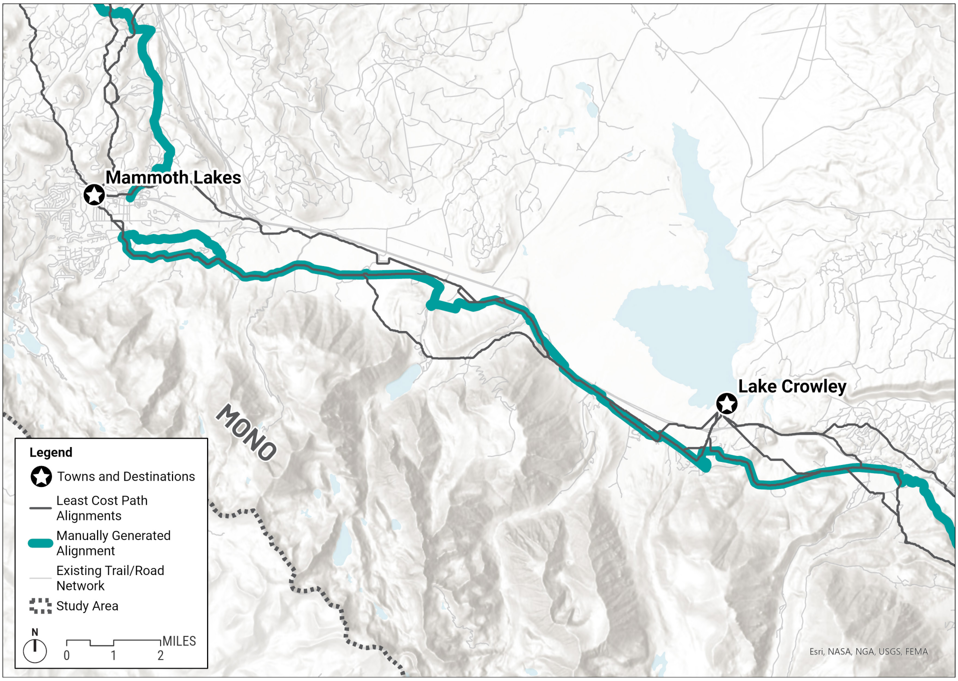

Fig. 4: Map illustrating example location of Least Cost Path (LCP) alignments overlaid with the stakeholder influenced manually generated alignment

3.2 Public Input

In the Fall of 2023, Alta Planning + Design (Alta) organized stakeholder workshops across Alpine, Mono, and Inyo counties in the Eastern Sierra. Throughout these workshops, stakeholders were divided into small groups and provided with a map book detailing four Least Cost Path (LCP) alignments. The map book sheets were scaled to illustrate 16 town-to-town segments, such as Mammoth Lakes to Lake Crowley, shown in Figure 4.

Stakeholder groups utilized the LCP alignments to center discussions on and pinpoint areas of opportunity and constraint associated with the LCP alignments. Participants annotated map book pages with handwritten comments and hand-drawn alignments, which could be considered for the subsequent development of a preferred alignment alternative. Upon completing the public outreach phase, Alta staff digitized handwritten and hand-drawn comments into GIS software. They then synthesized the data by creating written summaries that identified common themes observed in stakeholder comments for each town-to-town segment.

Table 3: The current alignment, drafted to reflect stakeholder comments and public feedback, is compared with the alignments computed by the Least Cost Path analysis. The amount of overlap is indicated as a distance and percentage.

