A Parameter Settings

Most navigation meshes are built based on various parameters. For simplicity, we use one set of parameter settings for all experiments.

Precision. For the CDG, Recast, and NEOGEN, we used voxels of 0.2 meters in all three dimensions. This is the smallest voxel size at which we could obtain results in most environments. For the CDG, we enforced a maximum resolution of 512 pixels in all dimensions. This kept the construction times manageable for environments that were too large to allow a precision of 0.2m.

For the grid baseline method, we reduced the voxel size to 1×1m in the horizontal plane to prevent the program from taking too much time and memory. We could keep the voxel height at 0.2m.

For the CDG, we used a minimum disk radius of 0.1m (to prevent the method from generating many small disks) and a maximum disk radius of $100{,}000$m (which is essentially infinite in our examples).

Filtering. We have created our input environments such that they are entirely walkable and no more surfaces need to be filtered out. Therefore, for all voxel-based methods, we used a maximum surface slope of 60 degrees, a character radius of 0, and a character height of 0.5m. These settings ensured that all environments could (in theory) be covered completely.

Recast offers various other parameters that need to be tweaked for each environment to get the best results. Through preliminary experiments, we obtained the following values that gave good results in most environments: Tiling: Off; Max climb: 0.5; Min region size: 0; Merged region size: 10,000; Partitioning: Watershed; Max edge length: 500; Max edge error: 1.3; Vertices per polygon: 6; Detail mesh sample distance: 6; Detail mesh max error: 1.

Other. To compute ECMs, we used the implementation based on the Boost Voronoi library [Boost 2015]. It computes a 2D Voronoi diagram in $\mathcal{O}(n \log n)$ worst-case time, and it can process multiple layers of an MLE at the same time by using parallel threads.

For NEOGEN, we used a convexity relaxation parameter of 0. Increasing this parameter leads to fewer regions (i.e. a smaller dual graph) and a higher region complexity. Thus, the 'best' value for this parameter depends on the application.

B Results

The values of all metrics can be found in Tables 2 to 5 on the following pages.

Environment				Navigation mesh	Coverage						Connectivity	
					Free space covered		Incorrect area		Overlap			
Name	Total area (m^2)	#CCs	#Boundaries		Absolute	Relative	Absolute	Relative	Absolute	Relative	#CCs	#Boundaries
Military	36,876.82	1	16	CDG	36,198.31	0.98	7.90	0.00	15,613.55	0.30	3	176
				Recast	36,629.42	0.99	7.27	0.00	0.01	0.00	1	16
				NEOGEN	36,876.82	1.00	0.00	0.00	0.00	0.00	1	16
				Grid	36,736.63	1.00	107.37	0.00	0.00	0.00	1	17
University	8,370.68	1	82	CDG	7,821.35	0.93	11.42	0.00	3,387.29	0.30	274	214
				Recast	8,106.06	0.97	51.38	0.01	0.00	0.00	1	81
				NEOGEN	8,370.68	1.00	0.00	0.00	0.00	0.00	1	82
				Grid	8,335.13	1.00	27.87	0.00	0.00	0.00	1	45
Zelda	5,642.25	1	57	CDG	5,262.52	0.93	10.40	0.00	2,311.22	0.31	609	211
				Recast	5,457.23	0.97	35.56	0.01	0.00	0.00	1	57
				NEOGEN	5,642.24	1.00	0.00	0.00	0.00	0.00	1	57
				Grid	5,545.39	0.98	135.61	0.02	0.00	0.00	1	59
Zelda2x2	22,632.42	1	226	CDG	19,364.63	0.86	85.68	0.00	6,790.28	0.26	9	594
				Recast	21,900.31	0.97	122.55	0.01	0.00	0.00	1	226
				NEOGEN	22,632.42	1.00	0.00	0.00	0.00	0.00	1	226
				Grid	22,178.87	0.98	484.12	0.02	0.01	0.00	1	227
Zelda4x4	90,529.70	1	906	CDG	65,922.95	0.73	842.89	0.01	16,245.82	0.20	244	1,536
				Recast	87,652.50	0.97	542.35	0.01	0.00	0.00	1	906
				NEOGEN	90,529.69	1.00	0.01	0.00	0.00	0.00	1	906
				Grid	88,679.73	0.98	1,911.23	0.02	0.03	0.00	1	921
City	207,518.40	1	181	CDG	197,001.40	0.95	302.53	0.00	82,909.38	0.30	204	367
				Recast	206,304.50	0.99	103.55	0.00	0.40	0.00	3	183
				NEOGEN	207,518.40	1.00	0.04	0.00	0.00	0.00	4	185
				Grid	206,050.10	0.99	1,524.91	0.01	0.00	0.00	2	203
Maze8	31.00	1	1	CDG	22.10	0.71	0.35	0.01	6.37	0.22	11	4
				Recast	23.23	0.75	0.57	0.02	0.00	0.00	1	1
				NEOGEN	29.00	0.94	0.00	0.00	0.00	0.00	2	2
				Grid	31.00	1.00	0.00	0.00	0.00	0.00	1	1
Maze16	127.00	1	1	CDG	90.96	0.72	1.77	0.01	35.08	0.28	29	39
				Recast	100.47	0.79	2.15	0.02	0.00	0.00	1	1
				NEOGEN	125.00	0.98	0.00	0.00	0.00	0.00	3	3
				Grid	126.00	0.99	0.00	0.00	0.00	0.00	2	2
Maze32	511.00	1	1	CDG	352.45	0.69	6.36	0.01	74.51	0.17	92	135
				Recast	418.44	0.82	10.61	0.03	0.00	0.00	1	1
				NEOGEN	507.00	0.99	0.00	0.00	0.00	0.00	11	11
				Grid	511.00	1.00	0.00	0.00	0.00	0.00	1	1
Maze64	2,047.00	1	1	CDG	1,445.65	0.71	25.04	0.01	503.57	0.26	618	374
				Recast	1,415.99	0.69	28.25	0.02	0.00	0.00	30	11
				NEOGEN	2,003.00	0.98	0.00	0.00	0.00	0.00	45	45
				Grid	2,045.00	1.00	0.00	0.00	0.00	0.00	4	1
Maze128	8,191.00	1	1	CDG	5,066.94	0.62	109.58	0.02	896.21	0.15	1,188	3,548
				Recast	7,464.19	0.91	6,428.45	0.52	4,807.87	0.39	123	89
				NEOGEN	7,951.00	0.97	0.00	0.00	0.00	0.00	164	164
				Grid	8,184.00	1.00	0.00	0.00	0.00	0.00	8	8

Table 2: *Results for the coverage and connectivity metrics in the 2D environments. We report these only for CDG, Recast, and the grid because the other methods do not attempt to discover $\mathcal{E}_{free}$ themselves. '#CCs' is an abbreviation of 'number of connected components'. The descriptions of all metrics can be found in Section 5.*

Environment				**Navigation mesh**	**Coverage**						**Connectivity**	
					Free space covered		Incorrect area		Overlap			
Name	Total area (m^2)	#CCs	#Boundaries		Absolute	Relative	Absolute	Relative	Absolute	Relative	#CCs	#Boundaries
ParkingLot	1,921.50	1	9	CDG	1,819.68	0.95	0.07	0.00	675.84	0.27	178	81
				Recast	1,849.52	0.96	1.24	0.00	0.00	0.00	2	10
				NEOGEN	1,920.88	1.00	0.63	0.00	0.00	0.00	1	9
				Grid	1,861.50	0.97	4.51	0.00	0.00	0.00	4	11
Library	3,154.06	1	4	CDG	2,951.06	0.94	9.62	0.00	1,108.37	0.27	256	137
				Recast	3,046.73	0.97	9.14	0.00	0.41	0.00	1	4
				NEOGEN	3,132.65	0.99	21.41	0.01	0.00	0.00	1	4
				Grid	2,947.75	0.93	243.26	0.08	0.00	0.00	1	4
Oilrig	75,746.52	1	26	CDG	70,551.81	0.93	3,688.22	0.04	27,946.73	0.28	578	468
				Recast	74,933.66	0.99	124.29	0.00	3.30	0.00	1	29
				NEOGEN	73,475.38	0.97	2,271.13	0.03	0.00	0.00	1	26
				Grid	74,183.09	0.98	1,714.92	0.02	0.00	0.00	1	30
Neogen1	4,748.44	3	12	CDG	4,341.39	0.91	550.79	0.09	1,731.02	0.29	43	176
				Recast	4,659.20	0.98	16.38	0.00	7.65	0.00	3	17
				NEOGEN	4,519.90	0.95	203.78	0.05	0.00	0.00	3	15
				Grid	4,449.82	0.94	70.04	0.02	0.00	0.00	6	46
Neogen2	9,600.56	11	33	CDG	9,237.81	0.96	214.07	0.02	4,120.91	0.31	175	159
				Recast	9,431.68	0.98	14.29	0.00	5.07	0.00	10	27
				NEOGEN	9,371.87	0.98	20.71	0.00	0.00	0.00	6	27
				Grid	9,334.44	0.97	237.17	0.03	0.00	0.00	10	36
Neogen3	9,642.51	10	20	CDG	9,349.64	0.97	35.66	0.00	3,884.67	0.29	58	347
				Recast	9,440.83	0.98	8.82	0.00	0.57	0.00	15	22
				NEOGEN	9,527.26	0.99	15.06	0.00	0.00	0.00	10	18
				Grid	9,297.01	0.96	133.04	0.01	0.00	0.00	28	27
Tower	12,093.88	1	19	CDG	10,615.44	0.88	141.53	0.01	3,746.06	0.26	2,052	1,105
				Recast	11,672.40	0.97	425.70	0.04	5.26	0.00	1	256
				NEOGEN	-	-	-	-	-	-	-	-
				Grid	11,121.91	0.92	945.09	0.09	0.00	0.00	1	225
BigCity	280,897.00	1	301	CDG	-	-	-	-	-	-	-	-
				Recast	277,326.20	0.99	2,820.01	0.01	15.14	0.00	8	1,796
				NEOGEN	-	-	-	-	-	-	-	-
				Grid	-	-	-	-	-	-	-	-