SEGMENT	CURRENT ALIGNMENT	COMPUTED ALIGNMENTS							
		USER FOCUSED		QUICK & DIRECT		TREADS LIGHTLY		QUICK & LIGHT	
	Distance (Miles)	Distance (Miles)	% Overlap	Distance (Miles)	% Overlap	Distance (Miles)	% Overlap	Distance (Miles)	% Overlap
Markleeville to Topaz Lake	26.38	8.36	31.7%	11.78	44.7%	9.36	35.5%	11.21	42.5%
Topaz Lake to Coleville	8.08	1.91	23.6%	8.05	99.7%	8.28	102.5%	7.49	92.8%
Coleville to Walker	14.60	0.62	4.3%	4.47	30.6%	4.61	31.6%	5.87	40.2%
Walker to Bridgeport	39.92	4.77	11.9%	13.99	35.0%	10.65	26.7%	13.57	34.0%
Bridgeport to Lee Vining	43.53	2.93	6.7%	13.88	31.9%	3.14	7.2%	6.64	15.2%
Lee Vining to June Lake	18.70	2.37	12.7%	1.79	9.5%	2.46	13.2%	1.61	8.6%
June Lake to Mammoth Lakes	21.20	0.05	0.2%	3.41	16.1%	2.84	13.4%	3.22	15.2%
Mammoth Lakes to Lake Crowley	5.11	3.45	67.4%	2.81	55.0%	1.58	30.9%	2.27	44.5%
Lake Crowley to Paradise	17.48	7.22	41.3%	5.79	33.1%	9.39	53.7%	1.92	11.0%
Paradise to Rovana to Bishop	33.98	4.00	11.8%	9.44	27.8%	3.30	9.7%	7.00	20.6%
Bishop to Big Pine	76.85	20.24	26.3%	31.60	41.1%	18.89	24.6%	29.94	39.0%
Big Pine to Independence	7.00	3.97	56.8%	4.47	63.9%	4.04	57.7%	4.44	63.5%
Independence to Lone Pine	8.08	0.08	1.0%	0.08	1.0%	0.08	1.0%	0.08	1.0%
Lone Pine to Owens Lake	17.54	1.52	8.7%	2.86	16.3%	1.82	10.4%	2.47	14.1%
Owens Lake to Olancha	35.43	7.90	22.3%	10.25	28.9%	10.95	30.9%	10.73	30.3%
Total for All Segments	**373.88**	**69.38**	**18.6%**	**124.66**	**33.3%**	**91.38**	**24.4%**	**108.48**	**29.0%**

Building upon the LCP-generated alignments and synthesizing stakeholder comments along with hand-drawn routes, a singular alignment was manually drafted to connect all identified towns and destination areas within the study area. In the upcoming phase of stakeholder engagement, the manually drafted alignment will be shared with key stakeholders to gather feedback and further adjust the single alignment alternative.

In Table 3, we compare the manually drafted alignment with the four alignments generated by the Least Cost Path analysis. Using a 200ft buffer as a tolerance, we calculated the amount of overlap using an "intersect" tool. For the entire study area, the computed alignments had up to 33.3% overlap (the "Quick & Direct" path) and as low 18.6% overlap (the "User Focused" path) with the manually drafted alignment.

4 Discussion

This project highlights several issues that apply to the use of digital technology for trail planning and design. Spatial data is a valuable resource. Managing, manipulating, and creating spatial data using GIS is an effective way to describe, analyze, and plan trails in the landscape. We relied on GIS data to understand the existing infrastructure of rural soft-surface roads and trails. Both the spatial characteristics of roads and trails (where are the alignments, how do they connect) and their attributes (what is their designation, who owns and manages them) can be embedded in the data. Due to the vast study area covering multiple jurisdictions, the available GIS data is inconsistent. Further, it is often incomplete, missing segments of rural roads or missing key attributes. To overcome the disconnectedness of roads in the GIS data, we rasterized this dataset and used a Least Cost Path approach to find connections between the roads in the dataset, which were "low cost." This approach was faster and more efficient than editing topology errors within the road and trails data. Such editing would be required to use a network analysis approach (ESRI 2023), which relies on topologically correct vector data. We found that rasterizing the network data was an effective solution to the problem of incomplete data with topology errors. We interpreted the results critically and skeptically and used them as a guide to be refined by manual drafting. A limitation of the our methods is that the results are reflective only of the data included in the model. The data used in the model represents many important factors for trail development, but is missing other factors such as land ownership. Such factors were under consideration during the process of drafting a refined alignment.