Table 3: *Results for the coverage and connectivity metrics in the multi-layered environments. An empty row indicates that the navigation mesh could not be computed for the corresponding algorithm and environment.*

Environment	Navigation mesh	Complexity						Performance			
					Region complexity			Construction time (ms)		Memory usage (MB)	
		$\|V\|$	$\|E\|$	$\|\mathcal{R}\|$	Average	SD	Total	Average	SD	Average	SD
Military	LCT	120	134	120	9.00	0.00	1,080	0.80	0.40	0.88	0.00
	ECM	58	72	214	14.83	2.16	3,174	7.23	0.01	29.99	0.02
	CDG	1,168	2,078	1,168	4.00	0.00	4,672	44,256.03	85.58	79.74	0.01
	Recast	101	115	101	11.55	2.88	1,167	1,055.51	9.84	24.76	0.00
	NEOGEN	52	66	52	15.40	3.58	801	15.90	0.70	66.53	0.32
	Grid	36,844	72,755	36,844	12.00	0.00	442,128	205.39	2.24	77.88	0.38
University	LCT	732	812	732	9.00	0.00	6,588	5.90	0.30	1.16	0.01
	ECM	329	409	1,134	15.04	2.29	17,055	31.14	0.06	33.02	0.02
	CDG	3,309	4,369	3,309	4.00	0.00	13,236	27,866.70	17.94	68.72	0.00
	Recast	402	481	402	11.88	2.78	4,776	209.72	1.79	9.08	0.00
	NEOGEN	261	341	261	16.80	8.13	4,386	94.90	2.51	86.46	3.07
	Grid	8,363	15,460	8,363	12.00	0.00	100,356	106.69	1.23	54.05	0.31
Zelda	LCT	554	608	554	9.00	0.00	4,986	4.60	0.49	1.07	0.00
	ECM	289	344	895	14.93	2.30	13,359	23.53	0.07	32.34	0.01
	CDG	3,579	4,233	3,579	4.00	0.00	14,316	28,802.21	26.55	68.47	0.00
	Recast	321	376	321	12.12	2.77	3,891	159.42	0.80	8.14	0.00
	NEOGEN	205	260	205	16.04	6.31	3,288	59.10	2.39	80.67	0.41
	Grid	5,681	10,193	5,681	12.00	0.00	68,172	92.35	0.85	51.69	0.28
Zelda2x2	LCT	2,248	2,472	2,248	9.00	0.00	20,232	19.00	0.77	1.79	0.00
	ECM	1,148	1,372	3,602	14.92	2.30	53,754	107.45	0.47	41.89	0.03
	CDG	5,636	8,850	5,636	4.00	0.00	22,544	31,915.01	57.39	75.47	0.03
	Recast	1,281	1,505	1,281	12.16	2.84	15,573	736.57	3.04	24.00	0.17
	NEOGEN	820	1,044	820	16.15	6.35	13,245	246.60	8.49	125.54	1.80
	Grid	22,663	40,658	22,663	12.00	0.00	271,956	201.52	1.97	73.82	0.24
Zelda4x4	LCT	9,007	9,911	9,007	9.00	0.00	81,063	96.21	1.08	4.73	0.00
	ECM	4,580	5,484	14,436	14.92	2.30	215,424	438.66	2.81	78.67	0.31
	CDG	11,996	16,564	11,996	4.00	0.00	47,984	39,629.89	40.84	105.19	0.01
	Recast	5,105	6,009	5,105	12.17	2.84	62,148	3,275.23	8.29	89.36	0.68
	NEOGEN	3,289	4,193	3,289	16.15	6.36	53,103	1,040.90	19.45	253.26	2.49
	Grid	90,591	162,537	90,591	12.00	0.00	1,087,092	796.62	13.17	153.34	0.30
City	LCT	2,553	2,732	2,553	9.00	0.00	22,977	33.40	0.49	2.11	0.00
	ECM	1,442	1,621	4,679	14.42	2.16	67,491	162.69	0.41	45.54	0.02
	CDG	3,451	5,278	3,451	4.00	0.00	13,804	44,140.58	380.99	83.88	0.02
	Recast	1,527	1,706	1,527	11.90	3.08	18,168	11,833.70	9.93	135.15	0.00
	NEOGEN	1,164	1,343	1,164	13.61	5.17	15,846	330.70	6.18	126.86	0.79
	Grid	207,575	408,383	207,575	12.00	0.00	2,490,900	1,431.77	10.35	200.95	3.17
Maze8	LCT	26	25	26	9.00	0.00	234	0.20	0.40	0.84	0.00
	ECM	30	29	51	14.71	2.32	750	1.54	0.01	29.40	0.00
	CDG	68	59	68	4.00	0.00	272	1,105.43	9.50	32.18	0.01
	Recast	14	13	14	11.57	1.05	162	1.00	0.00	2.12	0.00
	NEOGEN	12	10	12	14.25	3.70	171	3.20	0.60	63.72	2.02
	Grid	31	30	31	12.00	0.00	372	62.39	1.44	41.17	0.17
Maze16	LCT	81	80	81	9.00	0.00	729	0.70	0.46	0.88	0.00
	ECM	84	83	156	14.85	2.25	2,316	4.28	0.02	29.84	0.01
	CDG	310	319	310	4.00	0.00	1,240	2,508.26	9.16	38.90	0.01
	Recast	42	41	42	11.71	1.44	492	7.30	0.46	2.25	0.00
	NEOGEN	39	36	39	14.62	3.05	570	9.20	0.75	63.98	2.66
	Grid	126	124	126	12.00	0.00	1,512	63.77	1.32	42.09	0.22
Maze32	LCT	363	362	363	9.00	0.00	3,267	3.40	0.49	1.02	0.00
	ECM	358	357	686	14.89	2.23	10,212	18.05	0.03	31.87	0.00
	CDG	1,084	1,138	1,084	4.00	0.00	4,336	5,458.99	5.88	45.90	0.00
	Recast	184	183	184	11.77	1.34	2,166	391.64	0.66	2.83	0.00
	NEOGEN	168	157	168	14.75	2.86	2,478	38.90	0.83	77.59	1.89
	Grid	511	510	511	12.00	0.00	6,132	72.58	1.51	46.24	0.11
Maze64	LCT	1,422	1,421	1,422	9.00	0.00	12,798	12.50	0.67	1.64	0.00
	ECM	1,392	1,391	2,672	14.88	2.24	39,756	70.34	0.25	40.16	0.01
	CDG	4,805	4,488	4,805	4.00	0.00	19,220	13,448.17	19.51	55.80	0.01
	Recast	602	572	602	11.63	1.45	6,999	11,834.30	11.52	4.64	0.00
	NEOGEN	636	591	636	14.74	2.91	9,372	161.30	6.08	109.03	2.69
	Grid	2,045	2,041	2,045	12.00	0.00	24,540	94.05	0.62	54.51	0.31
Maze128	LCT	5,674	5,673	5,674	9.00	0.00	51,066	62.21	0.75	3.99	0.00
	ECM	5,567	5,566	10,710	14.88	2.24	159,336	306.97	0.63	71.75	0.23
	CDG	25,135	44,910	25,135	4.00	0.00	100,540	56,150.68	93.81	92.84	0.01
	Recast	2,590	2,480	2,590	11.73	2.01	30,393	52,746.20	19.62	11.19	0.00
	NEOGEN	2,574	2,410	2,574	14.73	2.98	37,914	654.80	12.03	199.44	1.89
	Grid	8,184	8,176	8,184	12.00	0.00	98,208	250.38	2.70	81.05	0.26

Table 4: *Results for the complexity and performance metrics in the 2D environments. The descriptions of all metrics can be found in Section 5.*