The role of spatial computing in this project has an iterative relationship with public outreach and engagement. Engagement workshops prior to the production and presentation of LCP alignments lacked spatially explicit information needed to identify viable alignment alternatives through the large study area. By presenting the model and its results to the public, the project team received feedback on both the model itself and the results (i. e. the proposed trail alignments in the landscape). KLOPROGGE et al. (2011) describe such models as value laden. The model reflects certain values about the trail corridor, the destinations it connects, and its relationship to the landscape. Feedback about values is important because it can help guide discussion and decision-making in later stages in the process. By offering feedback about specific locations & alignments, community stakeholders contributed volunteered geographic information (VGI) (SUI et al. 2012) that informed the revision of the manually drafted route. In future studies, VGI could be collected earlier in the project and help form the data on which the model is built. For example, VGI about existing roads and trails could complement incomplete data from official sources. This approach would be especially effective in regions where there is less GIS data available from official sources.

Instead of generating the best alignment for the trail, the results of the LCP model reflect alternatives that favor a set of chosen variables. We recognize the model does not design the final trail alignment. It does generate alignments that allow for fruitful discussion among "the people of the place" (STEINITZ 2012). The analysis based on cost surfaces allowed us to easily manipulate the results by changing the weighting of the cost surface variables. We found the methodology to be valuable for this generative phase of the project. This type of GIS analysis allowed us to generate distinct paths – which were not necessarily bound to incomplete or disconnected vector data – and solicit valuable feedback from local people.

We view the process of GIS modeling as part of a design process. TULLOCH (2016) suggests that the shaping of the algorithms and analytical models used for computer-mediated design may be a creative act itself. Further, iteration and careful interpretation of model results can also allow for creativity in a workflow that relies heavily on computing (TULLOCH 2016). Our interpretation and representation of the results as a starting point rather than the final product allowed the project team to remain flexible and creative in shaping and refining the Towns to Trails Plan.

5 Conclusion and Outlook

In conclusion, novel geoprocessing tools provide utility for regional scale trail planning, as evident through our exploration of spatial data, computation, and public participation for the Eastern Sierra Towns to Trails plan. Our study demonstrates the need for innovative approaches to address the complexities arising from incomplete and inconsistent spatial data, especially in projects spanning multiple jurisdictions. The use of geospatial modelling and computation, as highlighted in our case study, offers a practical strategy for generating diverse alignment alternatives and fostering collaborative decision-making.

This study highlights the validity of developing alternatives at scale through raster-based Least Cost Path (LCP) analysis. By crafting multiple cost surfaces based on a range of project values, we successfully yield a spectrum of trail alignments to be presented to stakeholders for deliberation and consideration. This approach recognizes the intricate nature of trail planning, particularly in a regional context, highlighting the generative role of computing in the preliminary stages of the planning process.

Our investigation also acknowledges the limitations of the modelling approach, conceding that it constitutes only a segment of the broader planning process. The spatial data, though valuable, suffers from incompleteness and inconsistency, and the modelling becomes obsolete as we move further along in the planning process. It is critical to interpret and refine LCP generated results, understanding that the model does not plan the trail, but offers a starting point for informed discussions among stakeholders.

The success of trail planning projects depends on people’s involvement and the presence of local champions and stakeholders to guide the planning process. Public participation, as exemplified in stakeholder workshops, assumes a pivotal role in shaping the next phase of trail alignments in the Towns to Trails plan. Looking forward, we posit that future regional trail planning efforts can build upon the approach presented here to directly involve the public and stakeholders in the spatial modelling process. The move towards a more participatory approach in shaping the models weighting and criteria would further empower communities and ensure that resultant trail plans resonate with local values and priorities. Thus, our study lays the groundwork for a holistic and inclusive methodology for regional trail planning, acknowledging the dynamic nature of technology, data, and community engagement in our field.

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