Environment	Navigation mesh	Complexity						Performance			
					Region complexity			Construction time (ms)		Memory usage (MB)	
		$\|V\|$	$\|E\|$	$\|\mathcal{R}\|$	Average	SD	Total	Average	SD	Average	SD
ParkingLot	ECM	61	68	108	15.08	2.33	1,629	7.16	1.53	31.45	0.20
	CDG	779	873	779	4.00	0.00	3,116	6,686.30	18.02	53.33	0.01
	Recast	60	66	60	11.35	1.98	681	31.60	0.66	3.53	0.00
	NEOGEN	24	31	24	20.75	4.58	498	53.00	0.00	63.07	0.01
	Grid	1,866	3,493	1,866	12.00	0.00	22,392	88.84	3.13	49.18	0.29
Library	ECM	216	218	377	14.51	2.35	5,469	13.07	2.27	33.48	0.38
	CDG	1,758	2,173	1,758	4.00	0.00	7,032	11,374.29	31.39	59.02	0.01
	Recast	111	113	111	12.19	2.65	1,353	62.41	0.80	4.72	0.00
	NEOGEN	74	76	74	20.64	8.85	1,527	56.10	4.35	71.39	0.05
	Grid	3,191	5,801	3,191	12.00	0.00	38,292	211.99	22.58	54.12	0.29
Oilrig	ECM	603	629	1,283	14.72	2.23	18,891	55.67	10.68	38.52	0.76
	CDG	4,858	6,316	4,858	4.00	0.00	19,432	45,585.04	61.95	100.93	0.01
	Recast	324	353	324	12.35	3.08	4,002	2,280.03	6.43	49.79	0.23
	NEOGEN	253	279	253	23.44	12.99	5,931	219.80	6.18	107.94	0.49
	Grid	75,898	147,409	75,898	12.00	0.00	910,776	2,827.53	51.75	707.46	10.02
Neogen1	ECM	438	444	1,148	14.67	2.41	16,842	158.49	25.01	45.62	0.00
	CDG	1,017	1,651	1,017	4.00	0.00	4,068	19,911.95	24.38	101.37	0.03
	Recast	103	114	103	11.80	3.27	1,215	281.58	0.92	8.89	0.00
	NEOGEN	193	202	193	23.21	28.35	4,479	1,924.90	18.25	195.75	0.02
	Grid	4,519	8,494	4,519	12.00	0.00	54,228	1,498.18	43.75	192.09	0.12
Neogen2	ECM	390	403	1,240	14.86	2.32	18,426	43.40	6.22	37.58	0.46
	CDG	2,170	2,911	2,170	4.00	0.00	8,680	32,356.20	50.54	95.81	0.01
	Recast	198	213	198	11.74	2.97	2,325	208.62	1.28	8.58	0.00
	NEOGEN	295	312	295	15.31	7.11	4,515	245.60	4.20	93.33	0.45
	Grid	9,571	18,374	9,571	12.00	0.00	114,852	498.23	23.05	80.71	6.43
Neogen3	ECM	439	439	984	14.54	2.35	14,304	24.52	2.67	36.07	0.34
	CDG	2,070	3,319	2,070	4.00	0.00	8,280	32,919.54	80.55	82.33	0.01
	Recast	275	276	275	11.66	3.08	3,207	213.52	1.63	8.40	0.00
	NEOGEN	218	218	218	15.26	8.77	3,327	100.90	3.42	76.77	0.50
	Grid	9,430	17,962	9,430	12.00	0.00	113,160	523.35	54.51	109.36	1.40
Tower	ECM	4,988	5,019	9,416	14.37	2.38	135,300	139.45	17.94	72.63	0.58
	CDG	12,643	14,281	12,643	4.00	0.00	50,572	51,898.69	129.44	169.52	0.03
	Recast	1,155	1,437	1,155	12.47	3.02	14,400	538.25	3.79	16.22	0.05
	NEOGEN	-	-	-	-	-	-	-	-	-	-
	Grid	12,067	21,755	12,067	12.00	0.00	144,804	3,699.97	60.07	192.12	1.08
BigCity	ECM	32,167	32,554	69,176	14.41	2.37	997,053	756.03	5.45	299.44	0.90
	CDG	-	-	-	-	-	-	-	-	-	-
	Recast	9,394	11,345	9,394	12.27	3.11	115,260	16,353.00	28.15	216.66	0.20
	NEOGEN	-	-	-	-	-	-	-	-	-	-
	Grid	-	-	-	-	-	-	-	-	-	-

Table 5: *Results for the complexity and performance metrics in the multi-layered environments. An empty row indicates that the navigation mesh could not be computed for the corresponding algorithm and environment.*